# A Study Assessing the Opportunities and Potential of Soybean Based Products and Technologies

Developed by

informa economics
an AGRA informa company

For

The Agricultural Utilization Research Institute

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## Disclaimer

This report was produced for Agricultural Utilization Research Institute (AURI). Informa Economics, Inc. ("Informa") has used the best and most accurate information available to complete this study. Informa is not in the business of soliciting or recommending specific investments. The reader of this report should consider the market risks inherent in any financial investment opportunity. Furthermore, while Informa has extended its best professional efforts in completing this analysis, the liability of Informa to the extent permitted by law, is limited to the professional fees received in connection with this project.

# I. Executive Summary

Based on demand/market potential, economic feasibility, stage of development and strength of institutional support, Informa Economics, Inc. ("Informa") narrowed down a list of more than 100 emerging soybean products and technologies to 8 of the most promising, considered to have the greatest potential to add significant value to Minnesota's soybean commodity production. However, as with the potential of any biobased product or technology, the development of these emerging products and technologies will be heavily reliant on future market prices (especially for petroleum) and government policies. The following are what Informa considers to be the top 8 products and technologies for soybeans at this point in time.

## A. Renewable Diesel

Renewable diesel is a diesel substitute derived from any triglyceride feedstock (such as soybean oil) based on conventional hydroprocessing technology. Unlike biodiesel, renewable diesel replicates the chemical structure of its diesel counterpart, therefore working seamlessly with existing distribution infrastructures, storage systems, and engines. Renewable diesel also has better cold-flow properties than biodiesel.

One significant advantage of this process is its ability to utilize a wide array of input;s as free fatty acids (FFAS) can be completely converted to biofuel. The process' energy balance, however, is reportedly less favorable than conventional transesterification, implying higher processing costs. Still, the processing cost difference with transesterification is expected to be relatively low and is more than offset by the compatibility with existing distribution infrastructures. Renewable diesel can be pipelined, whereas biodiesel is generally either trucked or railed.

Three companies have developed standalone hydrotreating processes: Neste Oil, Syntroleum, and UOP/Eni. The first standalone U.S. renewable diesel plant, Dynamic Fuels LLC, a joint venture between Syntroleum and Tyson Foods, is expected to become operational in 2010.

## B. Enzymatic Transesterification

Enzymatic transesterification is a novel approach to the conventional chemical transesterification process used to produce biodiesel. Although still under development, the process holds considerable potential considering its advantages over its chemical counterpart:

- Compatibility with feedstocksof various quality (the process converts FFAs);
- Fewer process steps;
- Higher quality of glycerin;
- Improved phase separation (no emulsification from soap); and
- Reduced energy consumption and wastewater volumes.

Still, a number of hurdles need to be overcome before enzymatic transesterification becomes commercially available. Currently the two biggest problems researchers are examining deal with the reaction speed and enzyme durability. Furthermore, the cost of the enzyme needs to be lowered in order to make the process cost competitive.

Overall, progress is being made and it is expected that the process could become cost competitive relative to chemical transesterification within three years. Other than some efforts done by the USDA Agricultural Research Service ("ARS"), most of the research is being conducted abroad, especially in Europe and Asia. Currently, the largest private company involved in enzymatic transesterification is Novozymes.

### C. Soy-Based Polyols

Polyols are chemical building blocks used primarily as reactants to make polymers, polyurethanes in particular. These chemical compounds have historically been produced using petroleum-based feedstocks but are now increasingly made from vegetable oils. Natural oil polyols (NOPs) offer multiple advantages over their petroleum-based counterparts. Specifically, their use results in significant reductions in greenhouse gas (GHG) and volatile organic compounds (VOCs) emissions.

Since their initial development, NOP technologies have overcome the problems of consistency and odor that plagued the first generations and now offer products with performance that rivals petroleum-based polyols. NOPs are now used in a number of polyurethane foam applications including furniture, bedding and flooring products.

The United Soybean Board estimates the annual North American product demand for polyols represents 3.4 billion pounds, with a conservative estimate of the potential for soy-oil-based polyols of about 600 to 800 million pounds (2006 estimates). The market for NOPs has great growth potential if prices for petroleum rise as the economy rebounds, and as manufacturers become more eco-friendly.

Several companies including Cargill, The Dow Chemical Company, Urethane Soy Systems Co. are already involved in the manufacturing of these compounds.

### D. Epichlorohydrin

Epichlorohydrin is an epoxy raw material, increasingly used in applications in the electronics, automotive, aerospace and windmill sectors. It is traditionally derived indirectly by reacting propylene with chlorine. The process, however, is somewhat inefficient due to the formation of unwanted chlorinated organics that are expensive to dispose of. New glycerin-to-epichlorohydrin technologies, however, reduce energy consumption by about one-third, generate less than 1/10th of the wastewater and considerably less salt and chlorinated organics, when compared to traditional production processes. Until recently, however, this pathway was uneconomical due to the high price of glycerin.

According to information released by Solvay and Dow in 2007, the demand for epichlorohydrin has significantly outpaced production and there is significant growth potential, especially in regions with large biodiesel/glycerin production like Europe or the U.S. It is important to stress, however, that since 2008 a number of chemical firms that had unveiled plans to use glycerin as a feedstock for the production of chemicals have either shelved or delayed projects. Indeed, although glycerin production has increased in recent years, glycerin has proven to be very volatile with large price swings, and there are concerns in picking suppliers as a number of biodiesel facilities in the U.S. have shut down. Dow Chemical, Solvay SA and Spolchemie have announced plans to produce epichlorohydrin from glycerin.

## E. Soy-Based Wood Adhesive

The use of soy-based adhesives is not *per se* new to the chemical industry, as they were first studied in the 1920s and 1930s. Nevertheless, poor functional properties and price competitiveness at the time relative to petroleum-based adhesives limited their use.

Today, phenol-formaldehyde (PF) and urea-formaldehyde (UF) resins enjoy a dominant place in the wood adhesive market. Nevertheless, environmental and health concerns along with rising costs for resins have prompted a resurgence of interest in developing new soy-based products. An additional factor supporting the growing adoption of soy-based adhesives has been the passage in California of a law limiting the level of formaldehyde that can be emitted from interior panel products. Since companies manufacturing wood adhesives often cannot modify their products solely for California, the California rule is rapidly becoming a national standard, supporting the growth of soy-based adhesives.

Companies like Hexion Specialty Chemicals, Ashland/Heartland, and Eka Chemicals have commercialized several soy-based glues. These glues generally perform at least as well as their petroleum-based counterparts.

Out of the 3.72 billion lbs of wood adhesives estimated to have been used in the U.S. in 2006, 40-50 million pounds of soy-based glue systems are estimated to be in use. In the next few years, the United Soybean Board expects that soy-based wood adhesives could account for as much as 20% of the U.S. market.

## F. High-Oil Soybeans

New high-oil soybean varieties have the potential to provide a significant increase in vegetable oil production and to help processors meet the growing demand for vegetable oil for food and bio-fuel. The prospect of increasing the oil content in soybeans is especially appealing since it has the potential to add value to soybean production considering that most new soybean applications are focused on the oil part as opposed to the protein.

Monsanto's Renessen joint venture with Cargill is currently researching a high-oil soybean variety that could increase oil content by 3% to 5%, without a loss in protein or grain yield. The first generation of the new variety is projected to be commercialized within 2-4 years and is thought to have an acreage potential of 15-40 million acres. The second generation is in a much earlier phase of development but could be released within 10 years.

## G. High Stability Oil Soybeans

The phasing out of partial hydrogenation by food processors following the move away from *trans* fatty acids in food has generated a strong demand for highly stable vegetable oils. One solution brought forward by seed developers has been to develop oilseeds with a low content in polyunsaturated fatty acids that are prone to oxidation and that adversely impact the shelf-life of the oil.

The first improved trait brought to the marketplace was low-linolenic varieties. Asoyia, Monsanto and Pioneer all have released such value-added soybean varieties. Nevertheless, although more stable than conventional soybean oil, the oil from low-linolenic soybeans is still prone to rancidity and is not well suited for deep frying applications. As a result, seed companies have developed mid- and high-oleic varieties that have superior oxidative and flavor stability. Asoyia was the first seed company to release a mid-oleic/low-linolenic soybean variety in 2008, followed in July 2009 by Pioneer, which released Plenish, a brand of high oleic soybean oil. Monsanto is expected to commercialize Visitive III, a line of mid-oleic/low-linolenic/ low saturates in the next few years

With reported premiums as high as $0.60/bu, these soybeans offer farmers a great way to diversify and earn extra profit.

There were approximately 1.6 million acres of low-linolenic soybeans grown in the U.S. in 2007/08. Although 2008/09 acreage was disappointing due mainly to the limited performance of low-linolenic oil, the recent release of mid- and high-oleic soybean varieties is expected to significantly increase the demand for high-stability soybean oil. For instance, Monsanto estimates the acreage potential in the U.S. for its Vistive III soybean variety at 10-20 million acres.

## H. Aquaculture Feed

The global aquaculture industry is expanding steadily, averaging 6.6% growth over the past 10 years (1998-2007). As aquaculture keeps growing, so does the demand for protein meal. Fishmeal is the major protein source for aquaculture, but as aquaculture production outpaces fishmeal production, some are concerned fishmeal availability will constrain the expansion of the industry. As a result, researchers, aquaculture producers and feed manufacturers have been looking at alternative protein sources to replace fishmeal in diets.

Soybean meal can be used in aquaculture feed but anti-nutritional factors that reduce fish performance, particularly at higher inclusion levels, and in carnivorous fish specie doetshave limited its adoption. Contrary to soybean meal, however, soy protein concentrates (SPC) do not contain these high levels of anti-nutritional factors and can be utilized at higher inclusion rates. Consequently, SPC have the potential to play a major role in the aquafeed market

It is estimated that 3.1 million tonnes of fishmeal are currently consumed by the aquaculture market in the world. The current consensus is that SPC could account for 10-30% of the protein meal used in aquaculture feed. The U.S. Soybean Export Council estimates that, conservatively, the inclusion rate of SPC in aquafeed could reach 1 million tonnes.

There are currently only a few SPC producers in the U.S.: Cargill, ADM and Solae, with an additional player, Hamlet Protein, considering establishing a plant in Iowa.

# II. Introduction

The Agricultural Utilization Research Institute ("AURI") commissioned Informa Economics, Inc. ("Informa") to assess and identify those existing and emerging products and technologies (both domestic and international) associated with the biobased economy that will boost economic opportunities for the corn and soybean agricultural sectors in the United States and the State of Minnesota. The overarching objective of the project was to specify eight products or technologies for each commodity which would likely add value to the corn and soybean complexes over the next ten years. This project has been achieved by conducting a blend of desk research (review of the literature) and targeted interviews, by phone and in-person, with the companies that are producing the biobased products and the scientists and technology leaders that are conducting ground-breaking research in the ever-evolving biobased economy. In the end, this study provides AURI with recommendations regarding which products and technologies show the most promise, thereby laying the foundation as a roadmap which will serve as valuable input to AURI in their strategic planning processes.

## A. Report Layout

This introductory section precedes two distinct reports that have been prepared for AURI. The two distinct reports are the analyses, findings and recommendations for the biobased products and technologies for the respective commodities of corn and soybeans. The "corn report" and "soybean report" are distinct and stand alone from each other. The role of this introductory section is to "set the stage" for each of the reports by discussing the project methodology and process flow and presenting a general overview of the biobased and energy economies. This overview should provide the reader a framework from which to better appreciate the opportunities and complexities of the technologies and products that are discussed in the corn and soybean reports.

## B. Project Methodology and Process Flow

The biobased economy is a rapidly changing environment where government policies combined with volatile commodity prices can dramatically affect the returns to the participants in said markets. Given this ever-changing context, it was important to provide solid fundamental research with both quantitative (when available) and qualitative analyses to ascertain the top promising corn and soybean products and technologies. It should be noted that the final so called "top eight winners" for each commodity should not be viewed as a list that is "set in stone" because of the uncertain nature of the markets surrounding energy and agricultural commodities. The products and technologies that have been identified as the top eight in both reports actually have the potential to move up or down in relative importance as policies change and technological breakthroughs occur over time. The study team took into consideration the issues of market and political uncertainty when conducting the research. In the end, the goal was to provide recommendations to AURI regarding those products and technologies that have the highest probability of market success and can impact the State of Minnesota's economy.

The project could be characterized as being a continual flow process where feedback loops were put into place in order to test and retest the justification for including a product or technology in the study. Ultimately, the study was carried out in three Phases, which are summarized in Figure 1. The flow diagram highlights the use of multiple check points or "Phases" in order to "funnel" the products and technologies down to the two top eight lists. In Phase I, Informa conducted desk research that was extremely broad, identifying over 100 products and technologies each for corn and soybeans. Each product or technology was catalogued in a large matrix in which there was with a brief description of said product or technology, identification of the companies or institutions that are engaged in the respective "space," and also special notes.[1] In order to further refine the list in Phase I, four criteria were used by the research team in order to select a limited number of products and technologies that were deemed worthy for moving on to Phase II for more in-depth evaluation. The four criteria are based on those factors that are key characteristics for determining potential success in the marketplace. The four criteria were as follows:

1. **Demand/Market Potential:**
   This addresses the potential size (in value and volume) of the marketplace for a respective product or technology. Some biobased products or technologies, for example, may show significant promise regarding market penetration into existing markets or market adoption; however, the overall market may be extremely small and highly specialized. This means that the introduction of the product or technology would have very little impact to the economy at large. The economic returns or benefits would be confined to a very narrow sector of the economy because of the small market size. The ambition of the study team was to identify those products and technologies which are associated with bigger demand markets and thus potentially larger economic impacts.

2. **Economic Feasibility:**
   Just because a product can be produced or a technology can be used says nothing regarding the cost of producing the product or utilizing the technology. Some products or technologies have highly desirable results or characteristics; however, the cost associated with the product or technology is beyond what the marketplace will likely bear. It should be noted that economic feasibility can be accomplished by either public support (e.g., the 45 cent per gallon tax credit for ethanol production) or the ability of the product or technology to be produced in

[1] Note: Appendices at the end of each report display the large product and technology lists developed in Phase I.

such a manner that real economic returns are achieved without the aid of government support (or a blend of both the marketplace and government support as is the case for ethanol and biodiesel). The study team focused on specifying those products or technologies that would likely become commercially and economically viable over the next ten years.

3. **Development Stage:**
The development stage is important in the context of the expected planning time horizon of AURI. AURI has established the objective for Informa to identify those products or technologies that will likely have a material economic impact over the next ten years. This means that some products or technologies that might have been identified as being very promising would not be considered for inclusion in the final list because they are too early in the development cycle. Many products or technologies display significant promise from a technical perspective, meaning the mechanical or chemical execution of said technology or product can be achieved in the laboratory or at the pilot scale of operation. Success at the pilot scale level is desirable; however, the more significant hurdle, is the ability to transfer the technology or product to a commercial scale such that they can be introduced into the marketplace and expected to compete with other more traditional products or technologies.

4. **Strength of Institutional Support:**
The level of institutional support is critical for influencing the success or failure of launching a new product or technology. Institutional support can come in the form of either public or private support or a blend of both. Launching a new product on a "shoe string" budget out of someone's garage is the exception rather than the rule regarding the probability of success. Those products or technologies which have deep funding sources and access to production and distribution infrastructure and systems generally have a higher likelihood of achieving market penetration and the necessary traction to remain economically viable in the long-run. Large corporations such as DuPont or Cargill are generally advantaged relative to much smaller capitalized companies regarding the ability to invest in the development of new products and technologies and bring them to market on a significant scale. U.S. Federal agencies such as the U.S. Department of Energy (DOE) have also played a vital role in the discovery process of new products and technologies. The DOE has spent billions of dollars helping to fund the discovery of new products and technologies playing the role of a basic research benefactor and even a venture capital firm, investing in emerging products and technologies where often the private sector has deemed the initiatives as being too early-stage or risky to fund completely on their own. The study team evaluated all of the products and technologies in light of the

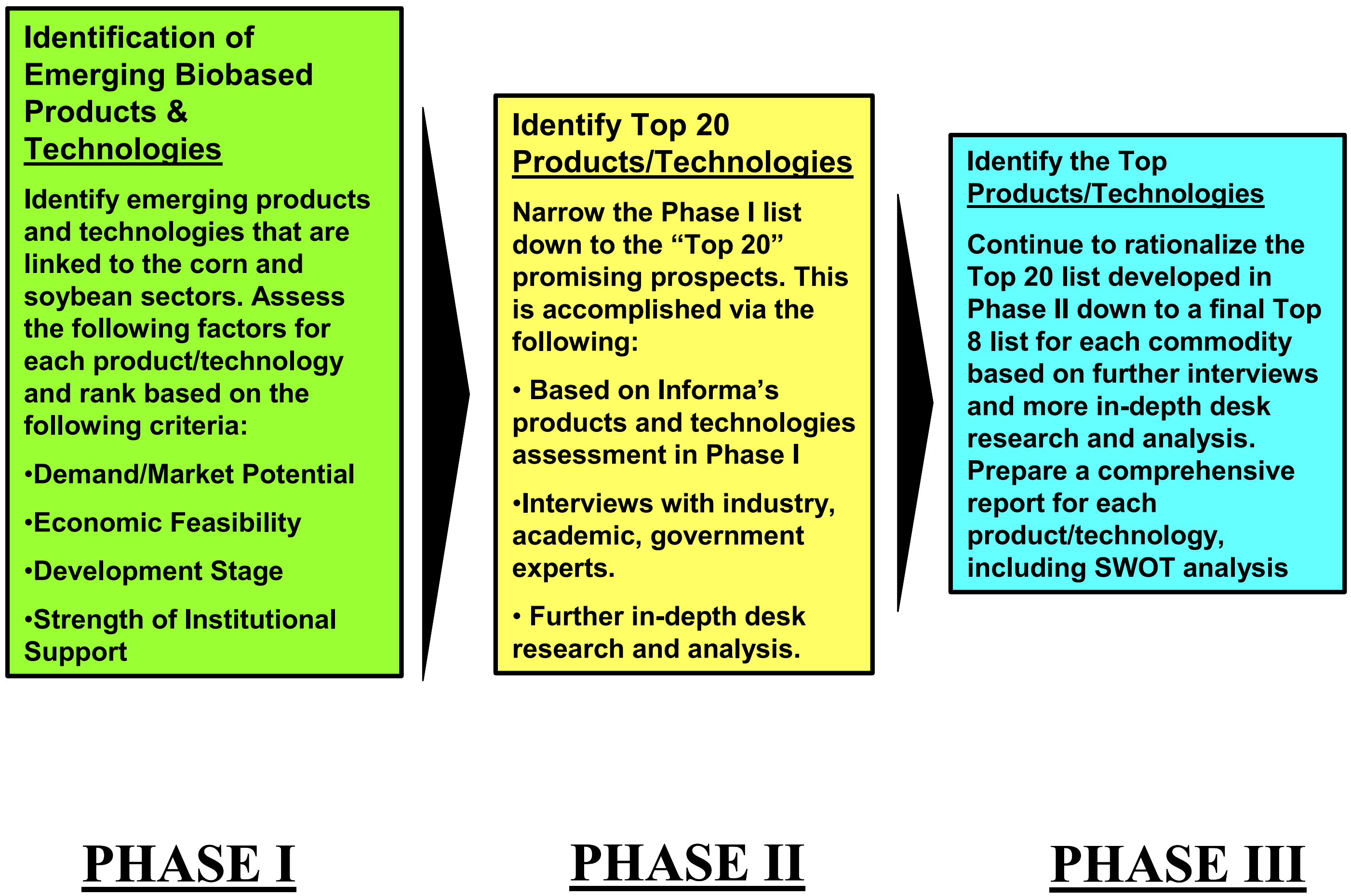
perceived extent of public and private support for the respective product or technology.

In Phase I quantitative scores were generated for each of the 100 products and technologies for corn and approximately 140 products and technologies for soybeans, where they were awarded a score of 10 (being the lowest), 20, 30 or 40 (being the highest) for each of the four criteria. Each of the four criteria was given different "weights" of importance, as follows: Demand/Market Potential 40%, Economic Feasibility 15%, Stage of Development 20% and Institutional Support 25%.[2] The combination of the criteria weights multiplied by the scores awarded each of the criteria generated a "weighted score" for each of the respective products or technologies. The Informa team independently scored and then ranked the products and technologies for corn and then soybeans. The scoring process was further refined to reflect an enhanced consensus of the team. The ranked scores led to a "Top 30" list for corn and a "Top 30 list" for soybeans. This concluded Phase I of the project.

Phase II began the process of refining the "Top 30" down to a "Top 20 list," each for corn and soybeans. The study team then began to strategically engage a broad cross section of academic and industry experts with interviews (site visits and telephone interviews) in order to reduce the top 30 list down to top 20. Examples of interviews and trips are as follows: trip to the National Renewable Energy Laboratory (NREL), trip to the National Corn to Ethanol Research Center (NCERC), trip to the USDA Agricultural Research Service Laboratory in Peoria, IL, phone interviews with Oak Ridge National Laboratory, MBI International (Michigan Biotechnology Institute), and numerous other private sector researchers. The experts were asked to comment on the top 30 list to identify a number of key points, (1) specify if there were any omissions from the list, and if so, what products/technologies should be included, (2) identify what products or technologies should be removed from the list, (3) provide an opinion on what product/technologies should be included in the top 20, and (4) distinguish what their preferredtop ten products/technologies were and explain in depth why. The Informa research team analyzed the findings from the interviews and constructed a product/technology top 20 list for each of the commodities.

[2] It is acknowledged that the reader of this report might perceive the weights given to each of the criteria should be changed depending on their point of reference. Informa, however, spent a significant amount of time developing this quantitative framework in order to remain sensitive to AURI's expectations and needs as an organization.

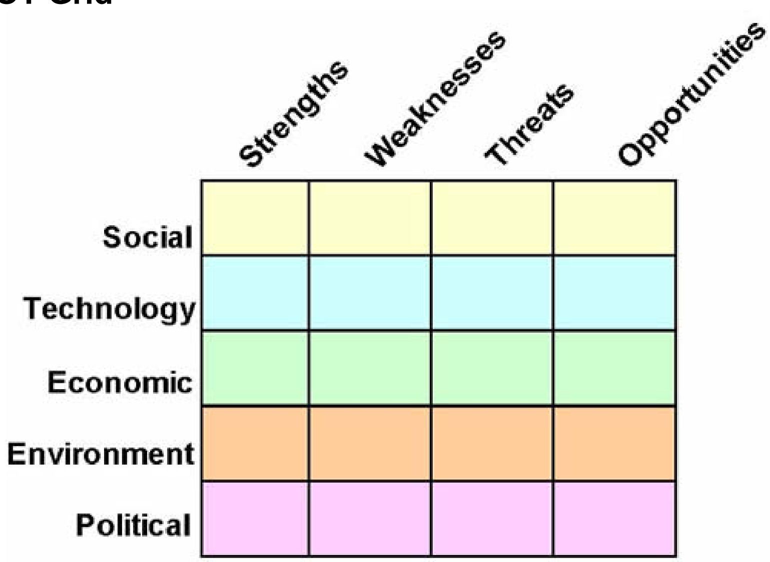
**Figure 1: AURI Corn and Soybean Project Flowchart**



The Informa research team then conducted more detailed desk research based on a consensus of the expert interviews and prepared brief position papers for each of the top 20 product/technologies for each commodity. The findings in Phase II formed the foundation for the final Phase III and the selection of the two "Top 8" lists. In Phase III highly targeted interviews were conducted for specific products/technologies. For example, succinic acid (a corn-based chemical) was a product that received significant attention and interest in the early stages of the project and was a logical product to move through Phase I and to Phase II and then into Phase III. Moving into Phase III, the team sought those individuals or firms that had special knowledge of succinic acid, such as MBI International and Bioamber (a firm that is dedicated to making succinic acid competitive with maleic anhydride). The highly targeted interviews and desk research in Phase III ultimately yielded the identification and selection of the "Top 8" products/technologies for corn and soybeans.

The selected top 8 products/technologies for corn and soybeans were then given detailed write-ups (more detailed than the top 20 write ups). Each of the detailed product/technology write ups includes an overview of the product/technology, an analysis of its market potential, profiles of the companies and research institutions that are involved in the space and SWOT analyses (Figure 2). SWOT analysis is a widely used and versatile paradigm for strategic planning where the acronym stands for Strengths, Weakness, Opportunities and Threats. The application of the SWOT model provided the framework to distill the key findings of research and analysis into a summary matrix which is easily understood and identifies the key aspects and issues for each products/technologies. Figure 2 displays the SWOT and how each of the product/technology was filtered through the grid structure. In the end, the key decision and policy makers at AURI have an authoritative reference tool to guide them in their strategic planning processes.

**Figure 2: SWOT Grid**



## C. Energy Markets: A Foundation for Biobased Products and Technologies

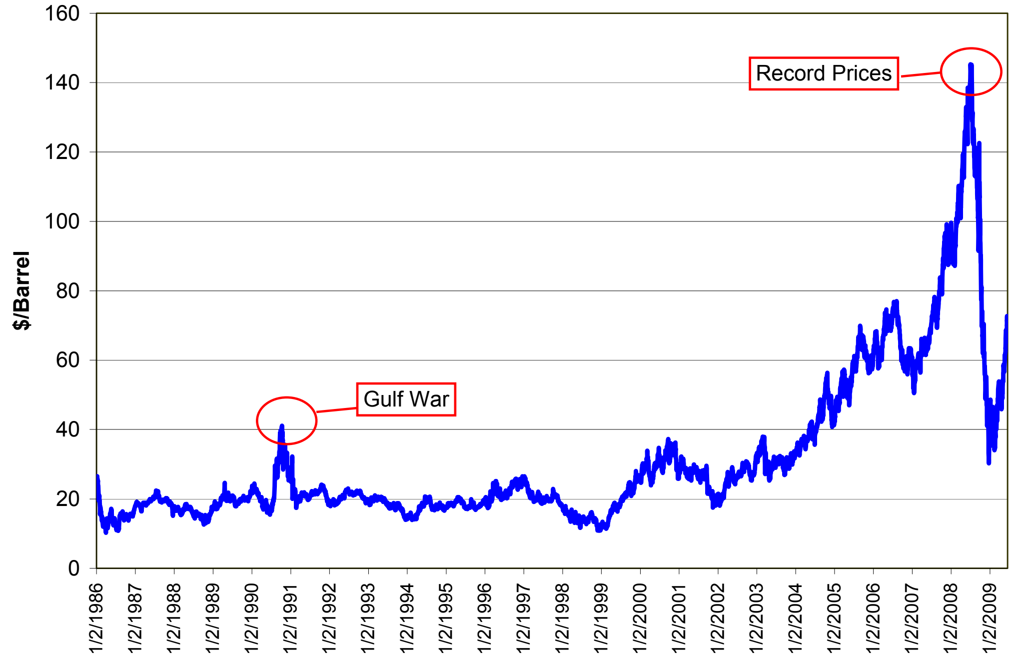
Petroleum is defined in Greek as being "rock oil" or more commonly known as crude oil. Crude oil or crude petroleum oil is a naturally occurring, flammable liquid found in rock formations in the Earth consisting of a complex mixture of hydrocarbons of various molecular weights, plus other organic compounds. Crude oil has always been a substance in plentiful supply; the demand for oil, however, has changed dramatically over time given the advent of the combustion engine and the rise of geopolitical tensions surrounding who owns the oil and where is the oil located. Initially, oil wasn't used as a fuel, in the 1860's oil was in fact hailed as a disinfectant, a vermin killer, hair oil, boot grease, and a cure for kidney stones. In 1933, the U.S. paid $275,000 to Saudi Arabia's King Ibn Saud for an oil concession. The King actually thought he'd sold the Americans sand, since the British didn't think there was oil there. After five years of disappointment, the Americans struck oil in Saudi Arabia. One expert at the time described Saudi Arabia's oil as "the single greatest prize in all history," a prophetic statement for the ages.

The true importance of oil worldwide wasn't understood until World War I and especially, World War II. World War II brought to light the notion of national security and the importance of the U.S. government having a safe supply of oil. After World War II, and the beginning of widespread economic recovery, it became clear that the world was going to need a lot more oil than the companies of Socal and Texaco in Saudi Arabia could provide. Since World II, the global landscape of the supply and demand for oil has become even more complex as synchronistic global expansion of developing countries coupled with continued Middle East conflicts has placed a new premium on petroleum.

Interest in the area of biofuels and biobased products (based on renewable carbohydrate feedstocks such as corn) has increased dramatically over the last ten years as energy prices, primarily crude oil, reached record highs. As described in this section, consumption of crude oil and refined products is on a very large scale, and as a result the potential market for biofuels and certain biobased replacements for petrochemicals is large.

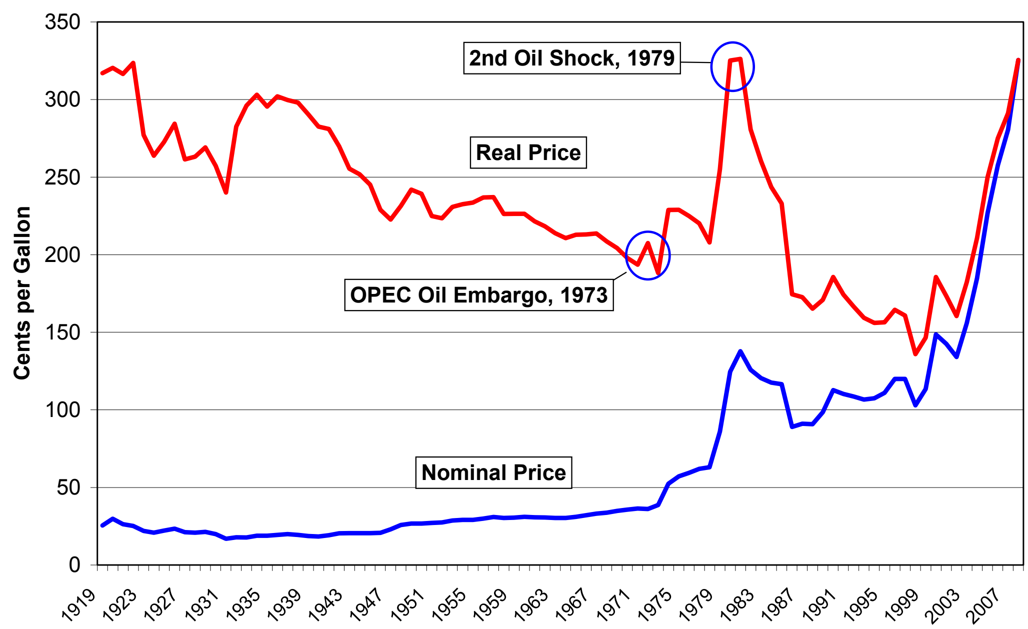
The recent price shock of 2008, quickly reminded U.S. consumers of their vulnerability and dependence on foreign sources of oil. Crude oil prices, as benchmarked by West Texas Intermediate (WTI) averaged only $19.09/barrel from 1986 to 1999, ranging from a low of $10.25/barrel to a high of $41.07 during this period of time. As global economies rapidly expanded and the infrastructure to supply oil increased at a much slower pace, nominal oil prices for the WTI crude reached record high levels on July 3, 2008, at $145.31/barrel (Figure 3). Adjusted for inflation, oil prices were actually in a long run decline since 1919 (Figure 4), with only brief price spikes. The 2008 jump in oil prices, however, elevated real prices to levels not experienced since the oil shock experienced in the late 1970's and early 1980's.

**Figure 3: Crude Oil Price, West Texas Intermediate: January 02, 1986 to June 16, 2009 (daily prices, nominal dollars)**




Source: U.S. Department of Energy, Energy Information Administration and Informa Economics.

**Figure 4: U.S. Real Gasoline Pump Price: Annual Average 1919-2008 (consumers price index-urban, 1982-84=1.00)**



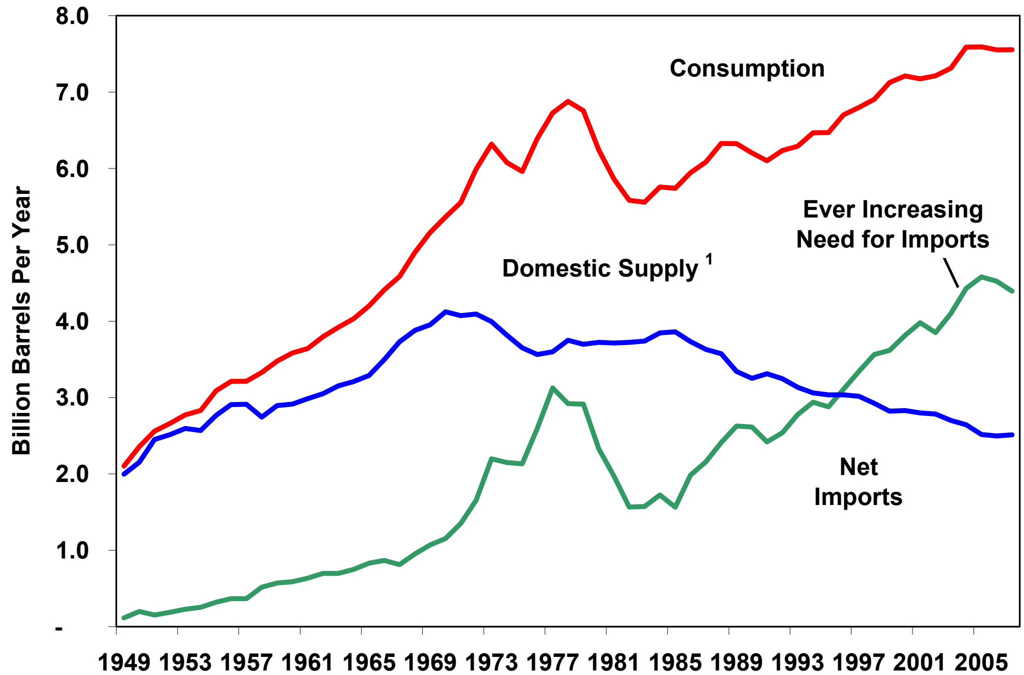

Source: U.S. Department of Energy, Energy Information Administration.

The higher real petroleum prices, concern over a slowdown in the development of new supplies of oil and the September 11, 2001, terrorist attacks and subsequent wars in Afghanistan and Iraq have renewed interest of the American public in finding ways to reduce this country's dependence on foreign imports of petroleum and develop new technologies that consume less gasoline, such as the upcoming Chevy Volt, with claims of achieving 230 miles per gallon (mpg). In 2006, the Bush administration acknowledged the need to find alternative, and preferably renewable, sources of energy. President Bush outlined in his 2006 State of the Union Address, the announcement of The Advanced Energy Initiative, which is designed to "help break America's dependence on foreign sources of energy." Former President Bush set as a national goal the replacement of more than 75% of the oil imports from the Middle East by 2025. The Advanced Energy Initiative provided for a 22% increase in clean-energy research at the U.S. Department of Energy (DOE). The intent of the funding increase was to accelerate breakthroughs in two critical areas, how we power our homes and businesses, and how we power our automobiles, thus stimulating a reduction in our country's demand for fossil based energy sources. The new Obama administration has followed through with a clear mandate to continue the country's need to address the energy predicament with new solutions. President Obama's comprehensive energy plan calls for some of the following initiatives:

- Help create five million new "green" jobs by strategically investing $150 billion over the next ten years to catalyze private efforts to build a clean energy future.
- Within 10 years, save more oil than we currently import from the Middle East and Venezuela combined.
- Put 1 million plug-in hybrid cars (cars that can get up to 150 mpg) on the road by 2015; cars that will be built in America.
- Ensure 10% of our electricity comes from renewable sources by 2012, and 25% by 2025.
- Implement an economy wide cap and trade program to reduce greenhouse gas emissions 80% by 2050.

Statistics are very clear and impartial regarding the trends of oil consumption and production in the U.S. Since the mid-1950s, the U.S. has imported more energy than it has exported. Consumption of petroleum, the most prominent U.S. energy resource, has expanded from 6.2 million barrels/day in 1950 to almost 20 million barrels/day in 2007, or an annual total of 7.5 billion barrels (Figure 5). During this period, petroleum imports have grown from being insignificant to surpassing U.S. domestic supplies. Most oil imports have been met by North American countries, with Canada and Mexico providing over 29.2% of U.S. petroleum needs in 2008 (Table 1). The U.S. is faced with the continual concern of consistent supplies in the future from politically sensitive regions such as the Middle East. In 2008, OPEC countries accounted for over 46% of U.S. oil imports. Saudi Arabia represented 11.9%, Venezuela 9.2% and Nigeria 7.7% of total U.S. oil imports in 2008.

## Figure 5: U.S. Petroleum Situation: 1949-2007




1/ Includes crude oil and natural gas plant liquids.

Source: U.S. Department of Energy, Energy Information Administration.

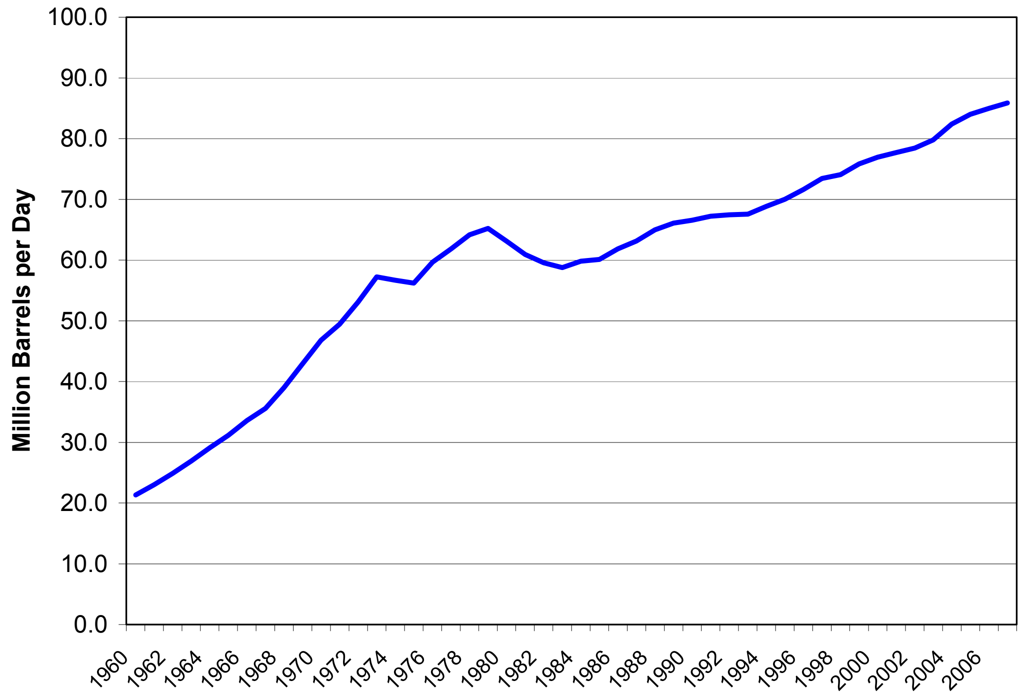
## Table 1: U.S. Imports of Crude Oil, by Country of Origin for 2008

| | Country of Origin | Thousand Barrels | Percent Total |
|---|---|---|---|
| 1 | Canada | 899,935 | 19.1% |
| 2 | Saudi Arabia | 560,705 | 11.9% |
| 3 | Mexico | 475,545 | 10.1% |
| 4 | Venezuela | 435,769 | 9.2% |
| 5 | Nigeria | 362,263 | 7.7% |
| 6 | Iraq | 229,300 | 4.9% |
| 7 | Algeria | 200,192 | 4.2% |
| 8 | Angola | 187,761 | 4.0% |
| 9 | Russia | 169,415 | 3.6% |
| 10 | Virgin Islands (U.S.) | 117,191 | 2.5% |
| | Rest of World | | 22.8% |
| | **Total** | 4,711,238 | 100.0% |
| | **Non OPEC Countries** | 2,530,488 | 53.7% |
| | **Persian Gulf** | 868,516 | 18.4% |
| | **Total OPEC Countries** | 2,180,750 | 46.3% |

Source: U.S. Department of Energy, Energy Information Administration.

The global supply of and demand for energy is being challenged not just by the level of U.S. consumption and political instability in certain oil-producing countries, but also by growing demand in emerging economies such as China and India. World consumption of petroleum rose from just over 20 million barrels/day in 1960 to 85.9 million barrels/day in 2007, a compound annual growth rate of 3.12% (Figure 6).

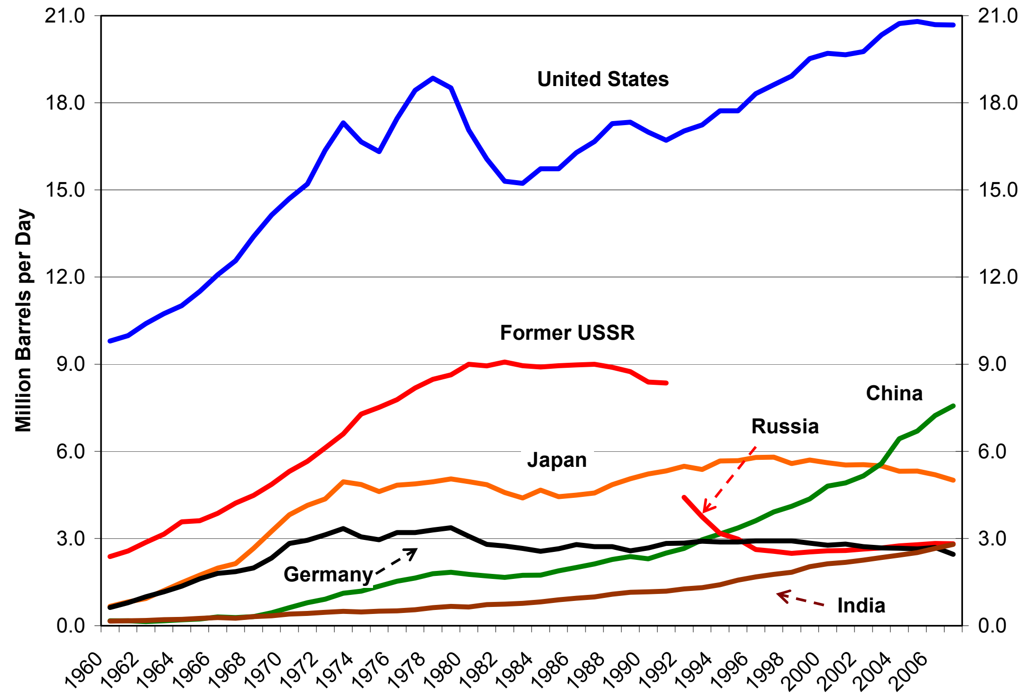
**Figure 6: World Daily Consumption of Petroleum, 1960-2007**




Source: U.S. Department of Energy, Energy Information Administration.

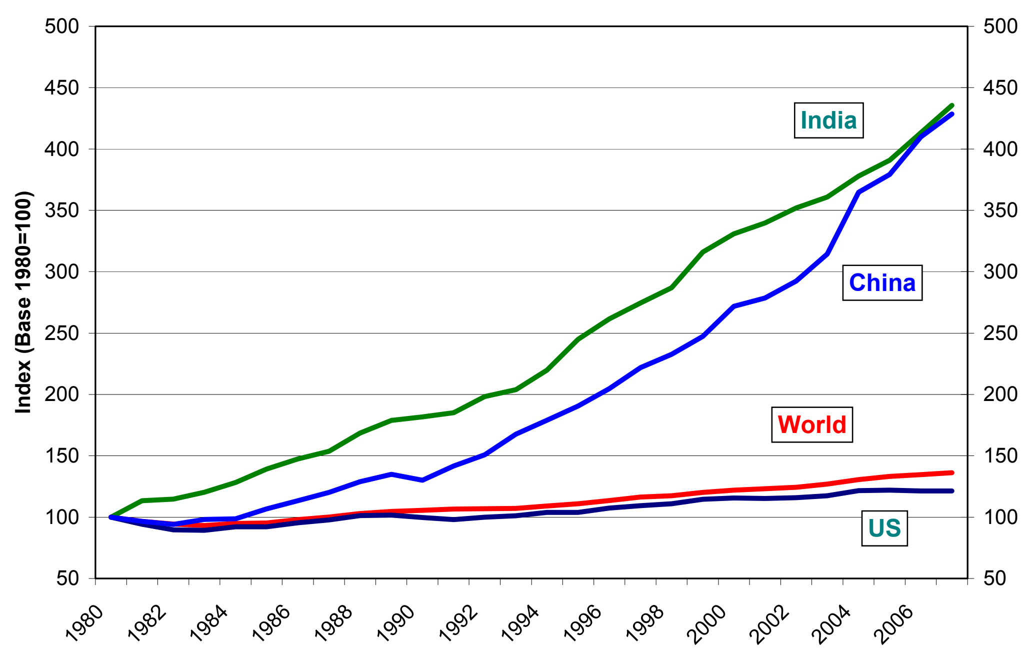
The U.S. is the most significant petroleum-consuming economy in the world (Figure 7). The former Soviet Union was second in importance until its breakup in the early 1990s; now China is the second-largest petroleum consuming economy. Since 1960, China has increased its consumption of petroleum faster than any country (over 3,000%), while India has increased consumption by almost 1,500% (Figure 8). More mature economies such as the U.S. and Canada actually exhibit growth rates that are below the world trend, this is also true for most of the major and mature economies in the European Union.

**Figure 7: Leading Petroleum Consuming Countries, Average Daily Consumption, 1960-2007**




Source: U.S. Department of Energy, Energy Information Administration and Informa Economics.

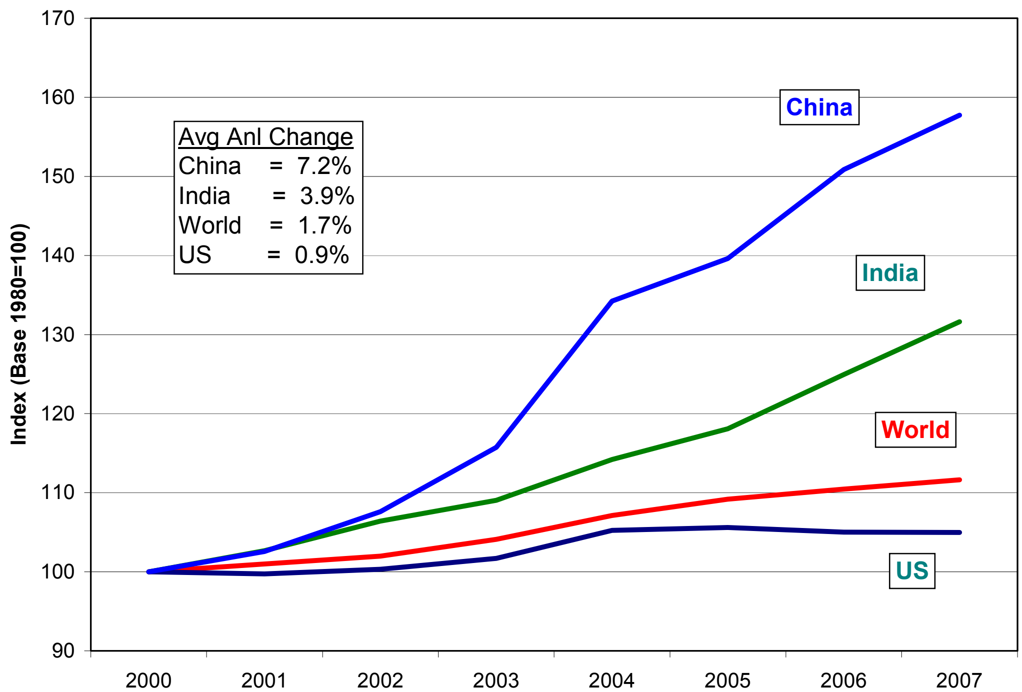
**Figure 8: Indexed Growth of Petroleum Consumption for Key Countries, 1980-2007 (Barrels of Oil Consumed Daily)**




Source: U.S. Department of Energy, Energy Information Administration and Informa Economics.

In recent years, the rate of growth for China, for example, has increased significantly (Figure 9). From 2000 to 2007, China's consumption of oil increased at an average annual rate of 7.2%; this was almost twice as fast as India's annual growth rate and significantly ahead of the U.S. annual growth rate of only 0.9%.

**Figure 9: Indexed Growth of Petroleum Consumption for Key Countries, 2000-2007 (barrels of oil consumed daily)**




Source: U.S. Department of Energy, Energy Information Administration and Informa Economics.

As previously mentioned, many European Union countries have generally fallen in their level of consumption of petroleum globally as emerging economies have rapidly increased their share of total petroleum demand (Table 2). From 1960 to 1969, the U.S. consumed, on average, 37.6% of the total global use of petroleum; the next largest oil consumer was the Former Soviet Union (FSU) at 11.6% (Table 3). Now the FSU has been dissolved and numerous developing countries have significantly expanded their economies, while the U.S. share of global oil consumption has actually declined to 25.7%, still extremely large; however, the impact of growing foreign economies is palpable. For example, often overshadowed by China and India, Brazil has also experienced rapid consumption in petroleum over the last 20 years (Table 4). Spain and Russia have also exhibited strong recent relative growth in oil consumption from 2000 to 2008.

## Table 2: Petroleum Consumption, Daily Average Barrels Consumed, Key Countries, 1960-2008 (million barrels)

| | 1960-69 | Rank | 1970-79 | Rank | 1980-89 | Rank | 1990-99 | Rank | 2000-08 | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| **WORLD** | **30.74** | | **57.03** | | **61.84** | | **70.26** | | **81.62** | |
| **Total OECD** | **22.47** | | **40.41** | | **39.11** | | **44.66** | | **48.65** | |
| **Total Non-OECD** | **8.27** | | **16.62** | | **22.72** | | **25.60** | | **32.97** | |
| **United States** | 11.56 | (1) | 16.98 | (1) | 16.27 | (1) | 17.878 | (1) | 20.17 | (1) |
| **China** | 0.24 | (12) | 1.28 | (9) | 1.93 | (5) | 3.294 | (3) | 6.25 | (2) |
| **Japan** | 1.69 | (3) | 4.65 | (3) | 4.69 | (3) | 5.564 | (2) | 5.26 | (3) |
| **Russia** | | | | | | | 3.068 | (4) | 2.73 | (4) |
| **Germany** | 1.45 | (4) | 3.13 | (4) | 2.73 | (4) | 2.862 | (5) | 2.67 | (5) |
| **India** | 0.24 | (13) | 0.51 | (13) | 0.88 | (13) | 1.524 | (13) | 2.47 | (6) |
| **Brazil** | 0.36 | (9) | 0.86 | (10) | 1.15 | (11) | 1.767 | (12) | 2.23 | (7) |
| **Canada** | 1.10 | (6) | 1.76 | (8) | 1.63 | (9) | 1.829 | (9) | 2.21 | (8) |
| **South Korea** | 0.05 | (14) | 0.33 | (14) | 0.61 | (14) | 1.772 | (11) | 2.17 | (9) |
| **Mexico** | 0.35 | (10) | 0.75 | (12) | 1.48 | (10) | 1.858 | (8) | 2.04 | (10) |
| **France** | 1.05 | (7) | 2.33 | (5) | 1.87 | (6) | 1.935 | (6) | 2.00 | (11) |
| **Italy** | 0.97 | (8) | 1.93 | (7) | 1.80 | (7) | 1.900 | (7) | 1.78 | (12) |
| **United Kingdom** | 1.42 | (5) | 2.07 | (6) | 1.66 | (8) | 1.810 | (10) | 1.76 | (13) |
| **Spain** | 0.25 | (11) | 0.83 | (11) | 0.94 | (12) | 1.177 | (14) | 1.55 | (14) |
| **Former USSR** | 3.56 | (2) | 7.16 | (2) | 8.94 | (2) | | | | |

Source: U.S. Department of Energy, Energy Information Administration, and Informa Economics.

## Table 3: Percent Share of World Petroleum Consumed by Key Countries, 1960-2008

| | 1960-69 | Rank | 1970-79 | Rank | 1980-89 | Rank | 1990-04 | Rank | 2000-08 | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| **WORLD** | **100%** | | **100%** | | **100%** | | **100%** | | **100%** | |
| **Total OECD** | **73.1%** | | **70.9%** | | **63.3%** | | **63.6%** | | **59.6%** | |
| **Total Non-OECD** | **26.9%** | | **29.1%** | | **36.7%** | | **36.4%** | | **40.4%** | |
| **United States** | 37.6% | (1) | 29.8% | (1) | 26.3% | (1) | 25.4% | (1) | 24.7% | (1) |
| **China** | 0.8% | (12) | 2.2% | (9) | 3.1% | (5) | 4.7% | (3) | 7.7% | (2) |
| **Japan** | 5.5% | (3) | 8.1% | (3) | 7.6% | (3) | 7.9% | (2) | 6.4% | (3) |
| **Russia** | | | | | | | 4.4% | (4) | 3.3% | (4) |
| **Germany** | 4.7% | (4) | 5.5% | (4) | 4.4% | (4) | 4.1% | (5) | 3.3% | (5) |
| **France** | 0.8% | (7) | 0.9% | (5) | 1.4% | (6) | 2.2% | (6) | 3.0% | (6) |
| **Canada** | 1.2% | (6) | 1.5% | (8) | 1.9% | (9) | 2.5% | (7) | 2.7% | (7) |
| **South Korea** | 3.6% | (14) | 3.1% | (14) | 2.6% | (14) | 2.6% | (8) | 2.7% | (8) |
| **Mexico** | 0.2% | (10) | 0.6% | (12) | 1.0% | (10) | 2.5% | (9) | 2.7% | (9) |
| **Brazil** | 1.1% | (9) | 1.3% | (10) | 2.4% | (11) | 2.6% | (10) | 2.5% | (10) |
| **Italy** | 3.4% | (8) | 4.1% | (7) | 3.0% | (7) | 2.8% | (11) | 2.4% | (11) |
| **United Kingdom** | 3.1% | (5) | 3.4% | (6) | 2.9% | (8) | 2.7% | (12) | 2.2% | (12) |
| **India** | 4.6% | (13) | 3.6% | (13) | 2.7% | (13) | 2.6% | (13) | 2.2% | (13) |
| **Spain** | 0.8% | (11) | 1.5% | (11) | 1.5% | (12) | 1.7% | (14) | 1.9% | (14) |
| **Former USSR** | 11.6% | (2) | 12.5% | (2) | 14.5% | (2) | | | | |

Source: U.S. Department of Energy, Energy Information Administration, and Informa Economics.

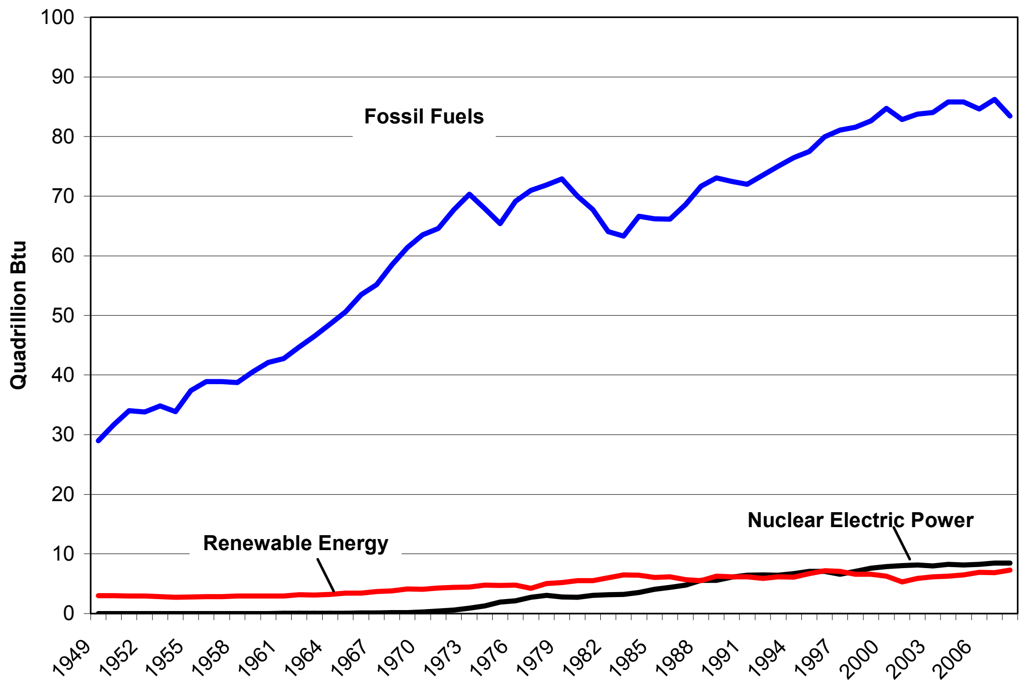
## Table 4: Annual Growth Rate of Petroleum Consumption in Key Countries, 1960-2008

| | Anl Rate 1960-69 | Rank | Anl Rate 1970-79 | Rank | Anl Rate 1980-89 | Rank | Anl Rate 1990-99 | Rank | Anl Rate 2000-08 | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| **WORLD** | 7.5% | | 3.4% | | 0.8% | | 1.5% | | 1.5% | |
| **Total OECD** | 7.6% | | 2.4% | | 0.3% | | 1.6% | | 0.2% | |
| **Total Non-OECD** | 7.4% | | 5.9% | | 1.7% | | 1.3% | | 3.5% | |
| **China** | 11.4% | (7) | 10.9% | (1) | 4.0% | (3) | 7.0% | (1) | 6.8% | (1) |
| **India** | 8.3% | (8) | 5.1% | (7) | 6.2% | (1) | 6.4% | (3) | 4.1% | (2) |
| **Brazil** | 6.1% | (11) | 8.5% | (4) | 2.5% | (5) | 4.8% | (4) | 1.8% | (3) |
| **Canada** | 6.0% | (12) | 2.6% | (8) | -0.5% | (12) | 2.0% | (6) | 1.7% | (4) |
| **Russia** | | | | | | | -8.4% | (14) | 1.5% | (5) |
| **Spain** | 18.6% | (2) | 6.0% | (5) | -0.5% | (11) | 3.6% | (5) | 1.2% | (6) |
| **Mexico** | 4.9% | (13) | 8.6% | (3) | 2.7% | (4) | 0.8% | (10) | 1.0% | (7) |
| **South Korea** | 26.1% | (1) | 10.8% | (2) | 4.9% | (2) | 6.5% | (2) | 0.4% | (8) |
| **United States** | 4.1% | (14) | 2.5% | (9) | 0.8% | (6) | 1.7% | (7) | 0.4% | (9) |
| **United Kingdom** | 7.9% | (9) | -1.8% | (14) | 0.3% | (7) | 0.0% | (13) | 0.0% | (10) |
| **France** | 11.5% | (6) | 1.5% | (11) | -2.0% | (14) | 0.9% | (9) | -0.3% | (11) |
| **Germany** | 12.6% | (5) | 1.4% | (12) | -1.0% | (13) | 0.5% | (11) | -1.2% | (12) |
| **Italy** | 13.1% | (4) | 1.0% | (13) | -0.1% | (9) | 0.4% | (12) | -1.6% | (13) |
| **Japan** | 16.1% | (3) | 2.4% | (10) | 0.1% | (8) | 1.0% | (8) | -1.7% | (14) |
| **Former USSR** | 7.6% | (10) | 5.4% | (6) | -0.2% | (10) | | | | |

Source: U.S. Department of Energy, Energy Information Administration, and Informa Economics.

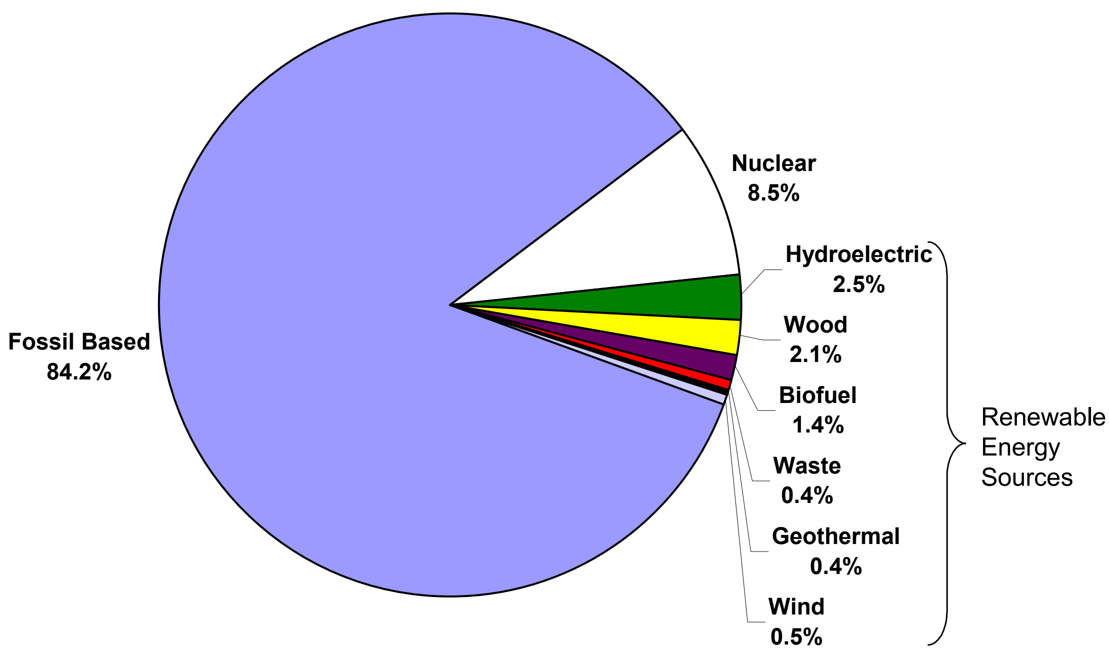
Since 1949, fossil fuel as a percentage share of total U.S. energy consumption has risen considerably relative to nuclear electric power and renewable energy sources (Figure 10). The U.S. consumed almost 30 quadrillion Btu of fossil fuels in 1949; this has increased significantly to approximately 85 quadrillion Btu of fossil fuels in 2008. Just as the U.S. relies heavily on petroleum as a primary source of energy, other sources play a significant role in the intricate energy balance (Figure 11). The U.S. uses an extensive amount of natural gas, coal, and nuclear electric power, with renewable energy growing more popular. In 2008, fossil fuel-based energy sources (coal, natural gas and petroleum) accounted for 84.2% of total U.S. energy consumed, with the remainder being nuclear electric power (8.5%) and renewable energy (7.3%).

**Figure 10: Energy Consumption by Source, 1949-2008**




Source: U.S. Department of Energy, Energy Information Administration

**Figure 11: Percent Energy Consumption by Source, 2008**

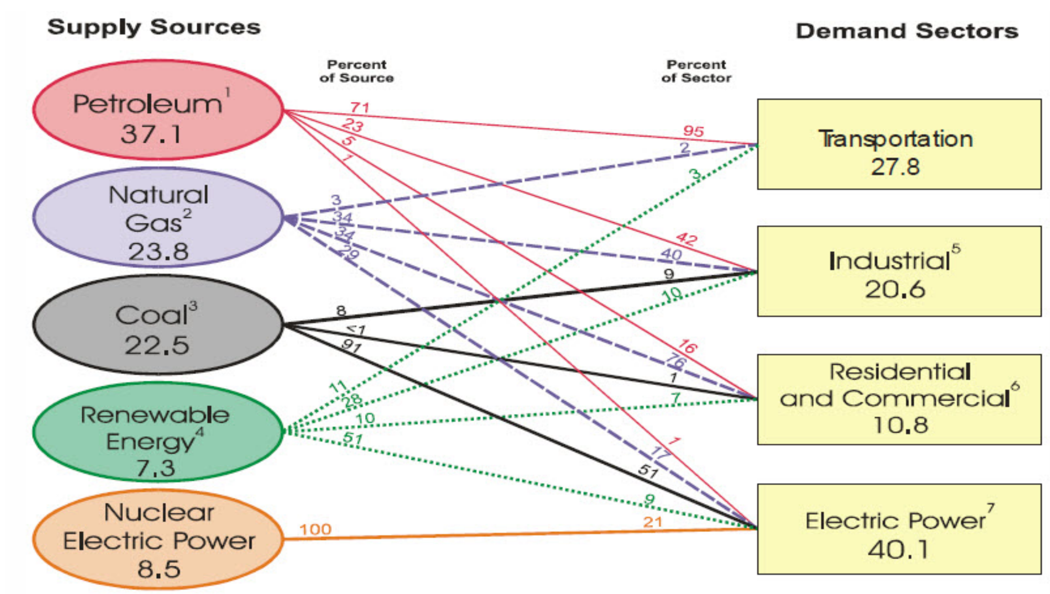



Source: U.S. Department of Energy, Energy Information Administration

There are four primary energy consuming sectors in the U.S. The four sectors are: residential, which accounts for 21.9% of the total energy consumption; commercial, which accounts for 17.9% of the total energy consumption; industrial, which accounts for 32.1% of the total energy consumption; and transportation, which accounts for 28.1% of the total energy consumption (Figure 12). Highlights of the supply/demand balance flow diagram are as follows:

- Transportation uses the largest share of petroleum at 71%, while the industrial sector uses 23% of petroleum and the remaining 6% goes to residential/commercial and electric power.
- The consumption of natural gas is evenly distributed between three sectors, with industry using 34%, residential/commercial using 34% and electric power using 29%; the remainder is consumed by transportation at only 3%.
- The consumption of coal primarily linked to two sectors, the generation of electricity at 91% and industrial consumption at 8%.
- Nuclear electric power is used exclusively, at 100% consumption, by the electric power demand sector.
- The use of renewable energy is divided across all four demand sectors with electric power using the most at 51% and industrial demand the second largest sector using 28%.

**Figure 12: U.S. Primary Energy Consumption by Source and Sector, 2007 (Quadrillion Btu)**




Source: USDOE, Energy Information Administration, Annual Energy Review 2007.

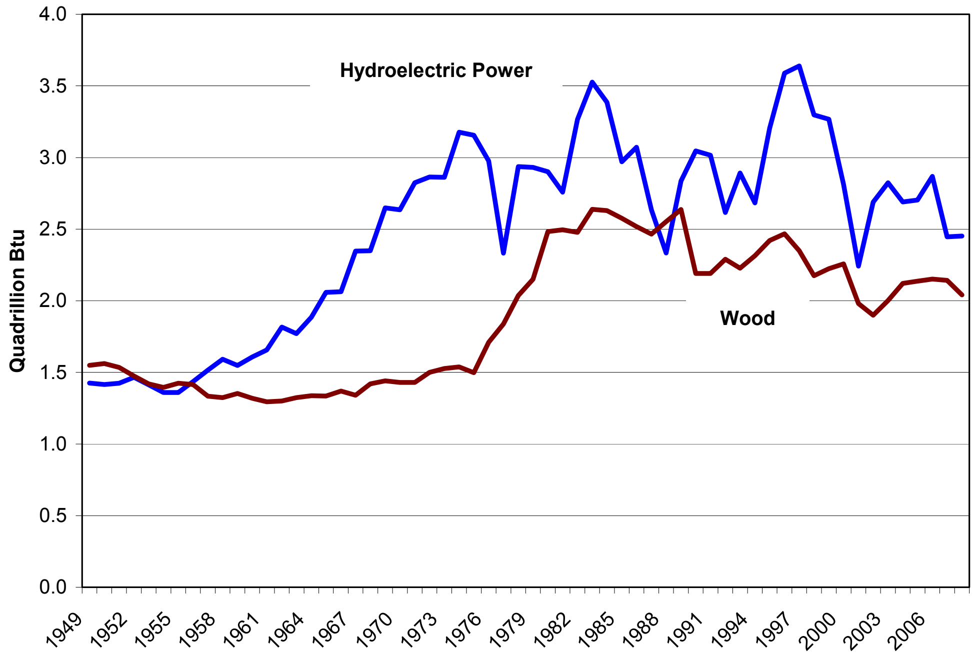
1 Excludes 0.6 quadrillion Btu of ethanol, which is included in "Renewable Energy."
2 Excludes supplemental gaseous fuels.
3 Includes 0.1 quadrillion Btu of coal coke net imports.
4 Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
5 Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
6 Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
7 Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

Briefly, the renewable energy sources can be segmented into the following general categories:

- Hydroelectric: Renewable energy from hydroelectricity.
- Wood: Wood, black liquor, and other wood waste.
- Waste**:** Municipal solid waste, landfill gas, sludge waste, tires, and agricultural byproducts, including animal waste, and other biomass (plant material and residue)
- Biofuels: Ethanol blended into motor gasoline and biodiesel.
- Geothermal: Geothermal electricity net generation, heat pump, and direct use energy.
- Solar: Solar thermal and photovoltaic electricity net generation, and solar thermal direct use energy.

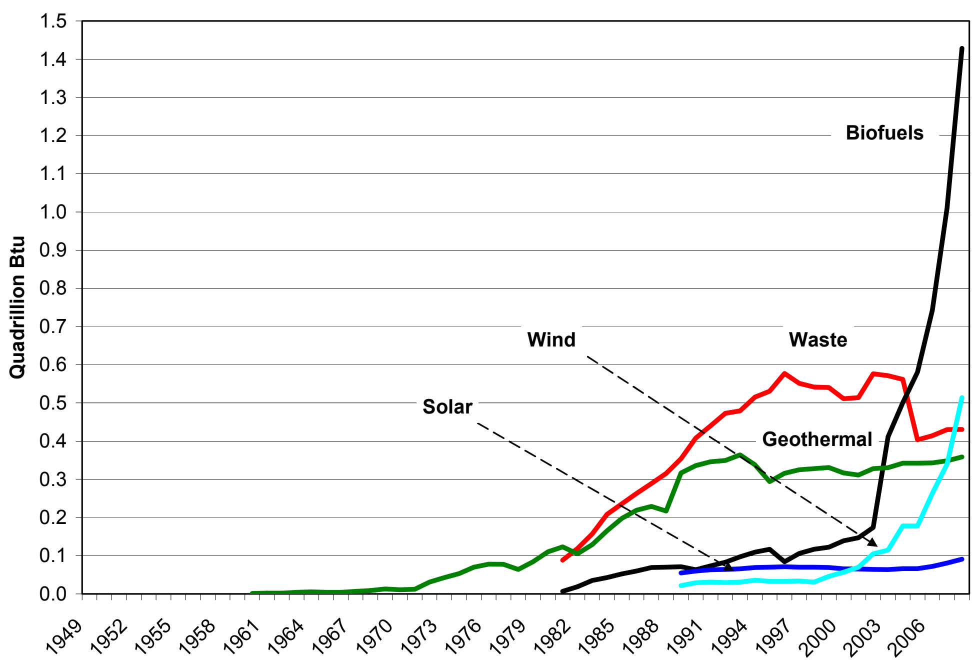
Hydroelectric power and wood-based power contribute the largest amount of renewable energy by a wide margin (Figure 13). However, their growth has remained flat since the 1980s. In general, other renewable energy sources have shown greater increases in their rate of adoption. Alcohol (ethanol) and wind based renewables have grown the most significantly from 1990 to the present (Figure 14).

**Figure 13: U.S. Renewable Energy Consumption by Source - Part I, 1949-2008**




Source: U.S. Department of Energy, Energy Information Administration, Monthly Energy Review.

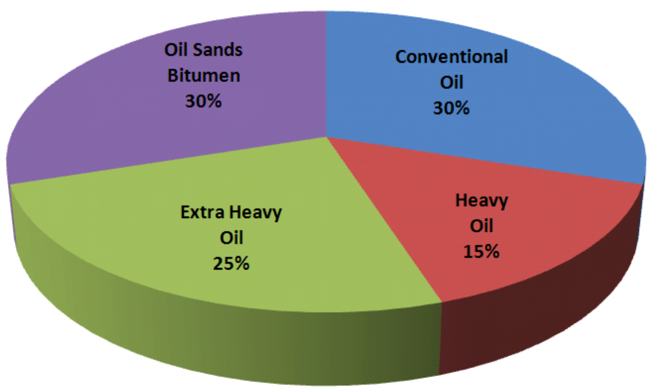
**Figure 14: U.S. Renewable Energy Consumption by Source - Part II, 1949-2008**




Source: U.S. Department of Energy, Energy Information Administration, Monthly Energy Review.

Today's marketplace is making a concerted effort to find larger supplies of renewable energy feedstocks and substitutes in order to replace the traditional fossil fuel (hydrocarbon based) sources of energy, as evidenced by such strong growth in the biofuels and wind sectors. Global economies are concerned that the supplies of conventional oil are declining rapidly and that the supplies of conventional oil might have passed what is called “peak oil.” Peak oil is defined as the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline. The concept is based on the observed production rates of individual oil wells, and the combined production rate of a field of related oil wells. The aggregate production rate from an oil field over time usually grows exponentially until the rate peaks and then declines, sometimes rapidly, until the field is depleted. Given the recent record prices for crude oil, the peak oil debate has gained significant attention with strong arguments both for and against the concept. Some experts have now estimated that total world reserves of *conventional* oil are now less than 30% of total oil supplies which include heavy oil, oil sands and extra heavy oil (Figure 15). The heavier oils are not easy to use (require special refining procedures) and are more expensive to extract compared to conventional oil. In addition to concerns over peak oil, energy security and mitigation of climate change are important reasons for the move toward biofuels and wind energy.

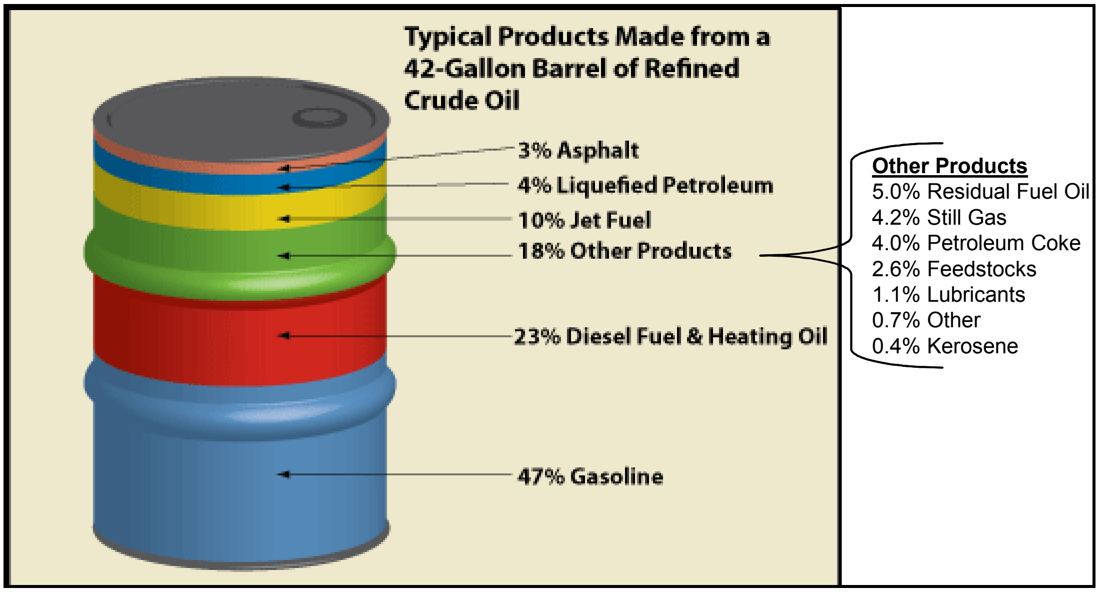
**Figure 15: Total World Oil Reserves**




Source: Alboudwarej, Husswin, Highlighting Heavy Oil, Oilfield Review, Summer 2006.

One of the reasons that conventional oil has become such a vital link and input in global economies is because of its chemical versatility which provides a plethora of uses. When refined, one barrel of crude oil yields about 19 gallons of finished motor gasoline, 9 gallons of diesel fuel, as a well as other petroleum based derivatives used in products such as ink, crayons, bubble gum, dishwashing liquids, deodorant, eyeglasses, records, tires, ammonia, and heart valves, etc. (Figure 16).

**Figure 16: Products Made from a Barrel of Crude Oil**[3]




Source: USDOE, Energy Information Administration and American Petroleum Institute.

In general, each barrel of oil in the U.S. is fractionated into fairly consistent components as described below.[4]

- **Gasoline:** Of all the crude oil refined for use in the United States, almost half (47%) becomes gasoline for automobiles, boats and other gasoline-driven motors.

- **Jet Fuel:** Airplanes utilize approximately 10% of a refined barrel of oil in the form of jet fuel.

- **Diesel Fuel and Home Heating Oil:** 23% becomes distillate, two-thirds of which is refined for diesel fuel for trucks, buses and other diesel engines, while the remaining one-third is used as home heating oil.

- **Boiler Oil:** Boiler oil, or residual fuel oil, makes up 5% of refined crude oil and is used on ships, in industrial boilers and in power plants to produce electricity.

- **Asphalt and Road Oil:** Asphalt and road oil accounts for 3% of crude oil consumption.

[3] Note: Percentages total 105% because of "processing gain." A 42 gallon barrel of oil actually yields 44 gallons of products.

[4] It should be noted that this crude oil fractionation recipe does vary by country, where a different economies require different input streams depending on the structure of their economies.

- **Other:** Approximately 9.4% of the crude oil is refined into non-energy related feedstocks for manufacturing products such as lubricants, wax, coke for steel making, and napthas that are used in the drycleaning process.

- **Petrochemical Feedstocks:** Petrochemical feedstocks, products of the refining process, make up the remaining 2.6% of all refined crude oil. Half of this is used to make plastics (approximately 1.3% of the total) for thousands of items such as tableware, furniture, aircraft and automobile parts, luggage, surfboards, helmets, medical supplies and packaging. The remaining 1.3% is used to make products such as solvents, synthetic fibers for wearing apparel, synthetic rubber, paints and coatings.

From a scientific and chemical perspective these refined crude oil products can be described as follows:

- **Petroleum gas** - used for heating, cooking, making plastics small alkanes (1 to 4 carbon atoms) commonly known by the names methane, ethane, propane, and butane, which is often liquified under pressure to create LPG (liquified petroleum gas).

- **Naphtha or Ligroin** - intermediate that will be further processed to make gasoline mix of 5 to 9 carbon atom alkanes, and a motor fuel liquid mix of alkanes and cycloalkanes (5 to 12 carbon atoms).

- **Kerosene** - fuel for jet engines and tractors; starting material for making other products as a liquid mix of alkanes (10 to 18 carbons) and aromatics.

- **Gas oil or Diesel distillate** - used for diesel fuel and heating oil; starting material for making other products liquid alkanes containing 12 or more carbon atoms.

- **Lubricating oil** - used for motor oil, grease, other lubricants; consists of liquid long chain (20 to 50 carbon atoms) alkanes, cycloalkanes, and aromatics.

- **Heavy gas or Fuel oil** - used for industrial fuel; starting material for making other products liquid long chain (20 to 70 carbon atoms) alkanes, cycloalkanes, and aromatics.

- **Residuals** - coke, asphalt, tar, waxes; starting material for making other products solid multiple-ringed compounds with 70 or more carbon atoms.

Consistent with the nomenclature or breakdown of how a barrel of oil is used in the U.S. as previously discussed, the DOE's, Energy Information Agency (EIA) estimated the volume of oil consumption per respective product category in 2007, as shown in Table 5. The average daily oil consumption for all refined oil products in the U.S. was approximately 20.5 million barrels in 2007. Annually, total oil consumption in the U.S. is a staggering 7.5 billion barrels of oil. Keep in mind that volumetrically a barrel of oil is approximately 42 gallons. Finished motor gasoline consumption was approximately 3.4 billion barrels in 2007; multiplying a barrel of oil times 42 gallons makes the volume of finished motor gasoline consumed in the U.S. even more imposing at an estimated level of 143 billion gallons. Even with this comprehensive list of petroleum products, a barrel of crude oil can be reduced into more specialized products; that is why the term feedstock is used to explain the potential to further add value to the crude stream.

**Table 5: Volume of U.S. Petroleum Products Consumed in 2007**

| | Annual (Thousand Barrels Per Day) | Annual (Thousand Barrels Total) |
|---|---|---|
| Finished Motor Gasoline | 9,286 | 3,389,390 |
| Distillate Fuel Oil | 4,196 | 1,531,540 |
| Liquefied Refinery/Petroleum Gases | 2,085 | 761,025 |
| Kero-Type Jet Fuel | 1,622 | 592,030 |
| Petroleum Coke | 490 | 178,850 |
| Still Gas | 697 | 254,405 |
| Residual Fuel Oil | 723 | 263,895 |
| Asphalt and Road Oil | 494 | 180,310 |
| Other Oils for Feedstocks | 350 | 127,750 |
| Naptha for Feedstocks | 294 | 107,310 |
| Lubricants | 142 | 51,830 |
| Miscellaneous Products | 63 | 22,995 |
| Kerosene | 32 | 11,680 |
| Special Napthas | 41 | 14,965 |
| Finished Aviation Gasoline | 17 | 6,205 |
| Waxes | 11 | 4,015 |
| Total | 20,543 | 7,498,195 |

Source: U.S. Department of Energy, Energy Information Administration.

The final markets for value-added refined crude oil product streams are extremely large and diverse in the U.S. Table 6 highlights the estimated value of the major markets that use both petroleum and biobased feedstocks (i.e., corn and soybeans). The markets range in value from the largest market; that is gasoline at $298 billion in 2006, down to the high emerging growth market for wood substitutes at $3.4 billion. All of these markets use hydrocarbon based petroleum feedstocks as an input to their manufacturing activities. The petroleum content level varies significantly across markets. Gasoline and diesel are exclusively petroleum based; however, the petroleum input stream is much smaller as a percent share of the total product volume for cosmetics and personal care products.

Biobased feedstocks continue to make inroads into these different markets at a significant rate. Many companies are espousing the virtues of being green and not using petroleum based feedstock; rather, they are focused on increasing their use of renewable sources of inputs. It is unclear just how far renewable feedstocks from corn and soybeans have penetrated these markets. The easiest markets to estimate are the gasoline and diesel markets where ethanol and biodiesel production volumes are closely tracked by the industries. Less clear is an adequate understanding, for example, of the actual percent share of the sanitary cleaning products market that is biobased. Many market estimates are bantered about with little clear empirical supporting evidence, compared to such reliable surveys as the U.S. Census of Manufacturing.

**Table 6: Major U.S. Markets for Petroleum and Biobased Feedstocks, 2006**

| Sector | Value of Shipments/Markets ($1,000) |
|---|---|
| Gasoline | 298,589,184 |
| Diesel (on highway) | 87,703,231 |
| Pharmaceuticals | 163,005,621 |
| Textiles (clothing, carpets, bedding linens, auto) | 38,028,266 |
| Lubricants (motor oil, transformer fluid, hydraulic fluids, etc.) | 11,308,102 |
| Solvents | 5,500,000 |
| Sanitary Cleaning Products (hand cleaners, janitorial cleaners, household, food service, laundry) | 34,267,288 |
| Cosmetics and Personal Care Products | 5,900,000 |
| Adhesives/binders | 9,230,331 |
| Paints and Coatings (inks, paints, etc.) | 22,558,703 |
| Plastics (films, containers, polymers, insulations, foams) | 203,496,075 |
| Resins and Synthetic Rubber Manufacturing | 93,499,662 |
| Fertilizers | 12,652,957 |
| Sorbents | 3,280,000 |
| Wood Substitutes Composite Panels | 3,380,000 |

Source: U.S. Department of Commerce: 2006 Census of Manufacturing, Freedonia Group, DOE: EIA, Informa Economics.

### 1. Conclusion

The biobased corn and soybean products and technologies will ultimately be challenged by two basic obstacles relative to petroleum; the first is economic and second is performance (attributes). The first challenge relates to the simple question: is the biobased product or technology cost competitive with traditional petro based feedstocks or related technological processes? In general, as petroleum prices rise, the easier it is to justify substituting a crude oil feedstock with a biobased corn or soybean feedstock. As petroleum prices fall the inverse is true, biobased feedstocks face inflection points in pricing where they become more costly relative to petroleum. The record high prices of crude above $100/barrel in 2008 provided significant opportunities for biobased products to gain interest from those manufactures that were looking to replace their high cost oil feedstocks.

The second question relates to how well the respective biobased product or technology performs relative to traditional petroleum manufacturing platforms. For example, in the world of lubricants, specifically motor oil, a significant amount of research has been conducted regarding the use of soybean oil as a potential replacement for motor oil. The challenge for soybean researchers has been to try and replicate the same qualities and characteristics of petroleum based motor oil regarding its ability to withstand high temperatures without experiencing any loss in lubricity. It is within this context that the Informa research team "set out" to indentify those corn and soybean based products and technologies that could successfully compete in terms of their relative economics and attributes compared to traditional hydrocarbon based petroleum products and technologies. It should be noted that petroleum markets have certainly played a major role in the recent interest and developments in biobased products and technologies; the growth however, has not been confined to only the large fuel markets. Significant advancements have occurred in numerous other markets because of the desirable environmental properties of renewability and biodegradability. These attractive properties are creating new and exciting opportunities for feedstocks that are based on corn or soybeans. Beyond biobased products/technologies, significant advances are also emerging in other fields like health with soy isoflavones or in more traditional ones like animal feed. Results and recommendations of this endeavor can be found in the individual commodity reports (i.e., for corn and soybeans).

# III. Phase II – Overview of Top 20 Soybean Products/ Technologies

After assessing the products/technologies listed in the Appendix section based on the criteria previously discussed (i.e., demand/market potential, economic feasibility, development stage and strength of institutional support), the top 20 products/technologies were identified. These products/technologies are briefly reviewed within this section and are listed in Table 7. Upon further analysis and interviews (see appendix), this list was then further refined down to the top 8, which are each presented in more detail within the next section (IV).

**Table 7: List of Top 20 Soybean Products/Technologies**

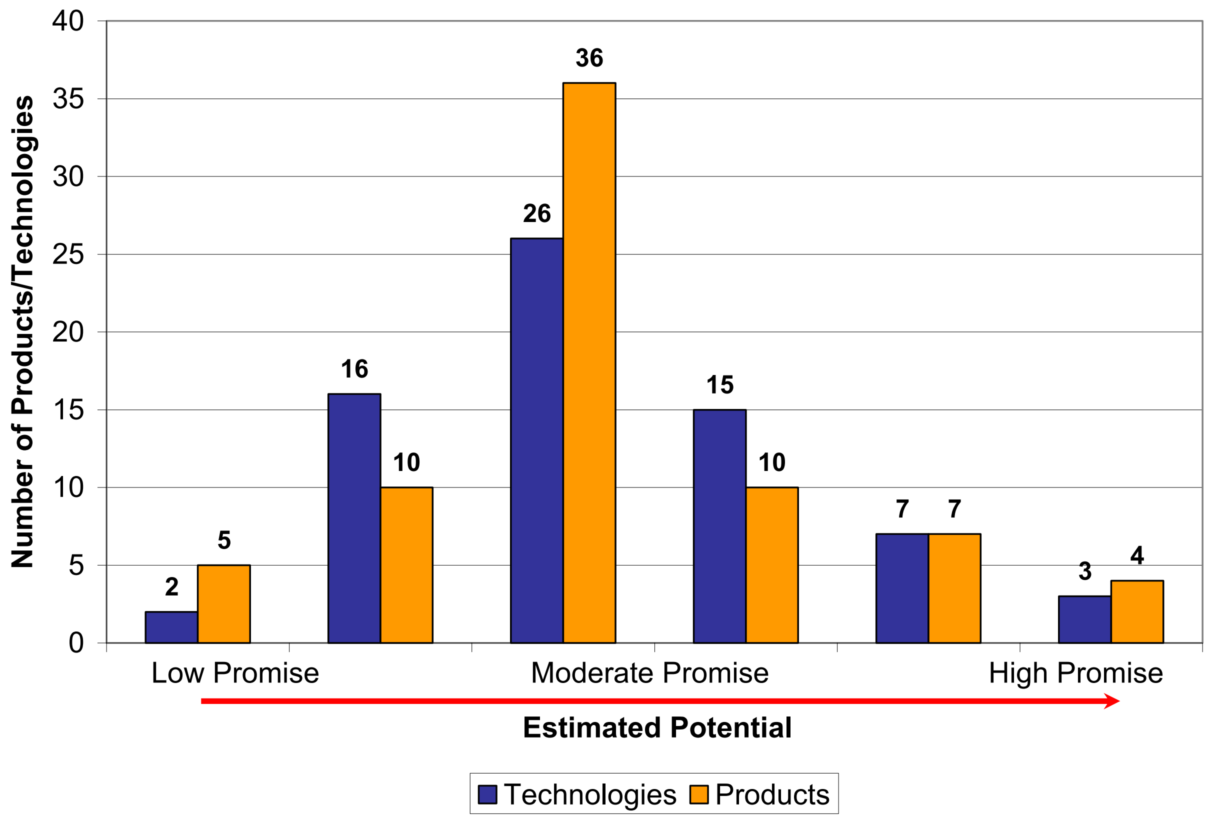
| Product/Technology Name | Soybean Origin | Product | Technology | Product/Technology Timeframe |
|---|---|---|---|---|
| **Renewable Fuel** | | | | |
| Biodiesel Additives | NA | ✓ | ✓ | Short Term |
| Enzymatic Transesterification | Soybean Oil | | ✓ | Short Term |
| Renewable Diesel | Soybean Oil | ✓ | ✓ | Short Term |
| Solid Transesterification Catalyst | Soybean Oil | | ✓ | Short Term |
| **Green Chemicals** | | | | |
| Epichlorohydrin | Glycerin | ✓ | | Medium Term |
| Epoxidized Soybean Oil | Soybean Oil | ✓ | | Short Term |
| Lubricant | Soybean Oil | ✓ | | Short Term |
| Polyols | Soybean Oil or Glycerin | ✓ | ✓ | Short Term |
| Propylene Glycol | Glycerin | ✓ | ✓ | Short Term |
| Soy Methyl Ester (non-fuel applications) | Soybean Oil | ✓ | | Short Term |
| Wood Adhesive | Soybean Protein | ✓ | | Short Term |
| **Soybean Crushing** | | | | |
| Enzymatic Degumming | Soybean Oil | | ✓ | Short Term |
| Supercritical Carbon Dioxide Extraction of Oil | Soybean | | ✓ | Short Term |
| **Value-Added Soybean Varieties** | | | | |
| High Oil Soybeans | Soybean | | ✓ | Medium Term |
| High Stability Oil Soybeans | Soybean | | ✓ | Short Term |
| Omega-3 Fortified Soybeans | Soybean | | ✓ | Medium Term |
| **Other** | | | | |
| Aquaculture Feed | Soybean Protein | ✓ | | Short Term |
| Animal Feed | Glycerin | ✓ | | Short Term |
| Olefin Metathesis | Soybean Oil | | ✓ | Short Term |
| Soy Isoflavones | Soybean | ✓ | | Short Term |

Short term: 0-3 years
Medium term: 3-5 years
Long term: > 5 years

It is important to keep in mind that this list is ever changing, as new developments are brought forth and as new information about these technologies becomes available. These products and technologies have the potential to move in either direction, up or down the list of top prospects.

Each of the 100+ products and technologies were assessed based on their demand/market potential, their economic feasibility, their stage of development, and their strength of institutional support. The distribution of the assessed potential for the reviewed products and technologies is presented within Figure 17. In order to facilitate the identification of the most promising emerging products/technologies, Informa also conducted interviews with industry specialists to provide confirmation and insight into the finalization of the top 20 list.

**Figure 17: Distribution of Soybean Products/Technologies Based on their Estimated Potential**




## A. Renewable Fuel

The advent of the biodiesel industry has created a large new outlet for soybean oil. Nevertheless, despite strong government support, the industry is struggling, as biodiesel production generally remains unprofitable. Overall production capacity utilization currently does not exceed 20%, and although biodiesel consumption is expected to increase at least in line with the Renewable Fuel Standard (1 billion gallons of biomass-based diesel by 2012), there is a possibility the RFS will favor animal fats and recycled grease over soybean oil because of lower greenhouse gas emissions. Still, new process technologies have the potential to improve the quality and/or the cost competitiveness of biofuels and could contribute to a larger use of biofuels.

### 1. Biodiesel Additives

In the early 20th century, Rudolph Diesel, the inventor of the diesel engine, experimented with fuels ranging from powdered coal, peanut oil and soybean oil. Ultimately, the most prevalent and cheap form of diesel feedstock emerged in the form of petroleum distillate (made from oil). As petroleum prices rose dramatically in the late 70's and reached an all-time high peaking at over $145/barrel for West Texas Intermediate in the summer of 2008, new and creative feedstocks have once again emerged for the production of biodiesel. Biodiesel companies are using vegetable oils (e.g., palm oil, corn oil, canola and especially soybean oil) as a potential feedstock as well as different types of animal fats from renderers and even spent greases from restaurants have been used to produce biodiesel. Even these various biodiesels can blended into different formulations ranging from B100 (100% biodiesel) down to B2 (2% biodiesel blended with 98% diesel fuel).

Since the industry began expanding in the late 1990s, soybean oil has clearly been the most prevalent source for making biodiesel in the U.S. Despite all of the numerous benefits of using and making soy-diesel, such as lubricity, ability to auto-ignite and high cetane levels there are a number of significant challenges faced by the users of soy-diesel. Chemically speaking, soy-diesel is a fuel comprised of mono-alkyl esters of long-chain fatty acids. These fatty acids have several unique characteristics which may cause operational difficulties for the user. The most significant issues facing the marketers and end users of biodiesel fuel are: low-temperature fluidity (known as cold flow) and thermal and oxidation stability.

- Cold flow is the problem where biodiesel performs significantly worse than traditional diesel fuel under cold conditions. When biodiesel begins to form wax crystals (called the cloud point) it can clog fuel lines and filters in a vehicle's fuel system. At even more extreme temperatures, biodiesel fuel can become a gel that cannot even be pumped; this is called the pour point (the temperature at which the biodiesel cannot flow). This is of course a major concern for the use of biodiesel in regions of the U.S. with colder climates.

- The use of vegetable oils and their high levels of unsaturates are well-known as root causes of fuel instability. Vegetable oils contain polyunsaturated fatty acids that are susceptible to oxidation, polymerization and gum formations.

These challenges have led to the investigation and development of various additives in hopes of alleviating the performance concerns of biodiesel under certain conditions. A number of companies have recently claimed to have made progress in the development of new additives. A list of some of these new biodiesel additive products is as follows:

- **Eastman Chemical, BioExtend 30HP**: this is a product that is designed to provide oxidative stability of biodiesel and blends up to B10. The company claims that their blend of antioxidants plus a chelating agent will offer protection against the detrimental effect of oxidative stability on metals contamination.

- The German company **BASF** has built a new plant to produce a number of products under the name of **Keroflux**. The Keroflux products are chemicals which improve the flow of fuel and diesel in the winter by dispersing wax crystals, even at low temperatures.

- **Amsoil, Diesel Concentrate Plus Cold Flow** Improver (DFC); the product combines a detergent and cold flow anti-gelling agent. The detergent helps to keep injectors, rings and piston crowns lubricated and free of soot. More importantly, is the inclusion of the Cold Flow Improver additive, which is claimed to reduce the cold filter plugging point by as much as 34ºF in ultra-low sulfur diesel fuel (ULSD).

- **Afton Chemical Corp**; Announced this summer (June 2nd) the launch of a new product line to address the cold flow problem. The company states that their research team, "have developed a new line of additives that represent a significant leap forward in performance and reliability for the end user."

### 2. Enzymatic Transesterification

The conventional transesterification process to produce biodiesel involves the reaction of triglycerides with methanol in the presence of a catalyst (mainly NaOH or KOH). This approach offers high yields and short reaction times but it is also associated with several problems:

- High energy consumption;
- Difficulty in glycerin recovery (the co-product of biodiesel production);
- High amount of alkaline waste water (as a result of the catalyst use); and
- Interference of free fatty acids with the catalyst[5].

Enzymatic reactions involving lipases can be an excellent alternative to produce biodiesel through a process referred to as alcoholysis, a form of transesterification reaction, or through an interesterification (ester interchange) reaction. By contrast, to conventional transesterification, the reaction temperature is much lower, recovery of the glycerin is simpler and there is no spent catalyst to remove or waste water to treat. Moreover, the free fatty acids in the feedstock can be completely converted to biodiesel. At this point, enzymatic transesterification is still being researched but it has the potential to significantly decrease production costs. Still, a number of shortcomings need to be addressed, including the high price of lipase and its short operational life.

[5] Conventional biodiesel technologies generally use feedstock with a FFA no higher than 0.2%, as FFAs neutralize the catalyst and form soaps that (i) complicate phase separation and (ii) form sediments that may plug pipes and filters. As a result, unless refined vegetable oil is used (i.e., max FFA ≤0.1%), conventional processes generally require a pre-treatment step to remove the FFAs in the feedstock.

Novozymes has already developed an operational enzyme but is still working on it so as to bring its cost down. The company has reportedly partnered with Piedmont Biofuels from North Carolina to improve the process. The project was awarded a $197,000 grant in 2009 by the Chatham County Economic Development Corporation in North Carolina. In addition to Novozymes, several research units including the USDA ARS are currently investigating the matter.

### 3. Renewable Diesel

Mono-alkyl esters of vegetable oil or animal fats (i.e., biodiesel) has, until now, been the sole source of "biomass-based diesel" in the U.S.. This situation, however, could soon change as Dynamic Fuels LLC[6] is expected to open the first renewable diesel facility in the U.S. early 2010.

Renewable diesel, sometimes also referred to as "green diesel" or "second-generation biodiesel"[7], is a diesel-like fuel derived from any triglyceride feedstock (like vegetable oil or animal fats). Unlike biodiesel, renewable diesel replicates the chemical structure of its diesel counterpart, therefore working seamlessly with existing distribution infrastructures, storage systems, and engines.

One major advantage of renewable diesel technologies over transesterification is that the product's cloud point (from +50°F to -4°F) can be tailored to the application, with yields increasing at higher cloud points. A key attribute of renewable diesel technologies is also their ability to utilize a wide array of inputs as free fatty acids can be completely converted to biofuel. Furthermore, contrary to biodiesel whose production is associated with the production of glycerin that currently has little value and can be hard to dispose of, the production of renewable diesel is associated with the formation of propane and other naphtha products that are much more valuable.

Technologies also provide flexibility in the type of biofuel produced. One excellent avenue is jet fuel as conventional biodiesel does not meet the cold-flow properties and high energy densities associated with jet fuel.

One weakness of renewable diesel over biodiesel is the higher conversion cost as the reaction requires a greater amount of energy. Moreover, renewable diesel has greater particulate emissions than biodiesel.

Several companies like Petrobras, UOP, Neste, Syntroleum, and Nippon Oil Corporation have developed renewable diesel technologies.

[6] A 50:50 venture between Tyson and Syntroleum.

[7] Note that many consider the use of the terms "green diesel" or "second-generation biodiesel" incorrect since renewable diesel, like conventional diesel fuel, is not easily biodegradable (green refers to the origin of the fuel) and it does not meet the definition of biodiesel in terms of fuel composition.

One should note that Petrobras and Nippon Oil Corporation technologies are based on a commingled hydrotreating process. Renewable diesel made using a commingled hydrotreating process (i.e., co-processing) is only eligible for a $0.50/gal tax credit compared to a standalone hydrotreating process.

#### 4. Solid Transesterification Catalysts

The conventional transesterification reaction to produce biodiesel consists in reacting a triglyceride feedstock with methanol in the presence of a liquid catalyst, generally sodium hydroxyde, potassium hydroxyde or sodium methylate. These homogeneous catalysts (i.e., they completely dissolve in the medium) are relatively effective and inexpensive. Nevertheless, they also suffer from several drawbacks:

- They require catalyst recovery and aqueous treatment steps.
- They cannot be recovered and lead to waste products, decreasing efficiency and increasing costs.
- Base catalysts react with free fatty acids (FFAs) to form soaps that (i) complicate phase separation and (ii) form sediments that may plug pipes and filters.
- Sodium methylate is highly explosive.
- The catalyst contaminates the glycerin co-product.

In order to circumvent these problems, it is possible to use heterogeneous catalysts, a solid whose surface is catalyzing reaction of liquids and/or gases. Heterogeneous catalysts are generally made from mixed metal oxide. A common approach is to have a reactor packed with catalyst particles, with the reactants flowing past.

Their use requires neither catalyst recovery nor aqueous treatment steps, thereby simplifying downstream separation steps and enabling the production of salt-free glycerin at purities exceeding 98%. Furthermore, the process can handle low-quality feedstocks with high levels of FFAs without the need for costly pre-processing steps. Also, the catalyst can be recovered and reused, which can cut biodiesel catalysis costs by up to two-thirds.

Several companies including Axens, Better Biodiesel, New Century Lubricants, and Süd-Chemie Group have already developed several variants of heterogeneous catalysts.

### B. Green Chemicals

The utilization of renewable resources as raw materials for green chemicals is gaining momentum in a context of high energy prices[8] and increasing efforts to decrease greenhouse gas emissions. Vegetable oils, and soybean oil in particular, bear an especially large potential for the substitution of currently used chemicals,

[8] $60+/bbl for crude petroleum oil is high by historical standards.

since monomers, fine chemicals and polymers can be derived from these resources in a straightforward fashion.

### 1. Epichlorohydrin

Epichlorohydrin is a high volume commodity chemical used largely in epoxy resins to produce plastics and elastomers. In 2003, the US production capacity was estimated at 960 million lbs. Most of the production is made from propylene and chloride as primary raw materials in a multi-step process. This process, however, suffers from some undesirable features, especially low yields. Moreover, inefficiencies in some of the reactions lead to the formation of unwanted chlorinated organics that are expensive to dispose of. Such factors have prompted the search for alternative routes to produce epichlorohydrin that are more efficient and environmentally friendly.

It has been known for decades that glycerin can be made to react with hydrochloric acid to form an intermediate dichlorohydrin that can then be converted to epichlorohydrin. This chemical path, however, traditionally was not used commercially to any significant extent because of the high cost of glycerin compared to propylene. The advent of the biodiesel industry that generates large amounts of glycerin, and the tight propylene market, have now reversed this situation.

Several companies, including Dow Chemical, Solvay SA and Spolchemie, have announced plans to commercialize epichlorohydrin from glycerin.

The production of epichlorohydrin from glycerin holds great potential but the volatility of glycerin prices along with the uncertainty surrounding the future of the biodiesel industry (tight economics and emergence of renewable diesel technologies that are not associated with any glycerin production) could act as major barriers.

### 2. Epoxidized Soybean Oil

The term “epoxide” indicates the presence of a three membered cyclic ether (also called oxirane or alkylene oxide) in which an oxygen atom is joined to each of two carbon atoms that are already bonded with each other. Chemically speaking, epoxides undergo reactions such as C-O bond cleavage, nucleophilic addition, hydrolysis and reduction under mild conditions and more rapidly than other ethers. Epoxides are formed by some oxidation reactions of alkenes with peracids. Epoxidized soybean oil (ESO) is the most prevalent epoxidized oleochemical (glycerol fatty ester). Soybean oil offers numerous advantages as a feedstock, such as low toxicity and inherent biodegradability. In general ESO shows excellent potential as a renewable material for industrial applications.

In recent years, extensive work has been conducted to develop polymers for epoxidized triglycerides or fatty acids. These renewable resource-based polymers can form a platform to replace/substitute for petroleum-based polymers through innovative design this biobased platform can compete and sometimes even surpass petroleum-based materials on a cost-performance basis with the added advantage of being eco-friendly. As a result, there is interest, for example, in the development of new biobased thermosetting polymers.

The current difficulties with some of the biobased polymers in commercial applications are mainly due to their inferior mechanical and thermophysical properties in comparison with conventional petroleum-based polymers. Therefore, it is currently difficult to completely replace petroleum-based polymer materials for nothing more than the necessary mechanical and thermophysical physical properties. It is not necessary, however, to completely replace petroleum-based polymer material with a biobased material. As a result, an excellent solution combines different features and benefits of both synthetic and biobased materials to reduce the dependence on petroleum. Consequently, biobased materials can be used to partly replace thermosetting resins, such as epoxy resin and unsaturated polyester.

The largest category of industrial ESO oil use includes plastics and resins. ESO is primarily used as a plasticizer or stabilizer to modify the properties of plastic resins such as polyvinyl chloride (PVC), and ESO can also be used as a reactive modifier or diluent[9] of other systems. For example, numerous studies of ESO and epoxy resin blends have been performed to obtain modified networks. More recently, researchers have begun to explore the feasibility of manufacturing composites from ESO. Up to now, the widespread structural application of ESO has been limited because of its low crosslinking density and mechanical performance. The development of soybean oil-based resins for structural applications is still a challenge for the polymer and composite industries.

Dow Chemical Company (Dow) used to be a major producer of ESO. In 2006, however, Dow announced their departure from ESO manufacturing. The primary firms in the ESO manufacturing market are Arkema, Chemtura and Ferro. Since 2006, these remaining firms have been faced with a challenging economic environment given the extreme price volatility and record high price levels of soybean oil. The rapid growth of the U.S. biodiesel industry and the demand for soybean oil as a feedstock is a key contributor to the difficult situation.

### 3. Lubricant

Biobased lubricants and especially soy-based lubricants can be considered a fairly mature area of research, where the pros and cons are well understood by the scientific community compared to mineral oil lubricants. This does not mean however, that soy-based lubricants do not have a significant opportunity for gaining market share from traditional petroleum based lubricants (mineral oils). In the end, the ultimate challenge of soy-based lubricants will be the ability to measure up to the technical and economic characteristics of mineral-oil (hydrocarbon based) lubricants while providing the desired benefit of being biodegradable.

[9] A diluent decreases the viscosity of a fluid.

The market potential for soy-based lubricants, both domestically and internationally, is quite large and diverse. This diversity is exemplified in the fact that many of the lubricant market studies exhibit a lack of consistency in the categories that they highlight. In general, the primary lubricant product categories are as follows: hydraulic fluid, two-cycle engines, bar/chain (chainsaws), crankcase (engines), drip oil, rail and flange, wire rope, metal cutting, dedusting.

Estimates by the Freedonia Group in 2007, identified the world market for lubricants as being approximately 11.8 billion gallons per year (41.8 million metric tons) and the market being segmented by the following categories:

- Engines 48%
- Process oils 15.3%
- Hydraulic oils 10.2%
- All other 26.5%

An estimate of the U.S. market for lubricants was conducted by the National Petroleum Refiners Association (NPRA) in 2006. The NPA estimated that the U.S. lubricant market is approximately a 2.5 billion gallon a year industry. Based on the NPRA study, the U.S. market is segmented into the following categories;

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

Two of the biggest hurdles facing the use of soybean oil (and most vegetable oils in general) as a lubricant are performance issues related to thermal oxidative and hydrolytic stability (note: traditional mineral oil lubricants do not have these problems). These issues are being addressed by the industry on a number of important fronts, they are as follows:

- The use of biotechnology (by such firms as Monsanto and DuPont) to produce soybeans that are high in oleic acid (18:1), with monosaturated levels that are better than canola/rapeseed.

- Non-transgenic modification of soybeans in order to develop new varieties with high levels of oleic acid (18:1) and lower levels of unsaturates.

- ADM and others are working on the development of low-cost soybean oil modification processes to produce high-temperature stability attributes.

- Researchers at such companies as Valvoline have been working on the blending of chemical additives in order to improve soybean oil stability. This pathway has proven to have a much lower cost of development compared to the other advancements.

Future demand for conventional lubricants will likely be consistent with the overall economic growth (based on Gross Domestic Product, GDP) of a respective country. This means that areas with faster anticipated economic growth such as China and India will probably experience much stronger demand for conventional lubricants versus slower growth economies such as the U.S. and Europe. A caveat is in order however, these faster growth regions will also be difficult to penetrate with soy-based lubricants unless favorable policies are enacted in those countries to promote the use of bio-based lubricants. Countries such the U.S. and regions like the European Union have been encouraging policies where biobased products such as soy-based lubricants are valued for their environmental benefits. Further policy progress in these "environmentally friendly" countries will be necessary along with significant technological advancements in order for soy-based lubricants to gain notable market share away from traditional mineral oil applications/markets.[10]

#### 4. Polyols

Polyols are chemical compounds whose main use is as reactants to make polymers, polyurethanes in particular. Although polyols traditionally originate from the petrochemical industry, a class of "renewable" polyols has recently emerged. These renewable materials, that qualify as "biobased products" under the Farm Security and Rural Investment Act of 2002, are made from vegetable oil and help reduce the carbon footprint of the various downstream applications. The United Soybean Board estimates the annual North American product demand for polyols represents 3.4 billion pounds, with a conservative estimate of the potential for soy-oil-based polyols of about 600 to 800 million pounds (2006 estimates). NOP or (natural-oil polyols)[11] made from such seed oils as soybean oil, are making inroads as a polyurethane precursor. In 2006, the US production of polyurethane was estimated at 6.3 billion lbs.

Dow Chemical (Dow) is one of the primary leaders in the utilization of soy-based polyols in the production of their trademarked product named RENUVA. Dow has high expectations for its RENUVA™ process since it creates polyols with a reduced impact on the environment.[12] Dow has gone to great lengths to conduct life-cycle analysis, the results show that the RENUVA™ technology is in fact greenhouse gas neutral and uses 60% fewer fossil fuels versus conventional polyols. The primary target markets for RENUVA™ are transportation, bedding, furniture, carpet, and CASE (coatings, adhesives, sealants, and elastomers) markets, with applications

[10] For example, the United States Department of Agriculture's BioPreferred[SM] program, which "aims to increase the purchase and use of renewable, environmentally friendly biobased products while providing "green" jobs and new markets for farmers, manufacturers, and vendors."

[11] Polyols are alcohols containing multiple hydroxyl groups with typical applications in food science and polymer chemistry.

[12] RENUVA is created by a four step process of methanolysis, hydroformulation, hydrogenation and polymerization. Interestingly, where the soybeans are grown (hotness or dryness of the season) impacts the fatty acid levels in the oil, the hydroformulation process is used to address the irregularity in the oil, thus providing a more uniform and predictable feedstock.

including seating, arm, headrest and headliner foams in vehicles; viscoelastic "memory" foam for bedding; carpet backing; and coatings, spray elastomers and one and two-component adhesives and sealants. Dow scientists believe that in some applications RENUVA™ has performance benefits over petroleum-derived foams, citing an improved compression set and enhanced hardness for greater durability. It should be noted that Dow is also looking at the use of other vegetable oils besides soybean oil (such as sunflower and canola) so that they are not vulnerable to sourcing only one feedstock for their process.

Cargill has also been active in the soy-based polyol market since 2005. Their branded product is called BiOH™ and they are initially targeting North America, European and Latin American markets. They will eventually expand their offerings in Asia. Cargill broke ground on a $22-million BiOH™ brand polyols manufacturing plant in Chicago in July 2008; the plant was expected to be fully operational in November 2009. The new production facility is claimed to be the first world-scale biobased polyols plant. Cargill estimates that the global market for polyols in polyurethane production stands at over 10 billion pounds and is expanding at 3-4% per year. Cargill is expected to compete in the same markets as Dow Chemical and their product RENUVA.

### 5. Propylene Glycol

Propylene glycol (PG) is also known by the systematic name of propane-1,2-diol. PG is an organic compound (diol alcohol) that is usually a faintly sweet and colorless clear viscous liquid that is hydroscopic (the ability of a substance to attract water molecules) and miscible (can be mixed in all proportions) with water, acetone and chloroform. Interest in PG relates to the production of biodiesel and the coproduction of glycerin. Glycerin can be used as a feedstock to produce PG which has created a great deal of interest in many large companies such as Dow Chemical, ADM and Cargill. These companies are interested in taking crude glycerin which has had limited value (has actually been used as boiler fuel and land filled) and converting it to a higher value product, i.e., PG to use in numerous applications.

Propylene glycol is a highly versatile product and is used in many value-added functions. A sampling of the uses of PG is as follows (note this is not and exhaustive list);

- Unsaturated polyester resins (UPRs) can be made from PG which is consumed primarily in the construction, marine and transportation industries (UPRs is the largest market for PG). Nearly three-quarters of UPR is reinforced with fiber glass or mineral fillers to form fiber glass reinforced plastics (FRPs), these are tough, lightweight composites.
- As a solvent in many pharmaceuticals, including oral, injectable and topical formulations.
- As a moisturizer in medicines, cosmetics, food, toothpaste, mouth wash and tobacco products.

- As a solvent for food colors and flavorings.
- As an ingredient, along with wax and gelatin, in the production of paintballs.
- As a less-toxic antifreeze.
- In hand sanitizers, antibacterial lotions and saline solutions.
- As a coolant in liquid cooling systems.
- To treat livestock ketosis, propylene glycol acts as a glucose precursor and may be effective as ketosis therapy, especially in mild cases or in combination with other therapies.[13]
- As the main ingredient in deodorant sticks.
- As an aircraft de-icer.

In the U.S., domestic consumption of PG has grown modestly over the last five years, led primarily by the production of UPR. The other market showing strong growth is in the area of personal care products. Going forward demand growth for PG will be heavily influenced by the status of the U.S. economy. ICB (ICIS Chemical Business) forecasts that the UPR market will expand at 1.5% per year and the personal care segment will grow at a slightly faster rate of 2.5% per year. While PG growth in the U.S. and Europe is predicted at GDP rates, Asia is expected to experience much stronger growth at approximately 7.0% per year.

Future expansion in the production of PG will depend heavily on two factors, the ready supply of glycerin from biodiesel production and the level of economic activity in a respective country/region. For example, Dow Chemical is currently in the process of "mulling" over its long-term strategy to produce what they are calling "green" propylene glycol (PGR or PG renewable) using glycerin from biodiesel as a feedstock. Mandy Bricco, global product director with Dow stated that, "we have sensed some customer interest on the green aspects of PGR/PG renewable, as well as a hedge against rising propylene feedstock prices. However, we must weigh factors such as the price of glycerin, the production of biodiesel and price of hydrocarbons in this decision."[14] If Dow did decide to build a new PGR facility, Bricco said, "it would be world scale in size" equating to 50,000-100,000 tonnes/year. ADM is constructing a 100,000 tonne/year PG and ethylene glycol facility in Decatur, IL, using glycerin and sorbitol as starting materials. Startup of the plant is expected to begin in the third quarter of 2009. Cargill has recently announced that they have suspended their joint venture with Ashland Chemical to construct a 65,000 tonne/year plant in Europe due to uncertainties in the economy and the volatility in commodity prices.

### 6. Methyl Soyate / Soy Methyl Ester (non-fuel applications)

Methyl soyate is also known as fatty acid methyl esters, soybean oil methyl esters and soy methyl ester. It is best known as biodiesel, but it also has other applications, which are discussed in this section. Methyl soyate is manufactured by the esterification of soybean oil. Soy oil is heated and reacted with methanol in the

[13] The Merck Veterinary Manual.
[14] Statement was made March 2009, press release.

presence of a catalyst. The reaction causes the separation of soy oil into methyl ester and glycerin. Following the separation, the crude glycerin goes to storage for further refining or other applications such as animal feed. The methyl ester goes through a number of finishing steps to derive the final product. Methyl soyate fits neatly in the category of being a versatile "green chemical" with numerous applications. As a chemical, methyl soyate is highly competitive in terms of its cost relative to petroleum chemicals, is low in toxicity, has a high flash point, has low VOCs (volatile organic compounds), is readily biodegradable and can be easily substituted for traditional hydrocarbon based chemicals such as solvents. Methyl soyate is ideally situated as a chemical to take advantage of the ever increasing regulatory pressure on ozone-depleting chemicals (ODCs), hazardous air pollutants (HAPs) and VOCs.

To date, most of the uses on methyl soyate have been in the following markets;

- Solvents: Methyl soyate has been used as a specialty chemical (versus a bulk commodity chemical) in the dissolving, suspending, carrying or removal of other materials. In 2007, the U.S. solvent market was approximately 11.9 billion pounds. Methyl soyate products participated in approximately 12% of the total market representing a 1.4 billion pound market. The estimated market share of the 1.4 billion pounds for methyl soyate is approximately 40 million pounds, or 2.8%.

- Cleaning Products: It is estimated that this market is the largest user of methyl soyate. Methyl soyate can be found in a broad array of both institutional and residential applications, such as hard surface cleaners, household cleaners, glass cleaners, flood cleaners, hand cleaners, bathroom cleaners, stainless steel cleaners and graffiti removers. Major consumer companies such as SC Johnson and Procter and Gamble have taken significant steps to assess their impact on the environment regarding the formulation of their products. This has to the introduction of many new greener products, especially in the area of cleaning products.

- Coatings, Inks and Adhesives: This is a fairly well established and mature market. Methyl soyate has been formulated into inks, for example, since the late 70's when the Newspaper Association of America was looking for different ways to make ink substitutes in order to replace the high cost of petroleum based ink. As previously mentioned, SC Johnson is very active in the area of sustainability and the use of renewable resources. For example, they limit the number of printed editions of its Public Report and encourages distribution via the Internet at www.scjohnson.com. Also, the report is printed with soy ink, which is naturally low in VOCs.

- Paint Strippers: This is a fairly small market, however it is gaining more interest because of the large number traditional stripping products that use methylene chloride (MeCL). MeCL is facing regulatory pressure because of worker safety and its ozone-depletion properties. Methyl soyate can be easily formulated with other organic cosolvents and surfactants, thus replacing the need for MeCL based strippers.

- Parts Cleaners and Degreasers: This is a large yet fragmented market that relies heavily on the use of mineral spirits for cold parts cleaning and trichloroethylene (TCE) for vapor degreasing. These chemicals are highly flammable and are also high in VOCs. Methyl esters can be easily combined with other biocosolvents to replace traditionally formulated parts cleaners and degreasers.

- Other Removers - Adhesives, Mastics, Resins, Inks, Asphalt and Rust: Methyl soyate can be used to replace numerous traditional solvents such as toluene, mineral spirits, MeCL and methyl ethyl keytone (MEK). Methyl soyate can be formulated to clean and remove many types of polymeric and petroleum based materials. One interesting application is the use in remediating the environment when there has been an oil or fuel spill. It is actually listed by the U.S. EPA on the National Contingency Plan product schedule for oil spills, and it is the only shoreline cleaner licensed by the State of California.

Environmental regulations will play an important factor in the further adoption and expansion of methyl soyate as a chemical in replacing hydrocarbon based petroleum products. The pricing of methyl soyate remains fairly competitive with other traditional chemicals, however, petroleum prices have fallen significantly from their record highs, meaning methyl soyate will likely need to rely more heavily on the advancement of green policies in the U.S. in the short-run.

### 7. Wood Adhesive

Wood adhesives are used in a number of applications including plywood, wood flooring, particleboard, oriented strand board (OSB), and medium-density fiberboard. Traditionally, urea formaldehyde, phenol formaldehyde, and phenol-resorcinol-formaldehyde resins have been the preferred adhesives.

Soy-based adhesives have been utilized to manufacture wood products for over 70 years, but until recently, their use was primarily limited to niche applications as a result of their lower performance and high cost relative to petrochemical-based resins. Nevertheless, environmental and health concerns along with rising costs for resins have prompted a resurgence of interest in developing new soy-based products.

Soy hydrolyzate, for instance, can be used with a phenolic resin in plywood, OSB and engineered wood product applications to reduce the use of the phenol component by up to 40%, while providing similar properties. Soy flour can also be used as a foaming agent for phenol formaldehyde resins in lieu of blood meal in order to reduce resin usage.

Companies like Hexion Specialty Chemicals, Hercules/Heartland, LCB Worldwide and USM Corporation have all developed their own soy-based adhesive.

In 2006, it is estimated that 3.72 billion lbs of wood adhesives were used in the U.S.. A weak housing market and the current economic recession are expected to adversely impact the demand for wood products, but a study released by the United Soybean Board in 2007 estimates that soy-based wood adhesives could account for as much as 20% of the U.S. market by 2011.

## C. Soybean Crushing

Crushing is the common process used to add value to soybean production. In 2007/08, 1.8 billion bu. of soybeans were crushed in the U.S. Because of the predominance of this process, it is critical to monitor new technological developments that can help improve the efficiency of this process.

### 1. Enzymatic Degumming

In vegetable oil refining, it is necessary to remove the impurities that affect the taste, smell, visual appearance and storage stability of the oil. The degumming step in the refining process consists of removing phosphatides that are not desirable because they settle out of the oil during shipping and storage and have adverse effects on the color and flavor of oil. Degumming is traditionally accomplished through chemical or physical processes. However, Danisco, Novozymes and Verenium have recently started to market an alternative to these processes with enzymatic degumming.

The principle of enzymatic degumming is to convert non-hydratable phosphatides into hydratable ones in a reaction catalyzed by a phospholipase. Both the phosphatides and enzymes are collected in the water phase and can be easily removed with a one-step centrifugation process.

Enzymatic degumming is an important new development in the oil refining industry as it provides a number of benefits over chemical and physical refining methods:

- Higher yields: Very little oil is lost in the process, due to little water usage, resulting in a 1-2% yield increase compared to the other methods, depending on the phosphatide content of the crude vegetable oil.

- Significant cost saving: The process is conducted at a lower temperature than conventional approaches and uses less water. Combined with the yield gain, these savings can add up to $1-11 per tonne (up to ½ cent per lb) depending on the process (chemical degumming tends to be more expensive), the yield increase, and vegetable oil prices.

- Environmentally friendly handling: No chemicals are used.

Enzymatic degumming can also be implemented by biodiesel producers that use crude vegetable oil as a feedstock. Additionally, the method does not generally increase free fatty acids as do other processes.

## 2. Supercritical Carbon Dioxide Extraction of Oil

Conceptually Supercritical Fluid Extraction (SFE) or in this case Supercritical $CO_2$ extraction (SC) has been around for a significant period of time. The applications and type of products produced using this extraction process, however, have been fairly limited because of the sophisticated and expensive high-pressure equipment that is required. As new equipment and analytical techniques have evolved, the SC process is finding numerous new uses and applications in the industrial and food grade processing areas. The increased demand for SC is being heavily influenced by the need for greater information on processing, quality control, contamination, environmental and food regulations, and the need for faster, more powerful, cleaner and cheaper analytical procedures required by chemists, regulatory agencies and regulatory agencies and quality control laboratories. The SC method of extraction can be characterized as being fast, reliable, clean, and advanced enough for numerous food and industrially related applications.

A supercritical fluid, which is a function of the SFE or SC process, is any substance at a temperature and pressure above its critical point. The fluid can diffuse through solids like a gas, and dissolve materials like a liquid. Additionally, close to the critical point, small changes in pressure or temperature result in large changes in density, allowing many properties of the feedstock to be "tuned". Supercritical fluids are suitable as a substitute for organic solvents in a range of industrial and laboratory processes. Carbon dioxide and water are the most commonly used supercritical fluids, being used for decaffeination and power generation respectively.

Most soybean crushing facilities in the U.S. utilize hexane as a solvent in their oil extraction processes. Hexane is a highly flammable and volatile chemical in that can also experience significant price swings. The hexane extraction process also yields crude soybean oil that must be degummed. The SC extraction process produces soybean oil which does not contain any phospholipids, thus eliminating the degumming step. Two issues are critical drivers in the future adoption levels of this process/technology in soybean crushing (1) capital costs and the continued advancement of the biodiesel industry and (2) environmental regulations.

- The SC extraction process has factual benefits compared to traditional hexane extraction. The biggest barrier to entry is the additional capital costs that are necessary for adoption of the technology. Two variables are important for overcoming the cost (1) continued expansion of the biodiesel industry and (2) the potential inclusion of the process in an integrated biodiesel facility (both crushing and biodiesel production). Syracuse University (SU) and The New York State Energy Research and Development Authority have been exploring the technical performance and economics of the integrated biodiesel model. In August 2006, they authored a report entitled "Integrated Multistage Supercritical Technology to Produce High Quality Vegetable Oil and Biofuels." The initial findings of the report have been highly favorable regarding the concept. Additional research continues at these institutions concerning the feasibility of the integrated model. Another economic consideration will also be required for advancing the SC method, a financial improvement of the biodiesel industry; over the last two years returns to the industry have been very weak which has caused new growth in capacity to stall.

- The SC process could gain greater interest if the government (EPA) imposes tighter regulations on the soybean crushing industry regarding the use of hexane.

- There is also a segment of the population that is willing to pay a premium for non hexane extracted soybean oil because of the environmental and toxicity concerns.

## D. Value-Added Soybean Varieties

Over the years, improvements in breeding tools and seed varieties have played a major role in improving farm performance and revenue. Seed developers are currently working on several promising new value-added soybean varieties that have the potential to increase farmers' revenues.

### 1. High Oil Soybeans

With all the new molecular breeding tools now available to seed developers, important gains in productivity and changes in product attributes are expected in the coming years. High-oil traits, in particular, have the potential to provide a significant increase in vegetable oil production and to help processors meet the growing demand for vegetable oil for food and bio-fuel. The prospect of increasing the oil content in soybeans is especially appealing since it has the potential to add value to soybean production considering that most new soybean applications are focused on the oil part as opposed to the protein.

Monsanto's Renessen joint venture with Cargill is currently researching a high-oil soybean variety that could increase oil content by 3% to 5%, without a loss in protein or grain yield. The first generation of the new variety is projected to be commercialized within 2-4 years and is thought to have an acreage potential of 15-40 million acres. The second generation is in a much earlier phase of development but could be released within 10 years.

### 2. High Stability Oil Soybeans

Since vegetable oils rich in polyunsaturated fatty acids (e.g., linolenic and linoleic fatty acids) are prone to oxidation and shelf-life issues, hydrogenation has been widely applied to convert unsaturated fatty acids ("FA") into saturated ones.

However, the controversy over trans fats and the subsequent emphasis on trans fat reduction has generated a strong demand for alternatives to partial hydrogenation. One solution brought forward by seed developers has been to develop through breeding and genetic modifications oilseeds with a low content in polyunsaturated FA.

The release of low linolenic varieties by Monsanto, Pioneer and Asoyia has been the first step in improving the oxidative stability of soybean oil. Nevertheless, the resulting oils still lack oxidative stability, due to a relatively high polyunsaturated fatty acid content, and have had limited success as a result.

The second step in improving stability has been to develop oils rich in oleic FA, a monounsaturated FA. Asoyia was the first player in this market by releasing a mid-oleic low-linolenic soybean variety in 2008, followed in July 2009 by Pioneer, which released Plenish, a brand of high oleic soybean oil. The high levels of oleic acid significantly increase the stability of the oil when used in frying and food processing applications. Additionally, there are numerous bio-based industrial applications for high oleic soy oil, including lubricants, foam products, liners and other oleo-chemical applications.

Additional modified oilseeds are at various stages of development. For instance, soybeans with increased levels of stearic acid are being developed as an alternative to partially hydrogenated fats and high saturate fats which are required to provide solidity and structure to certain foods. Monsanto expects to release this new variety within 4-8 years.

One particularity of these new seed varieties is that seed companies tend to utilize traditional breeding and marker assisted breeding by opposition to genetic modifications, which have a bad connotation for a segment of consumers.

These oilseeds are grown on a contract basis and sold at a premium. As a result, these new varieties have the potential to bring significant value-added for soybean producers.

### 3. Omega-3 Fortified Soybeans

Since the FDA has recognized the importance of omega-3 fatty acids for reducing the risk of coronary heart disease, a growing number of food companies have enriched their products in omega-3. According to Datamonitor, more than 1,200 products containing omega-3 were launched worldwide in 2006, with the biggest sectors coming from dairy, bakery and processed meats and fish. In fact, a recent study released by *Frost & Sullivan* predicts that the omega-3 ingredients market will grow at a rate of 24.3% annually, and will be worth $1.6 billion by 2014.

The omega-3 market has traditionally been dominated by fish oil but the animal-origin of the oil, its high price, and concerns over the sustainability of fish stocks have had the industry looking for alternatives. One of these alternatives has been to genetically modify soybeans to provide oil enriched in the omega-3 fatty acid called stearidonic acid (SDA).

SDA is an intermediate omega-3 fatty acid in the conversion of alpha-linolenic acid (ALA), an omega-3 found in plants, into eicosapentaenoic acid (EPA), the long-chain omega-3 found in fish. SDA is not as readily used by the body as EPA but it is much more stable and does not impart a fishy taste. As a result, oil rich in SDA can be incorporated into many existing foods without losing consumer acceptance.

In 2007, Monsanto and Solae announced a collaboration over the development of omega-3 from genetically-modified soybeans. Monsanto is expected to release the new soybean variety within 2-4 years.

## E. Other Soybean Products/Technologies

In addition to the aforementioned sectors of developments, there are numerous other initiatives that could help increase the demand for soybeans.

### 1. Aquaculture Feed

The global aquaculture industry is expanding steadily, averaging 6.6% over the past 10 years (1998-2007). Nevertheless, as aquaculture keeps growing, so does the demand for protein meal. Fishmeal, with 3.1 million tonnes currently consumed by the aquaculture market, is the major protein source for aquaculture, but as aquaculture production outpaces fishmeal production, some are concerned fishmeal availability will constrain the expansion of the industry, leading many producers to look for ways to lessen their dependence on fishmeal. As a result, researchers, aquaculture producers and feed manufacturers have been looking at alternative protein sources to replace fishmeal in diets.

It has been known for a long time that soybean meal can be used in aquaculture feed but anti-nutritional factors that reduce fish performance, particularly at higher inclusion levels and within carnivorous fish specie diets, have limited its adoption. In general, herbivorous fish species tend to be somewhat tolerant to plant proteins and can more easily substitute for fishmeal in the diet. Nevertheless, carnivorous species cannot tolerate plant proteins as well and have had less success in reducing their dependence on fishmeal.

Contrary to soybean meal, however, soy protein concentrates (SPC) do not contain these high levels of anti-nutritional factors and can be utilized at higher inclusion rates as well as within carnivorous fish specie diets. Consequently, SPC have the potential to play a major role in the aquafeed market

Only a few companies, ADM, Cargill and Solae, currently produce SPC in the U.S. but their production is food-grade and high prices have prevented their use in aquaculture. A few other companies, however, including Danish manufacturer Hamlet Protein, have developed processes to produce feed-grade SPC. This feed-grade SPC, with 56-60% protein compared to 65-67% for food grade applications, is far more competitive and is expected to play a role in the U.S. aquafeed market in the future. Already, Hamlet Protein has bought land in Iowa and intends to break ground on a new feed-grade SPC production facility in 2010.

### 2. Animal Feed

The production of biodiesel and ethanol generates co-products in the form of glycerin and distillers dried grains (DDGS) respectively. The renewable energy industry is faced with the opportunity/challenge of finding a home for these co-products in order to add meaningful revenue to their bottom line. In the production of biodiesel for example, a gallon of biodiesel from soybeans yields approximately two-thirds of a pound of crude glycerin.

For many years, U.S. crude glycerin production remained relatively flat (averaging between 300 to 350 million pounds per year), until 2003 when the biodiesel industry began to dramatically expand capacity. In 2008, Informa estimates that the U.S. biodiesel industry produced a total of 784 million pounds of crude glycerin. An additional amount of crude glycerin, approximately 14 million pounds, was produced from other processes such as the manufacture of soap.

The rapid rise in glycerin levels has far exceeded the demand for glycerin and caused the need to look for new/creative ways of utilizing glycerin. Typically, crude glycerin is refined for value-added applications, spread as a dust suppressant, burned as fuel or in some cases land filled. Recent research however, has explored the use of crude glycerin as a feed supplement. The USDA Agricultural Research Service, Iowa State University and Auburn University have been very active in the development of feeding trials using glycerin for poultry (layers and broilers) and swine at various stages of their lifecycle. Crude glycerin is approximately 85 percent glycerin with 10 percent water and 5 percent salts. The goal of the researchers has been to, "use glycerin as an energy source for swine and poultry. You have to have energy for pigs and chickens to grow, as well as amino acids and other items, and glycerin is used for growth and productive purposes."[15] Most of the research shows that crude glycerin provides energy to the swine and poultry diets with a caloric energy level that is similar to corn. Most of the swine rations had crude glycerin inclusion rates of 5 to 10 percent (replacement corn). At these inclusion levels studies have shown that there were, "no effects on weight, carcass composition, and meat quality in the pigs", from weaning to market weight. The layers and broilers experienced similar performance successes using lower glycerin inclusion rates in the 6 percent range.

Three important factors still remain concerning the use of glycerin, (1) logistics, (2) more consistent and better quality of glycerin and (3) price.

[15] Brian Kerr, USDA, Agricultural Research Service, Ames Iowa.

- Glycerin is highly liquid and the handling and storing of the co-product as an alternative feedstuff for swine and poultry in an integrated feed mill setting will require additional investigation. Another similar logistical issue is the need to limit the distance that the glycerin would have to be moved from the biodiesel plant and ultimately to the end user. Liquids are typically more difficult to handle and more costly to transport relative to solids (like corn).

- The biodiesel industry as with the corn to ethanol industry is challenged by providing consistent high quality co-products. The ethanol industry has made significant strides in providing more uniform DDGS to the feed industry. The biodiesel industry however, is not as consistent as the ethanol industry in the quality and consistency of glycerin production. Animal livestock nutritionists are very particular in the way that they formulate their rations, if the quality of a feedstock is not consistent overtime from a feed provider they will not include the product in their rations.

- Since crude glycerin is being considered a supplement to corn in the diets of livestock, the price of glycerin relative to corn will play a significant role in the usage of glycerin over time. Corn and glycerin prices can be very volatile and do not necessarily move together in the same manner. In the future, if glycerin is cheaper relative to corn on a pound to pound basis, then livestock nutritionists will be more likely to include crude glycerin in the animals' diets. If however, corn is cheaper relative to glycerin, it will be difficult to encourage the use of glycerin in the animals' diets.

### 3. Olefin Metathesis

In 2005, three scientists, Yves Chauvin, Robert H. Grubbs, and Richard R. Schrock shared the Nobel Prize in Chemistry for "the development of the metathesis method in organic synthesis," also known as the Grubbs reaction. Technically speaking, the process is defined as an organic reaction that entails the redistribution of alkylene fragments by the scission of carbon - carbon double bonds in olefins. Described in layman terms, "Metathesis is a reaction in which chemists selectively strip out certain atoms from one carbon compound and swap them with atoms from another compound. The end result is a custom-built molecule that has specialized properties"[16]

The process as defined by Robert Grubbs in his Nobel Laureate lecture as one that is based on "green chemistry" with the following characteristics;

- Starting material
    - Utilizes a renewable feedstock (such as soybean oil)
    - The starting material has simple structures

[16] Rhonda Hillbery, Caltech News.

- Processing
  - Few/no by products
  - No/little solvents (Water)
  - Low energy input
- Products
  - Replace polluting materials
  - Replace petroleum based material

As acknowledged in the lecture, a codevelopment program for the conversion of seed oils to value added chemicals was formed between Cargill, Materia[17] (www.materia-inc.com), California Institute of Technology and the Department of Energy (DOE) with the stated goal to replace petroleum based products with those from renewable resources. The renewable resources to concentrate development efforts are soybean and corn oils which are highly unsaturated (many double bonds) and can be modified by olefin metathesis to value added functional molecules. Total funding for the effort reached $3.8 million.

Cargill has the option to acquire an exclusive license from Materia to commercialize discoveries made in the field of the agreement.

In 2008, Materia announced the creation and independent financing of a new company built on the technology developed by the Materia and Cargill relationship. The new firm that emerged was Elevance Renewable Sciences (www.elevance.com). Elevance has moved aggressively to expand operations by recently securing more than $40 million in venture capital led by investments from TPG STAR, L.P. and TPG Biotechnology Partners II, L.P. Elevance has a stated goal of generating $1 billion in sales by 2016 by participating in the $500 billion a year global specialty chemicals market. K'Lynne Johnson, CEO of Elevance stated the following, "Elevance was founded to create a next generation specialty chemical company that can leverage multiple feedstocks such as soy, canola and corn." The company's first highly visible product was the Cargill branded NatureWax, natural soy wax. Elevance promotes NatureWax as "a premium natural soy wax that allows candle makers to create superior soy wax candles with outstanding manufacturing performance, excellent fragrance holding and improved pour. Soy candles made with Cargill's NatureWax burn slower and last longer than paraffin wax candles giving candle lovers more value and satisfaction." Because all of these companies are privately held, there is no sales data (value or volume) regarding initial success of NatureWax.

[17] Materia, Inc. was founded in 1998 to commercialize olefin metathesis catalyst technology. Materia is a privately held corporation headquartered in Pasadena, California with additional manufacturing facilities in Huntsville, Texas with a total of 60 employees.

### 4. Soy Isoflavones

Soy isoflavones are a class of phytoestrogens—plant-derived compounds with estrogenic activity. They have been studied for their role in cancer prevention and slowing down the ageing process in peri-menopausal women, and have proved to be a popular alternative to hormone replacement therapy for those wishing to control menopause symptoms without resorting to drugs. However some critics claim that isoflavones can increase the incidence of epithelial hyperplasia and cause goitre and hyperthyroidism.

Isoflavones are present in relatively large amounts in virtually all soy products, with the exception of soy-protein concentrate. Soy isoflavone are also available in the form of dietary supplements, extracts and supplements are available as dietary supplements without a prescription in the U.S.

ADM is the primary producer of isoflavones in the U.S. Acatris, a Dutch company with its American regional office in Minneapolis, is another large producer of isoflavones. There are several processes reported for isoflavone purification, but ADM reportedly extracts isoflavones from soy molasses while Acatris uses soy germ.

Although conflicting studies regarding the health effects of isoflavones have slowed down the growth of this market, the aging of the U.S. population present some growth prospects.

# IV. Phase III Top 8 Soybean Products/Technologies

Upon further analysis of the top 20, which was based on information gathered from more in-depth desk research and interviews with general experts within the field of biobased product and technologies and with product/technology specific representatives, the top 20 list was refined down to the top 8 considered to have the greatest potential to add significant value to Minnesota's soybean production.

This section reviews the top 8 products and technologies, which are listed in Table 8, in more detail than was presented in the previous section.

**Table 8: Top 8 Soybean Products and Technologies**

| Product/Technology Name | Soybean Origin | Product | Technology | Product/Technology Timeframe |
|---|---|---|---|---|
| Enzymatic Transesterification | Soybean Oil | | ✓ | Short Term |
| Renewable Diesel | Soybean Oil | ✓ | ✓ | Short Term |
| Epichlorohydrin | Glycerin | ✓ | | Medium Term |
| Polyols | Soybean Oil or Glycerin | ✓ | ✓ | Short Term |
| Wood Adhesive | Soybean Protein | ✓ | | Short Term |
| High Oil Soybeans | Soybean | | ✓ | Medium Term |
| High Stability Oil Soybeans | Soybean | | ✓ | Short Term |
| Aquaculture Feed | Soybean Protein | ✓ | | Short Term |

Short term: 0-3 years
Medium term: 3-5 years
Long term: > 5 years

## A. Renewable Diesel

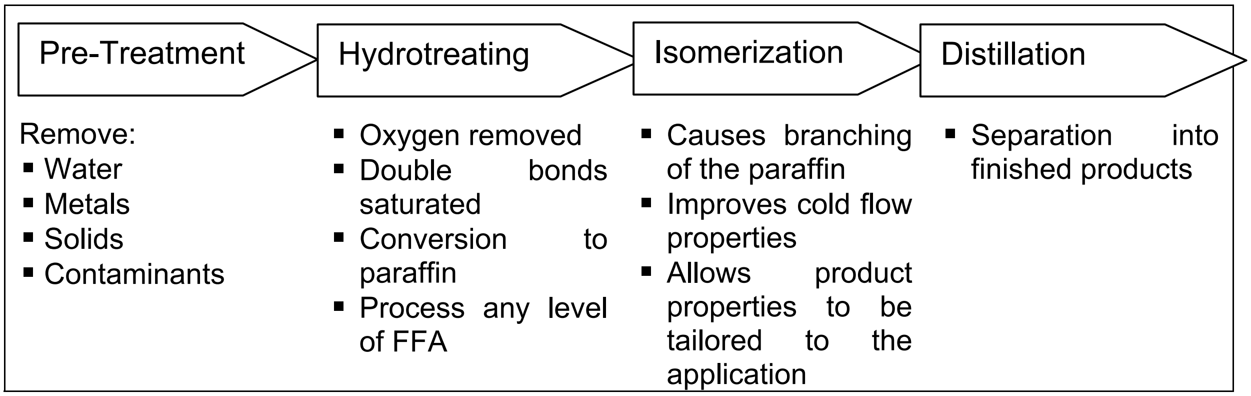
### 1. Product/Technology Overview

Existing technology for producing diesel-like fuel from animal fats and vegetable oils has largely centered on transesterification of fats and oils with methanol in the presence of a catalyst to produce fatty acid methyl esters, commonly referred to as biodiesel. While biodiesel has many desirable qualities such as low particle emissions, a good cetane number and lubricity, it also suffers from poor storage stability, marginal cold flow properties, excessive solvency, and engine compatibility issues. Renewable diesel, on the other hand, is a diesel substitute derived from any triglyceride feedstock based on conventional hydroprocessing technology that is already widely deployed in refineries. Unlike biodiesel, renewable diesel replicates the chemical structure of its diesel counterpart, therefore working seamlessly with existing distribution infrastructures, storage systems, and engines. Additionally, the cold flow properties of the fuel can be adjusted in the process, with yields increasing at higher cloud points. Finally, contrary to biodiesel whose co-product is glycerin (that currently has very little value), renewable diesel has several valuable co-products that include propane and naphtha.

Renewable diesel is produced by hydrotreating the triglyceride feedstock with a metal catalyst. The reaction pathway involves hydrogenation of the C=C bonds of the feedstock followed by alkane production by three different pathways:

decarbonylation, decarboxylation and hydrodeoxygenation. The straight chain alkanes can then undergo isomerization and cracking to produce lighter and isomerized alkanes. In some cases, pretreatment may be required to remove contaminants such as solids or salts. A significant advantage of this process is its ability to utilize a wide array of inputs as free fatty acids (FFA) which can be completely converted to biofuel. Conversion of feed and the volumetric yield of hydrocarbon products is 100%. A simplified flow diagram of the process is shown in Figure 18.

**Figure 18: Simplified Process Flow of Renewable Diesel Production**




Source: Syntroleum

The process requires significant amounts of hydrogen in the hydrotreating phase. Nevertheless, feedstocks rich in saturated fats such as palm oil and animal fats require substantially less hydrogen than feedstocks higher in olefin (i.e., unsaturation) content such as soybean oil. For that reason, palm oil and animal fats are favored to soybean oil from an energy balance standpoint. It should be noted, however, that the yield obtained with soybean oil has been reported higher than with animal fats.

One advantage of renewable diesel technologies is that they provide flexibility in the type of biofuel produced. For example, jet fuel can be produced, which represents an excellent new market for the industry considering biodiesel does not meet the cold-flow properties and high energy densities associated with jet fuel.

No information on the energy balance of renewable diesel is available, but considering the reaction conditions, it would appear that it is less favorable than with transesterification. This fact would explain the higher processing costs associated with renewable diesel, even though no specific costs are publicly reported for renewable diesel. Still, the processing cost difference with transesterification is expected to be relatively low and is more than offset by the compatibility with existing distribution infrastructures, which includes pipeline. Hence, renewable diesel can be pipelined whereas biodiesel is generally either trucked or railed. Capital cost requirements are reportedly similar to transesterification. For instance, UOP reports that the capital costs associated with a 92 million gallon a year (mmgy) plant is $60-80 million.

One should note that renewable diesel made using a commingled hydrotreating process (i.e., co-processing) is only eligible for a $0.50/gal tax credit compared to a standalone hydrotreating process which receives a $1.00/gal. credit.

### 2. Market Potential

U.S. diesel consumption in 2008 was approximately 60.6 billion gallons. Although renewable diesel could, in theory, replace all this volume, its high price relative to regular diesel fuel and the limited availability of fats and oils (U.S. production of fats and oils was 35.8 billion lbs in 2008, or approximately 4.6 billion gallons) will limit its market to a fraction of the total diesel market.

In 2007, the Energy Independence and Security Act mandated the use of one billion gallons of biomass-based diesel by 2012. Hence, the maximum market potential for renewable diesel is one billion gallons[18]. More conservatively, however, renewable diesel will, in all likelihood, only account for part of this volume, with biodiesel accounting for the remainder.

There is currently no renewable diesel production in the U.S. but Dynamic Fuels LLC is expected to start operating a 75 mmgy plant in 2010.

### 3. Profiles - Companies & Research Institutions

Three companies have developed standalone hydrotreating processes: Neste Oil, Syntroleum, and UOP/Eni.

**Neste Oil**

Neste Oil is a Finnish refiner with a regional office in Houston, TX. Its technology, NExBTL ™, is a standalone renewable diesel process.

Neste Oil currently operates a renewable diesel unit at its Porvoo oil refinery in Finland, with a production capacity of 170,000 tonnes per annum (about 54 mmgy). A second NExBTL plant is under construction at Porvoo (170,000 t/a) and a third unit in Singapore (800,000 t/a). Neste has also recently broken ground on an 800,000 t/a plant in Rotterdam. NExBTL's raw materials include palm oil, rapeseed oil, and animal fats.

**Syntroleum**

Syntroleum Corporation is a U.S. company based in Tulsa, OK, and engaged in development and commercialization of proprietary fuel technologies. The company

[18] Note that renewable diesel derived from co-processing biomass with a petroleum feedstock does not qualify as biomass-based diesel.

owns the Biofining™ technology that can convert animal fat and vegetable oil feedstocks into middle distillate products such as renewable diesel and jet fuel.

In 2007, Syntroleum teamed with Tyson Foods to form a 50/50 joint venture called Dynamic Fuels LLC, which aims to produce synthetic fuels at multiple standalone commercial facilities. Syntroleum is to supply the technology for the plants, while Tyson is to supply the animal fats, greases and vegetable oil feedstocks.

Dynamic Fuels LLC is currently building a 75 mmgy plant in Geismar, LA. The facility cost estimate is $138 million. The project is being funded by cash investments from Tyson Foods and Syntroleum, plus the GO Zone bond proceeds. The facility is expected to become operational in 2010.

**UOP/Eni**

UOP LLC, headquartered in Des Plaines, IL, is a supplier and licensor of process technology, catalysts, adsorbents, process plants to the petroleum refining, petrochemical, and gas processing industries.

Together with Eni S.p.a., an Italian integrated energy company, UOP has developed the Ecofining process. The process uses conventional hydroprocessing technology to convert vegetable oil and animal fats to renewable diesel.

Two Ecofining processes are currently in development. The first license was to Italian refiner Eni for a 6,500 bbl/day (96 mmgy) facility to be located in Livorno, Italy. The second license is to Portugal's largest refiner, Galp Energia, for a 6,500 bbl/day facility to be located in Sines, Portugal. The two projects are planned to be completed in 2010.

## 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to renewable diesel.

**Table 9: SWOT – Renewable Diesel**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ Good cold flow properties.<br>▪ Compatible with current diesel storage and distribution systems. Renewable diesel can be pipelined, which confers a significant cost advantage over biodiesel.<br>▪ Better specifications than biodiesel.<br>▪ Renewable diesel produced in standalone plants can be used to comply with the biomass-based diesel mandate.<br>▪ Large market potential. | ▪ Renewable diesel technologies are more adapted to animal fats as a feedstock than soybean oil.<br>▪ Late entrant in the U.S. biomass-based diesel market. The U.S. already has over 2 billion gallons in biodiesel production capacity.<br>▪ Higher processing costs than biodiesel.<br>▪ Currently not economically competitive with diesel fuel without government incentives.<br>▪ Renewable diesel from co-processing does not qualify as a biomass-based diesel and is only eligible for a $0.50/gal tax credit. |
| **Opportunities** | **Threats** |
| ▪ The Renewable Fuel Standard (RFS) mandates the use of one billion gallons of biomass-based diesel by 2012.<br>▪ Renewable diesel technologies can be used to produce renewable jet fuel.<br>▪ High petroleum prices could bolster the demand for renewable fuels. | ▪ Low crude petroleum oil prices.<br>▪ The EPA has not yet released its final rule regarding the implementation of the RFS. In an initial draft, soybean oil-based biofuel did not comply as biomass-based diesel. There is a risk soybean oil-based biofuels will not comply as biomass-based diesel in the future.<br>▪ The indirect land use change controversy might be solved by grandfathering biodiesel plants built or under construction before the passage of EISA in December 2007, which would favor existing trans-esterification technologies already in place over renewable diesel ones.<br>▪ Development of biomass-to-liquid (BTL) technologies that would replace fats and oils by cellulosic material.<br>▪ Tight capital markets.<br>▪ Tight economics of biofuel production could prevent new investments. |

## B. Enzymatic Transesterification

### 1. Product/Technology Overview

Essentially, all biodiesel is produced using chemical transesterification. However, this multi-step process, which involves the reaction of triglycerides with methanol in the presence of a catalyst (mainly NaOH or KOH) and which may require extra process steps to eliminate the free fatty acids, suffers from multiple shortcomings:

- High energy consumption;
- Difficulty in glycerin recovery (the co-product of biodiesel production);
- High amount of alkaline waste water (as a result of the catalyst use); and
- Interference of FFAs with the catalyst[19].

Enzymatic transesterification, on the other hand, holds considerable potential considering its advantages over its chemical counterpart:

- Compatibility with feedstock of various quality (the process converts FFAs);
- Fewer process steps;
- Higher quality of glycerin;
- Improved phase separation (no emulsification from soap); and
- Reduced energy consumption and wastewater volumes.

As a result of these benefits, research efforts to develop the process have increased significantly over the last few years. However, a number of hurdles still need to be overcome before it becomes commercially available and the consensus is that the cost of the enzyme needs to be lowered in order to make the process cost competitive.

Currently the two biggest problems researchers are examining deal with the reaction speed and enzyme durability.

- Academic studies report long reaction times, meaning total tank volume needs to be larger resulting in higher capital costs.
- Enzymes are far more expensive than the chemical catalysts used for biodiesel production. Therefore, for the process to be cost effective, enzymes need to be recovered. This has led to the use of immobilized enzymes. Nevertheless, the carrier itself, as well as the immobilization process, adds significantly to the cost of the process. Furthermore, the addition of a solid phase to the reaction system generally results in slower reaction times. However, the development of new immobilization technologies may improve the cost competitiveness of the process.

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[19] Conventional biodiesel technologies generally use feedstock with a FFA no higher than 0.2%, as FFAs neutralize the catalyst and form soaps that (i) complicate phase separation and (ii) form sediments that may plug pipes and filters. As a result, unless refined vegetable oil is used (i.e., max FFA ≤0.1%), conventional processes generally require a pre-treatment step to remove the FFAs in the feedstock.

- Methanol and phospholipids have been reported to inactivate the enzyme. This is a very serious problem as it results in frequent replacement of the enzyme, hence increasing costs. Nevertheless, it appears that decreasing the methanol concentration and using degummed oil can overcome the problems.

Overall, good progress is being made and it is expected that the process could become cost competitive relative to chemical transesterification within three years. However, it is important to emphasize that many consider one of the main advantages of enzymatic transesterification to be its ability to utilize low-cost, low quality feedstocks with high FFA content, which favors animal fats and recycled grease over soybean oil, even though the availability of those is extremely limited relative to virgin vegetable oils.

### 2. Market Potential

The potential for enzymatic transesterification is to replace chemical processes currently being used. Just in the U.S., there are over 300 biodiesel plants with nearly 3 billion gallons in production capacity. Over the last few years, the biodiesel industry has been plagued with poor production margins and, if costs come down, enzymatic transesterification could significantly improve the bottom line for producers, hence increasing demand for soybean oil.

In 2007, the Energy Independence and Security Act mandated the use of one billion gallons of biomass-based diesel by 2012, and enzymatic transesterification processes could account for a large share of this volume.

### 3. Profiles - Companies & Research Institutions

Several institutions are currently engaged in enzymatic transesterification research. Nevertheless, other than some efforts by the USDA ARS, most of the research is being conducted abroad, especially in Europe and Asia. Currently, the largest private company involved in enzymatic transesterification is Novozymes.

**Novozymes**

Novozymes, headquartered in Denmark is a leader in the development and sale of enzymes for industrial uses. Novozymes has already developed an operational enzyme for enzymatic transesterification but is still working on improving reaction times and enzyme lifetime.

In Europe, Novozymes is part of a consortium of Danish companies and academic groups including Emmelev – a Danish biodiesel producer – the University of Aarhus, and the Technical University of Denmark, to establish a world-leading enzyme technology for the next generation of biodiesel production. The consortium received a EUR 2.4 million grant from the Danish National Advanced Technology Foundation (HTF) late 2008. The project will take place over the next three years and the goal is to develop and document a biodiesel process that is cost-effective and environmentally superior to chemical transesterification.

The company has also reportedly partnered with Piedmont Biofuels from North Carolina to improve its process. The project was awarded a $197,000 grant in 2009 by the Chatham County Economic Development Corporation in North Carolina.

### 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to enzymatic transesterification technologies for the production of biodiesel.

**Table 10: SWOT – Enzymatic Transesterification**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ Feedstock flexibility.<br>▪ Few processing steps.<br>▪ High quality glycerin.<br>▪ Low energy consumption. | ▪ High enzyme cost.<br>▪ Late entrant in the U.S. biomass-based diesel market. The U.S. already has over 2 billion gallons in biodiesel production capacity.<br>▪ Not proved at a commercial scale.<br>▪ Still at an early stage of development |
| **Opportunities** | **Threats** |
| ▪ Ongoing research to decrease process costs.<br>▪ High petroleum prices could bolster the demand for renewable fuels.<br>▪ The RFS as mandated in 2007 requires fuel to meet greenhouse gas emission standards. The lower energy consumption associated with enzymatic transesterification may favor this technology. | ▪ Low crude petroleum oil prices.<br>▪ Renewable diesel.<br>▪ The indirect land use change controversy might be solved by grandfathering biodiesel plants built or under construction before the passage of EISA in December 2007, which would favor existing transesterification technologies already in place.<br>▪ Development of biomass-to-liquid (BTL) technologies that would replace fats and oils by cellulosic material.<br>▪ Tight capital markets.<br>▪ Tight economics of renewable fuel production could prevent new investments. |

## C. Soy Polyols

### 1. Product/Technology Overview

With the trend in eco-friendly products gaining momentum, manufacturers are looking for solutions to reduce their environmental footprint and offer finished products that are both high quality and environmentally sound.

Polyols are chemical building blocks used primarily as reactants to make polymers, polyurethanes in particular. These chemical compounds have historically been produced using petroleum-based feedstocks but are now increasingly made from vegetable oils. Chemical pathways to produce these natural oil polyols (NOPs) are multiple, but overall, their use results in significant greenhouse gas (GHG) emission reductions. For instance, Cargill reports that its BiOH polyols generate 36% fewer GHG emissions than petroleum-based polyols. Another advantage of NOPs is that with more regulations and concerns over volatile organic compounds (VOCs), they offer an environmentally friendly option for many manufacturers as they can help reduce VOCs by up to 2/3.

Since their initial development, NOP technologies have overcome the problems of consistency and odor that plagued the first generations and now offer products with performance that rivals petroleum-based polyols. NOP are now used in a number of polyurethane foam applications including furniture, bedding and flooring products. Additionally, several producers report a significant improvement in the energy balance (e.g., -1 Cargill reports a -23% in total energy balance).

### 2. Market Potential

The United Soybean Board estimates the annual North American product demand for polyols represents 3.4 billion pounds, with a conservative estimate of the market potential for soy-oil-based polyols at about 600 to 800 million pounds (2006 estimates). NOPs made by such seed oils as soybean oil, are making inroads as a polyurethane precursor. In 2006, the U.S. production of polyurethane was estimated at 6.3 billion lbs.

The market for NOPs has great growth potential as prices for petroleum rise and manufacturers become more eco-friendly.

### 3. Profiles - Companies & Research Institutions

Several manufacturers have created soy polyols that are used in a wide range of applications including carpet-backing agents, spray-foam insulations, furniture, bedding products, body panels, etc. The main players in the NOP field are: Arkema Inc., Battelle Memorial Institute, BioBased Technologies, LLC, Cargill, The Dow Chemical Company and Urethane Soy Systems Co.

## Arkema Inc.

Arkema Inc. is a diversified chemicals manufacturer headquartered in Pennsylvania and with a facility in Blooming Prairie, MN. The company launched its Vikol line of soy polyols for polyurethane foams and coatings in 2006.

## Battelle Memorial Institute

Battelle is a large non-profit independent research and development organization headquartered in Columbus, Ohio. Battelle has developed several novel biobased polyols derived from soybean oil, other vegetable oils and glycerin. According to the non-profit organization, the cost of the polyols is expected to be significantly less than polyols derived from petroleum sources. Furthermore, coatings prepared from Battelle polyols would significantly out-perform coatings prepared from competing biobased polyols and would have comparable characteristics as coatings prepared from petroleum-based polyols.

Generally, Battelle's business strategy is to license technology to interested companies.

## BioBased Technologies, LLC

Biobased Technologies, headquartered in Rogers, AR, began its operations in 2003, specializing in the research and development of NOPs for the polyurethane industry. The company has launched Agrol®, a line of biobased polyols for flexible (slabstock and molded) and rigid (insulation) commercial and industrial polyurethane applications for coatings, adhesives, sealants, elastomers, etc.

## Cargill

Cargill has been active in the soy-based polyol market since 2005. Their branded product is called BiOH™. Cargill broke ground on a $22 million polyols manufacturing plant in Chicago in July 2008, expecting to be fully operational in the November 2009. The new production facility will be the first world-scale biobased polyols plant. Cargill is also producing polyols at one of its existing vegetable oil processing sites in Sao Paulo state, Brazil. Cargill estimates that the global market for polyols in polyurethane production stands at over 10 billion pounds for BiOH and is expanding at 3-4% per year.

## The Dow Chemical Company

Dow Chemical (Dow) is one of the primary leaders in the utilization of soy-based polyols in the production of their trademarked product named RENUVA. The primary target markets for RENUVA™ are transportation, bedding, furniture, carpet, and CASE (coatings, adhesives, sealants, and elastomers) markets, with applications including seating, arm, headrest, and headliner foams in vehicles;

viscoelastic "memory" foam for bedding; carpet backing; and coatings, spray elastomers, and one and two-component adhesives and sealants. Dow scientists believe that in some applications RENUVA™ has performance benefits over petroleum-derived foams, citing an improved compression set and enhanced hardness for greater durability. It should be noted that Dow is also looking at the use of other vegetable oils besides soybean oil (such as sunflower and canola) so that they are not vulnerable to sourcing only one feedstock for their process.

#### 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to soy polyols.

**Table 11: SWOT – Soy Polyols**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ Biobased product.<br>▪ Comparable characteristics relative to petroleum-based polyols.<br>▪ Reduction of VOCs emissions.<br>▪ Large market potential.<br>▪ Strong institutional support. | ▪ Not always economically competitive with petroleum-based polyols.<br>▪ Ability to substitute other vegetable oils for soybean oil as the primary raw material. |
| **Opportunities** | **Threats** |
| ▪ Evolution of environmental regulations.<br>▪ Growing population and world demand for plastics.<br>▪ High crude petroleum prices.<br>▪ Marketability of green products (government biobased program, LEED).<br>▪ Ongoing development of new soy-based polyols. | ▪ Low crude petroleum prices.<br>▪ Declining use of foams and plastics for environmental reasons in the U.S..<br>▪ Tight capital markets. |

### D. Epichlorohydrin

#### 1. Product/Technology Overview

Epichlorohydrin is an epoxy raw material, increasingly used in applications in the electronics, automotive, aerospace and windmill sectors. It is traditionally derived indirectly by reacting propylene with chlorine. The process, however, is somewhat inefficient due to the formation of unwanted chlorinated organics that are expensive to dispose of.

New glycerin-to-epichlorohydrin (GTE) technologies, however, reduce energy consumption by about one-third, generate less than 1/10th of the wastewater and considerably less salt, chlorinated organics, etc., when compared to traditional production processes. Until recently, however, this pathway was uneconomical due to the high price of glycerin. The advent of the biodiesel industry that generates large amounts of glycerin has now reversed this situation.

### 2. Market Potential

According to information released by Solvay and Dow in 2007, the demand for epichlorohydrin has significantly outpaced production. Although the current economic crisis may have somewhat impacted demand, there is significant growth potential, especially in regions with large biodiesel/glycerin production like Europe or the U.S.. Most of the growth is now being experienced in Asia, with Solvay reporting that demand has been expanding by more than 20% per year in China. One should note, however, that in recent years, U.S. exports to Asia have decreased as local production capacity has increased. In 2003, the U.S. production capacity was estimated at 960 million lbs.

It is important to stress that since 2008, a number of chemical firms had previously unveiled plans to use glycerin as a feedstock for the production of chemicals have either shelved or delayed projects. Indeed, although glycerin production has increased in recent years, glycerin has proven to be very volatile with large price swings. Some companies, also, have questioned the long term sustainability of glycerin given poor margins in the biodiesel industry, although the European and U.S. mandates should guarantee that large supplies of glycerin are available in the future.

### 3. Profiles - Companies & Research Institutions

Several companies, including Dow Chemical, Solvay SA and Spolchemie, have announced plans to commercialize epichlorohydrin from glycerin.

**The Dow Chemical Company**

Dow is one of the largest epoxy resins and intermediates manufacturers. With its subsidiary Dow Epoxy, it has a large epoxy resin supply capability in Texas USA and a strong production capacity in Germany. Epoxy resins are usually imported from these two countries to meet the supply needs in Asia.

Dow is currently developing a new 150,000 metric tons/year epichlorohydrin production facility in Shanghai. The plant, slated to start up in 2010, will be the first to use Dow's proprietary glycerin-to-epichlorohydrin technology.

**Solvay SA**

Solvay SA is an international chemical and pharmaceutical group with headquarters in Brussels, Belgium. The company has developed Epicerol ®, a process to convert glycerin to epichlorohydrin. After the successful completion of a first plant in France, Solvay is currently working on a new 100,000 tonnes/year epichlorohydrin production facility in Thailand. Solvay is to have invested $184 million in the new facility.

**Spolchemie**

Spolchemie is a large European manufacturer of synthetic resins based in the Czech Republic. The company is expected to start building an $80 million glycerin-to-epichlorohydrin facility in Malaysia in 2009.

## 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to epichlorohydrin.

**Table 12: SWOT – Epichlorohydrin**

| Strengths | Weaknesses |
| --- | --- |
| ▪ Compared to traditional production processes, glycerin-to-epichlorohydrin processes are more environmentally friendly.<br>▪ Epichlorohydrin produced from glycerin is similar to product made from traditional manufacturing processes.<br>▪ Biobased product.<br>▪ Depending on glycerin prices, processes may also be more competitive than conventional petroleum-based processes.<br>▪ Creates a new outlet for glycerin, as production has increased greatly with the advent of the biodiesel industry.<br>▪ Strong institutional support. | ▪ Glycerin price volatility<br>▪ Feedstock production dependent on biodiesel production. |
| **Opportunities** | **Threats** |
| ▪ Biofuel mandates in the U.S. and Europe could lead to large glycerin production.<br>▪ Evolution of environmental regulations.<br>▪ Growing world plastic (and epoxy resins) consumption.<br>▪ High energy prices.<br>▪ Marketability of green products (government biobased program, LEED). | ▪ Phasing out of transesterification technologies for new technologies like renewable diesel that do not produce glycerin.<br>▪ Use of large glycerin volumes for other chemical applications.<br>▪ Low energy prices.<br>▪ Tight capital markets. |

## E. Wood Adhesives

### 1. Product/Technology Overview

Soybean oil has emerged as a growing “green” feedstock to replace petroleum-based chemicals in various industrial applications. Soybean meal, on the other hand, has found little industrial uses. Since soybean meal accounts for 80% of the throughput volume in the soybean crushing industry, it is critical to develop “new” uses as it is meal demand that primarily drives soybean production.

One such emerging use for soybean meal is wood adhesives. The use of soy-based adhesives is not *per se* new to the chemical industry, as they were first studied in the

1920s and 1930s, but poor functional properties and price competitiveness at the time relative to petroleum-based adhesives limited their use. Today, phenol-formaldehyde (PF) resins enjoy a dominant place in the resin market for exterior wood composites, whereas urea-formaldehyde (UF) resins dominate the interior wood composites market. Nevertheless, increases in petroleum prices, concerns with formaldehyde emissions, along with greater interest in biobased products have led to an interest in replacing some phenol and urea formaldehyde in wood adhesives with soybean flour.

There is currently an opportunity to develop the market for soy-based adhesive:

- In 2004, the International Agency for Cancer Research announced that formaldehyde was a known carcinogen and many composite wood panel manufacturers looked for alternatives to current UF resin systems.

- In 2007, the California Air Resources Board (CARB) approved regulations to reduce the levels of formaldehyde that can be emitted from interior panel products. The CARB rule sets thresholds for emissions of formaldehyde from various panel products that take effect in two phases between 2009 and 2011. Since companies manufacturing wood adhesives cannot modify their products solely for California, the CARB rule is rapidly becoming a national standard.

- The rising prices of phenol resins have stimulated interest in replacing phenol in PF glues with soy.

It should be stressed that in formaldehyde-based resins, the interpenetration and covalent bonding (cross-linking) of polymer chains produce adhesives with high bond strength and moisture resistance. In proteins, however, chain interpenetration is hindered by protein molecular folding, which is the reason why denatured proteins are better adhesives. The proteins are denatured, with minimal hydrolysis, to maximize their incorporation into the final polymerized structure.

Companies like Hexion Specialty Chemicals, Ashland/Heartland, and Eka Chemicals have commercialized several soy-based glues. These glues generally perform at least as well as their petroleum-based counterparts.

However, the high viscosity and limited durability of soy-based glues still prevent their use in some applications and there is ongoing research to expand the number of products available. Some of the research is currently focused on the development of heat resistant adhesives and enzymatic processing for new soy hydrolyzates. The other challenge is to develop these soy-based glues at a cost advantage to conventional petroleum-based resins.

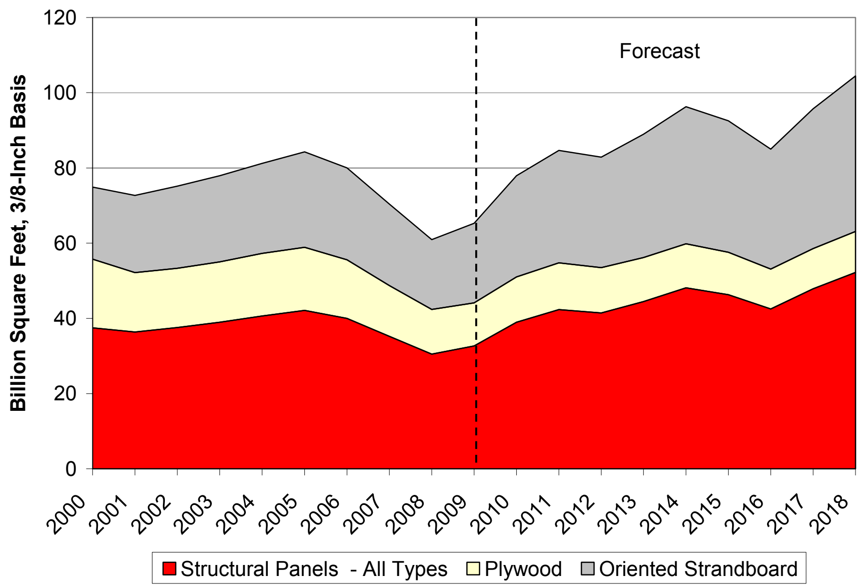
### 2. Market Potential

Out of the 3.72 billion lbs of wood adhesives estimated to have been used in the U.S. in 2006, 40-50 million pounds of soy-based glue systems are estimated to be in use today. In the next few years, the United Soybean Board expects that soy-based wood adhesives could account for as much as 20% of the U.S. market. Still, a weak housing market and the current economic recession are projected to adversely impact the demand for wood products and could slow-down the demand for soy-based adhesives.

Over the long term, however, demand for wood products is projected to resume its growth (Figure 19). Indeed, the fundamentals underlying consumptions have not changed. The population is growing, implying an increase in the number of households and, as a result, housing units.

The market for soy-based adhesives holds tremendous potential for soybeans considering some glues contain up to 90% soy flour.

**Figure 19: U.S. Structural Wood Panel Consumption by End-Use**




Source: RISI

### 3. Profiles - Companies & Research Institutions

A number of companies/institutions are currently involved in the development of soy-based wood adhesives.

**<u>Ashland</u>**

On November 13, 2008, Hercules Incorporated was acquired by Ashland Inc.

Hercules was involved early in the development of soy-based wood adhesives. The company owns the license for SOYAD®, a soy-based adhesive technology developed cooperatively with Columbia Forest Products, and Oregon State

University. The three organizations were awarded a 2007 Presidential Green Chemistry Challenge Award for their roles in developing and commercializing the technology.

Hercules also formed with Heartland Resource Technologies LLC a joint venture named H2H Innovations. The new company focuses on developing cost-competitive formaldehyde-free resins for decorative plywood, wood flooring, particleboard and medium-density fiberboard markets. The joint venture will also offer technologies for oriented strand board manufacturers that allow traditional phenolic resins to be extended, resulting in lower-cost adhesives with reduced formaldehyde content.

**Battelle Memorial Institute**

Battelle is a large non-profit independent research and development organization headquartered in Columbus, Ohio. Battelle is currently researching wood adhesives derived from wood flour. The process is undergoing further tests in several lumber mills throughout the Pacific Northwest and the Southeast.

Battelle has developed the PRF/Soy 2000 wood finger joint adhesive, a mixture of monomer (phenol formaldehyde), resorcinol, and soy protein.

Generally, Battelle's business strategy is to license the technology to interested companies.

**Heartland Resource Technologies**

Heartland was created in 2000 to develop green building products for the construction industry. Its business model is based on straight licensing and royalties.

Since July 2007, Heartland works with Hercules/Ashland to develop further SOYAD®.

**Columbia Forest Products**

One of the three institutions at the origin of SOYAD®, Columbia Forest Products is the exclusive seller of the product in North America.

**Hexion Specialty Chemicals**

Hexion Specialty Chemicals is the world's largest producer of binder, adhesive, coating and ink resins for industrial applications. As part of EcoBind™, a family of ultra-low emitting resin technologies for wood product manufacturers, Hexion has developed a soy/PVA wood adhesive that is formaldehyde-free.

## Eka Chemicals

Eka Chemicals is a manufacturer of bleaching and performance chemicals for the pulp and paper industry. The company has developed a wood adhesive formulated to bond green lumber during finger-jointing applications that uses a two-part system consisting of a soy-based adhesive and a phenol-resorcinol-formaldehyde resin.

## Oregon State University

Dr. Kaichang Li, an Associate Professor at Oregon State University, received a 2007 Presidential Green Chemistry Challenge Award for a non-toxic adhesive used in the production of wood composite panels. The adhesive was developed jointly with Hercules (now Ashland Chemicals) and Columbia Specialty Chemicals.

Li has also been receiving soybean checkoff support for his project that uses soy adhesive to bond oriented strand board (OSB).

### 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to soy-based wood adhesives.

**Table 13: SWOT – Soy-Based Wood Adhesives**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ Low formaldehyde emissions.<br>▪ Meet LEED certification requirements.<br>▪ Can help meet the new California formaldehyde emission requirements.<br>▪ Less expensive than petroleum-based adhesives in some applications.<br>▪ Large market potential. | ▪ High viscosity and durability problems may limit the use of soy-based adhesives in some applications. |
| **Opportunities** | **Threats** |
| ▪ Environmental policy.<br>▪ Development of heat resistant adhesives and enzymatic processing for new soy hydrolyzates.<br>▪ The housing market is projected to resume its growth in the coming years as the economy improves.<br>▪ High energy prices.<br>▪ Marketability of green products (government biobased program, | ▪ Low energy prices.<br>▪ Soybean flour price.<br>▪ Currently weak housing market. |

| | |
|---|---|
| LEED). | |

## F. High-Oil Soybeans

### 1. Product/Technology Overview

With all the new molecular breeding tools now available to seed developers, important gains in productivity are expected in the coming years. High-oil traits, in particular, are likely to provide significant increase in vegetable oil production and will help processors meet the growing demand for vegetable oil for food and bio-fuel. The prospect of increasing the oil content in soybeans is especially appealing since it has the potential to add value to soybean production, especially considering that most new soybean applications are focused on the oil part by opposition to the proteins.

Monsanto's Renessen joint venture with Cargill is currently researching a high-oil soybean variety that could increase oil content by 3% to 5%, without a loss in protein or grain yield. The first generation of the new variety, that would increase oil yield by 1-3%, is projected to be commercialized within 2-4 years. The second generation, that could increase oil yield by an additional 1-3%, is in a much earlier phase of development but could be released within 10 years. By 2019, soybean oil yields could therefore reach 25% compared to about 19% currently, hence effectively increasing oil production by nearly 26%. Based on conversations with Monsanto's representatives, the high-oil trait could ultimately be combined with some of the agronomic traits already available like Roundup Ready.

It is important to stress that this new variety will not require the soybeans to be identity preserved since there is no change in the composition of the oil or the proteins. However, it will require that grain elevators measure the oil content to determine the payment to the farmers, which is not currently done.

### 2. Market Potential

Monsanto currently estimates the acreage potential in the U.S. for the first generation high-oil soybean variety at 15-40 million acres, which represents 20-53% of the estimated 2008/09 planted soybean acreage (75.7 million acres). Assuming the five-year yield average experienced between 2003/04 and 2007/08, 40.7 bu/acre, these 15-40 million acres would represent a 10-26% increase in U.S. soybean oil production.

### 3. Profiles - Companies & Research Institutions

Renessen is a joint venture between Cargill and Monsanto, bringing together Monsanto's expertise in biotechnology and plant breeding with Cargill's capabilities in animal nutrition, grain processing, and logistics. To date, Renessen is the only major company that has been reported developing high-oil soybean varieties.

### 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to high-oil soybeans.

**Table 14: SWOT – High-Oil Soybeans**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ 3-5% increase in oil content.<br>▪ No loss in protein or grain yield.<br>▪ No need for identity preservation.<br>▪ Large market potential.<br>▪ Strong institutional support. | ▪ Grain elevators will have to start measuring the oil content of soybean shipments in order to determine the price received by farmers. |
| **Opportunities** | **Threats** |
| ▪ Combine the high-oil traits with other agronomic traits.<br>▪ Growth in vegetable oil demand for food and industrial activities<br>▪ High vegetable oil prices, soybean oil in particular.<br>▪ The indirect land use change controversy might be solved by grandfathering biodiesel plants built or under construction before the passage of EISA in December 2007, which would favor existing transesterification technologies already in place.<br>▪ Concerns over the level of saturated fat in food products may limit the use of palm oil in the future and favor other alternative vegetable oils like soy. | ▪ Low vegetable oil prices, soybean oil in particular.<br>▪ Growth of oil palm and canola that yield more oil per acre of production.<br>▪ Soybean oil-based biodiesel does not meet the greenhouse gas emission threshold as set by the Notice of Proposed Rulemaking released by the EPA with regard to the implementation of the RFS as amended in 2007. |

## G. High Stability Oil Soybeans

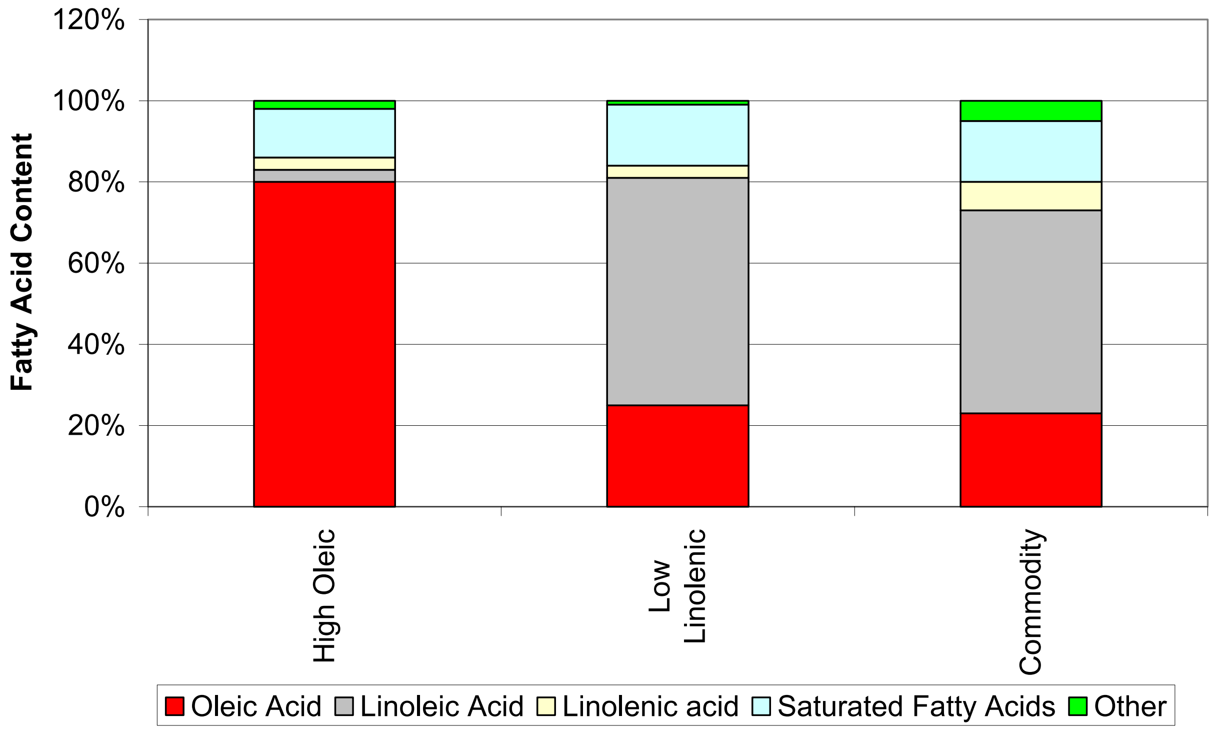
### 1. Product/Technology Overview

The phasing out of partial hydrogenation by food processors following the move away from *trans* fatty acids in food has generated a strong demand for highly stable vegetable oils. One solution brought forward by seed developers has been to develop oilseeds with a low content in polyunsaturated fatty acids. Polyunsaturated fatty acids (e.g., linolenic and linoleic fatty acids) are indeed prone to oxidation and decreasing the oil content in these fatty acids (FA) enables extended shelf-life.

The first step in improving the stability of vegetable oils has been to limit the content of linolenic FA, a FA with three unsaturations. Such oils are commonly referred to as low-linolenic oils (Figure 20). These oils, however, are generally still rich in linoleic FA, a FA with two unsaturations, which prevents their use in heavy frying applications. Asoya, Monsanto and Pioneer all have, to date, released low-linolenic oils.

The second step in improving the stability of vegetable oils is to limit the content of linoleic FA. Such oils are rich in oleic FA, a monounsaturated FA, and are commonly referred to as high- or mid-oleic oils. These oils are very stable and have numerous food and industrial applications.

**Figure 20: Fatty Acid Content of High Stability Soybean Varieties**




Source: Pioneer

It is important to stress, however, that the taste commonly associated with fried food is due to the presence of linoleic FA. As a result, mid-oleic/low-linolenic oils are perfectly adapted to frying applications whereas high-oleic oils are ill-suited. High-oleic oils, in contrast are better adapted to oleo-chemical applications, which include lubricants, coatings, paintings, foam products, and green chemicals.

Asoyia was the first seed company to release a mid-oleic/low-linolenic soybean variety in 2008, followed in July 2009 by Pioneer that released Plenish, a brand of high oleic soybean oil. Monsanto is expected to commercialize Visitive III, a line of mid-oleic/low-linolenic/ low saturates in the next few years (Table 15). Visitive III is an advanced version of Vistive (low-linolenic), which is currently commercialized.

**Table 15: Mid- and High-Oleic Soybean Varieties Overview**

| Company | Product | Description | Availability |
|---|---|---|---|
| Asoyia | Asoyia Mid Oleic Ultra Low Lin | Min. 50% oleic acid<br>Max. 1% linolenic acid | Now |
| Monsanto | Vistive III | Min. 50% oleic acid<br>Max. 3% linolenic acid<br>Low saturated fat | 2-5 years |
| Pioneer | Pioneer High-Oleic | 80-90% oleic acid<br>Max. 3% linolenic acid<br>12% saturated fat | Now |

Source: Qualisoy

With reported premiums as high as $0.60/bu, these soybeans offer farmers a way to diversify and earn extra profit, although it is important to stress that yields and identity preservation may complicate matters for farmers.

### 2. Market Potential

There were approximately 1.6 million acres of low-linolenic soybeans grown in the U.S. in 2007/08. Acreage was initially anticipated to reach 3-3.5 million acres in 2008/09 but lower than expected demand for low-linolenic oil forced seed companies to revise estimates downward to less than 1 million acres. The main reason for this disappointing result is the limited improvement in oxidative stability that prevented the use of the oil in deep-frying applications, especially considering the high premiums asked for the oil. Food manufacturers favored blends of oils (which could include canola oil, palm oil, and even limited amounts of partially-hydrogenated oil) and/or the use of antioxidants to prevent rancidity and extend shelf-life (low-linolenic soybean oil). Nevertheless, the recent release of mid- and high-oleic soybean varieties is expected to significantly increase the demand for high-stability soybean oil. For instance, Monsanto estimates the acreage potential in the U.S. for its Vistive III soybean variety at 10-20 million acres.

### 3. Profiles - Companies & Research Institutions

Three companies, Asoyia, Monsanto and Pioneer Hi-Bred, market the new high-stability oil soybean varieties. Qualisoy is also an important player as the group was founded to develop and commercialize varieties with enhanced compositional traits that add value to U.S. soybeans and soy products.

**Asoyia**

Asoyia is a farmer and employee-owned seed company based in Iowa City, IA. Asoyia markets the soybean varieties developed at Iowa State University.

In September 2008, Asoyia received a $300,000 from the USDA under the Value-Added
Producer Grant program in connection with the release of their ULTRA Low Linolenic Soybeans.

**Monsanto**

Monsanto, based in St. Louis, MO, is a major international seed developer. Monsanto is currently distributing Vistive I, a low-linolenic soybean variety, and is expected to release Visitive III, a mid-oleic/low-linolenic/ low saturates variety within the next few years. A high stearate variety, that would be used in margarine and spreads, is in an early stage of development.

**Pioneer Hi-Bred**

Pioneer Hi-Bred, a DuPont business, has developed Treus, a line of high stability soybeans. Low-linolenic and high-oleic varieties are currently available. The soybean varieties were developed in cooperation with Bunge.

**Qualisoy**

Qualisoy™ is a collaborative effort between farmers and all levels of the soybean industry to develop and commercialize varieties with enhanced compositional traits that add value to U.S. soybeans and soy products. The group originated from a soybean checkoff-funded initiative and was introduced in 2004.

The Qualisoy Board consists of 22 individuals representing all components of the U.S. soybean industry. The Qualisoy Board includes seven USB farmer-leaders, three representatives from multinational technology corporations, two representatives from regional technology corporations, four individuals representing various soybean processors and end users, one farmer-leader from the American Soybean Association, two farmer-leaders from Qualified State Soybean Boards, one academic and one scientist from USDA's Agricultural Research Service (ARS).

## 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to high stability oil soybeans.

**Table 16: SWOT – High Stability Oil Soybeans**

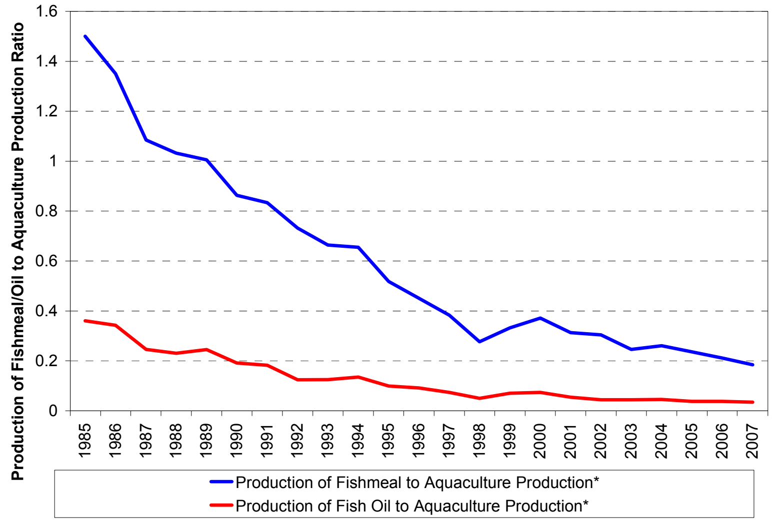
| **Strengths** | **Weaknesses** |
|---|---|
| ▪ No trans fats.<br>▪ Only food products that have less than 0.5g of trans fats can claim 0g of trans fats on their nutritional label.<br>▪ High- and mid-oleic soybean oils are extremely stable.<br>▪ High-oleic varieties open many new industrial applications.<br>▪ Premium paid to farmers growing high-stability soybeans.<br>▪ In the U.S., consumers are used to the taste of soybean oil in frying applications.<br>▪ Strong institutional support. | ▪ Low-linolenic soybean oil is not stable enough for frying applications.<br>▪ Some farmers have reported a yield drag for low- linolenic soybeans over conventional varieties.<br>▪ Identity preservation is necessary for high-stability soybeans.<br>▪ High cost of high stability soybean oil relative to conventional soybean oil. |
| **Opportunities** | **Threats** |
| ▪ Mid-oleic and high-oleic soybean varieties offer a significant improvement over low-linolenic varieties in terms of oxidative stability.<br>▪ Concerns over the level of saturated fat in food products may limit the use of palm oil in the future and favor other alternative vegetable oils like soy. | ▪ Low soybean oil prices.<br>▪ Canola, corn and sunflower oils are far more stable than conventional soybean oil and can be used in lieu of high-stability soybeans.<br>▪ Interesterification technologies offer an alternative to high stearate soybean varieties for spread and margarine applications.<br>▪ The use of antioxidants can prevent the need for high stability oils.<br>▪ Despite being high in saturated fats, palm oil usage increased as a way for food companies to avoid trans fats and associated labeling. |

## H. Aquaculture Feed

### 1. Product/Technology Overview

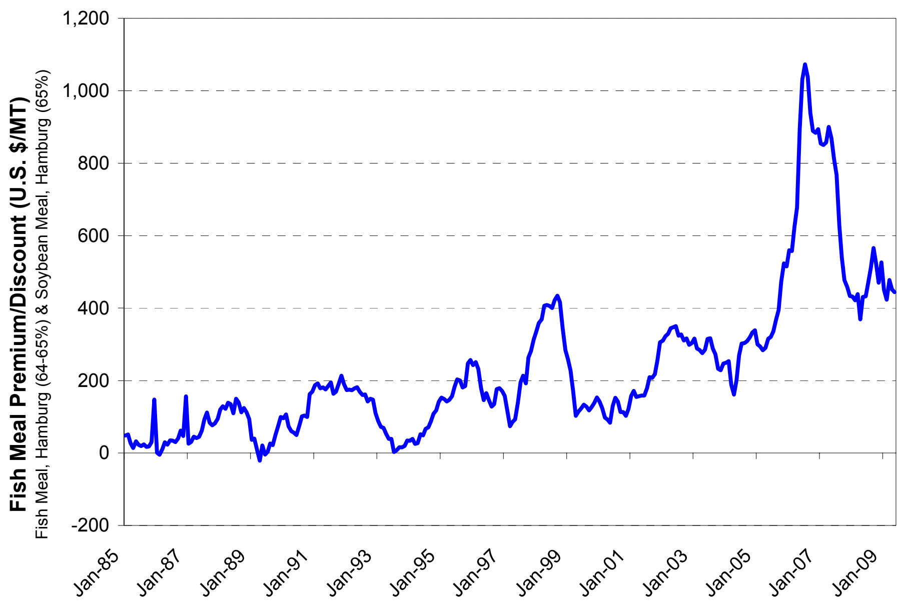
The global aquaculture industry is growing steadily, averaging 6.6% over the past 10 years (1998-2007), while fishmeal supplies have remained relatively stagnant (Figure 21). This supply and demand imbalance has driven up the premium for fishmeal over other protein meals including soybean meal (Figure 22), and while this premium has receded from the peaks seen in 2006 and 2007, it remains high relative to historical averages. Yet, over time fishmeal prices are expected to keep increasing, as supplies continue to tighten and demand continues to grow. This has led many aquaculture producers to look for ways to lessen their dependence on fishmeal.

**Figure 21: Fishmeal and Fish Oil Supply and Demand Imbalance**




Source: FAO, FIGIS & Oil World
*World aquaculture production – top 5 global fishmeal/oil consuming species: salmon, trout, carp, shrimp, and marine fish.

**Figure 22: Fishmeal Premium/Discount to Soybean Meal**




Source: Oil World

It has been known for a long time that soybean meal can be used in aquaculture feed but anti-nutritional factors that reduce fish performance, particularly at higher inclusion levels, and in carnivorous fish specie diets have limited its adoption. In general, herbivorous fish species tend to be somewhat tolerant to plant proteins and can more easily substitute for fishmeal in the diet. Nevertheless, carnivorous species are more affected by anti-nutritional factors and cannot tolerate plant proteins as well.

Contrary to soybean meal, however, soy protein concentrates (SPC) do not contain these high levels of anti-nutritional factors and can be utilized at higher inclusion rates as well as in carnivorous fish specie diets. Consequently, SPC have the potential to play a major role in the aquafeed market

SPC is made by removing a portion of the carbohydrates from the high protein soybean meal. There are different SPC production methods. The most frequent method used for producing SPC is alcohol extraction. This results in a product that is higher in protein and lower in anti-nutritional factors. SPC generally has 65-67% protein.

By most industry accounts, SPC has not commonly been used within the aquaculture industry, despite being a relatively good fishmeal substitute, because it has been priced too high for that market. Most SPC sales are focused on the more lucrative food market (by opposition to feed) where it is used as a functional or nutritional ingredient in products such as baked goods and cereals, as well as meats.

Some companies, like Hamlet Protein, have recently started to target the feed market. Hamlet uses a biological enzyme process that yields a product with a protein content of 56% which is slightly less than that of standard SPC. Production costs, however, are reportedly lower, which enable the product to be competitive in the feed market.

Price is the primary factor limiting current SPC utilization within the aquaculture industry. In order to increase SPC utilization within the aquaculture market by any significant degree, SPC is going to have to be priced at a sustained discount to fishmeal. Nevertheless, even priced competitively, it will take some time for the industry to become familiar with SPC and to gain trust in its performance.

### 2. Market Potential

It is estimated that 3.1 million tonnes of fishmeal are currently consumed by the aquaculture market in the world. By comparison, world SPC production was estimated to be 575 thousand tonnes in 2005, with less than 150 thousand tonnes used in aquafeed.

The current consensus is that SPC could account for 10-30% of the protein meal used in aquaculture feed. The U.S. Soybean Export Council estimates that, conservatively, the inclusion rate of SPC in aquafeed could reach 1 million tonnes. This represents a significant increase over current uses and indicates that SPC production could nearly triple in the future.

### 3. Profiles - Companies & Research Institutions

There are currently only a few SPC producers in the U.S., ADM, Cargill and Solae, with an additional player, Hamlet Protein, considering establishing a plant in Iowa.

One should note that Imcopa, a Brazilian soybean processor, also produces SPC.

**ADM**

Archer Daniels Midland Company (ADM) produces a wide range of functional soy protein concentrates under its NutriSoy® product line. All the soy protein products are targeted to the food market. ADM has reportedly no interest in the aquaculture market at this point.

**Hamlet Protein**

Hamlet Protein, headquartered in Denmark, manufactures an enhanced soy protein product that is similar to SPC. Hamlet uses a biological enzyme process that yields a product with a protein content of 56% which is slightly less than that of SPC and which has reduced anti-nutritional factors. The company currently operates one plant in Horsens, Denmark and has recently bought land in Iowa with the intention of breaking ground in the spring of 2010 on a feed grade SPC (enhanced soy protein) manufacturing facility.

**Solae**

The Solae Company is an alliance between DuPont and Bunge Limited to bring more soy protein and other soy products on the market. Solae produces a range of soy protein concentrates but, like ADM, it has reportedly no interest in the aquaculture market at this point.

### 4. SWOT

The following is a summary of the strengths, weaknesses, opportunities, and threats relative to soy protein concentrates as an aquaculture feed.

**Table 17: SWOT – Aquaculture Feed**

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ SPC can be used in carnivorous fish feed.<br>▪ SPC can replace 10-30% of the protein meal used in aquaculture feed. | ▪ Food markets can add much more value to SPC than feed markets.<br>▪ SPC cannot completely replace fish meal in diets.<br>▪ Current production costs are high. |
| **Opportunities** | **Threats** |
| ▪ Declining fishmeal stock.<br>▪ Increasing fishmeal prices relative to other proteins.<br>▪ Growing aquaculture industry. | ▪ All the SPC for the feed market is currently coming from Europe and Brazil.<br>▪ Tight capital cost markets.<br>▪ High soybean meal prices. |

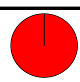
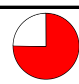
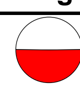
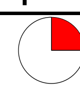
# V. Appendices

## A. Soybean Products/Technologies

All through the process to complete this study, Informa Economics reviewed a large array of emerging soy-based products and technologies. Over 100 products and technologies were evaluated based on their market potential, economic feasibility, stage of development and strength of institutional support. This appendix lists the products/technologies that were reviewed. While Informa attempted to be as complete and as accurate as possible in its evaluation of each of these products/technologies, it is acknowledged that given the lack of perfect information about all four assessment criteria for all 100+ products and technologies, the potential of some products and/or technologies may have been under/over estimated. Furthermore, this list is by no means exhaustive as, for example, many new products/technologies are under development and are kept confidential.

Note that the stage of development was divided into four distinct phases as shown in Table 18.

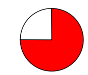
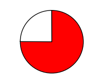
**Table 18: Development Stage**

| Well Established | Initial Commercialization | Early Development Stage | Research/ Conceptual Stage |
|---|---|---|---|
|  |  |  |  |

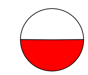
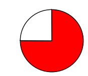
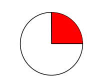
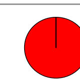
## 1. Soybean Technologies

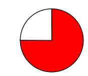
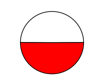
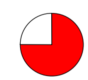
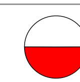
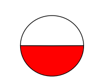
### a) Soy-based Chemicals

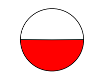
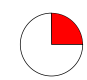
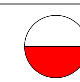
**Table 19: List of Emerging Technologies to Produce Soy-Based Chemicals**

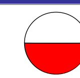
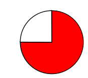
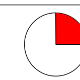
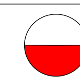
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Olefin Metathesis | Soybean Oil | The technology allows carbon atoms in natural oils to "swap" places, enabling new chemical compounds and manufacturing processes. | - Adhesives<br>- Agricultural fungicides<br>- Candles<br>- Diesel (improves biodiesel fuel properties)<br>- Lubricants<br>- Personal care and cosmetics<br>- Plastics<br>- Textiles | Davy Process Technology<br>Elevance Renewable Sciences |  |
| Soy-Based Polyols | Soybean Oil or Glycerin | Polyols are utilized extensively for polyurethane coatings, foams and adhesives. Most polyols in use today are derived from petroleum refining. Several companies have introduced technologies to produce biobased polyols derived from vegetable oil (glycerin might also be used). | - Adhesives<br>- Carpet-backing agents<br>- Coatings<br>- Elastomers<br>- Flexible foam cushioning for furniture, bedding and automotive products<br>- Paints and varnish<br>- Plastics<br>- Sealants | Archer Daniels Midland<br>Battelle Memorial Institute<br>BioBased Technologies, LLC<br>Cargill<br>Chevron Phillips Chemical<br>Dow Chemical<br>Ferro Corporation<br>Merquinsa<br>Textile Rubber & Chemical Co.<br>Urethane Soy Systems Co. |  |

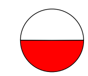
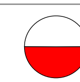
 

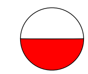
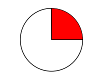
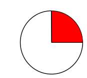
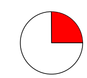
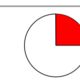
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Sophorolipid Production | Soybean Oil or Glycerin | Glycerin and/or soybean oil used as a fermentative substrate for the microbial synthesis of sophorolipids, which are glycolipids with multiple pharmaceutical applications. | - Cosmetics and personal care products<br>- Detergent<br>- Emulsifier<br>- Pharmaceuticals<br>- Skin care | Saraya Co., Ltd<br>Soliance<br>USDA |  |
| Rhamnolipid Production | Soybean Oil | Soybean oil can be used as a fermentative substrate for the microbial synthesis of rhamnolipids, which are glycolipids with various surfactant properties. | - Cosmetics and personal care products<br>- Enhanced oil recovery (petroleum industry)<br>- Food additives<br>- Pharmaceuticals<br>- Sanitary cleaning products | Cargill<br>Rhamnolipid, Inc. |  |
| Hydrolytic Product of Polymerized Epoxidized Soybean Oil (Hydrogel) | Soybean Oil | Epoxidized soybean oil is cross-linked into a polymer by thermal polymerization with triethylene glycol diamine. | - Pharmaceuticals (e.g., drug delivery, wound care, breast implant materials, tissue engineering) | USDA ARS |  |
| Modified Soy Proteins for Polymer Applications | Soy Proteins (meal, flour, concentrate or isolate) | Isolated soybean protein are chemically treated in various reactive processes to modify the protein chain to impart desired functional properties. These chemical processes are used to modify the functional nature of the soy polymer and optimize the properties for use in industrial applications. | - Adhesives<br>- Paints and coatings<br>- Pharmaceuticals | DuPont<br>University of Missouri |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Triglyceride-Based Polymers | Soybean Oil | Broad range of chemical routes to use oils to make polymers. Some routes consist in functionalizing the triglyceride with polymerizable chemical groups, while others consist in converting the triglyceride to monoglycerides through glycerolysis. | - Adhesives<br>- Automotive<br>- Coatings<br>- Cosmetics and personal care<br>- Paper<br>- Pharmaceuticals<br>- Plastics<br>- Rubber<br>- Textiles/clothing | Ashland Chemical Co<br>Degen Oil & Chemical Co.<br>Hexion Specialty Chemicals<br>New Century Coatings<br>PPG<br>Reichhold<br>Rust-Oleum<br>Sherwin-Williams<br>University of Delaware<br>University of Southern Mississippi |  |
| Epoxidized Allyl Soyate | Soybean Oil | The resin is prepared through a two-step chemical process involving transesterification and epoxidation | - Coating<br>- Manufacturing of composite materials<br>- Plastics | University of Missouri |  |
| Acrylated Epoxidized Soybean Oil | Soybean Oil | Acrylated epoxidized soybean oil is synthesized from the reaction of acrylic acid with epoxidized triglycerides. | - Coating<br>- Plastics | Cytec Industries<br>University of Delaware |  |
| Maleinized Soy Oil Monoglyceride | Soybean Oil | Soybean oil monoglycerides, obtained by the glycerolysis of soybean oil, are reacted with maleic anhydride to produce maleinized soy oil monoglyceride. | - Composite material with glass fibers | University of Delaware |  |
| Maleinized Hydroxylated Oil | Soybean Oil | Various chemical pathways to synthesize maleinized hydroxylated oil from oil. | - Composite material | University of Delaware |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Plasticizers Derived from Vegetable Oils | Soybean Oil | These vegetable oil-based plasticizers are made by method which includes the basic steps of (i) creating ester linkages by attaching fatty acids derived from vegetable oils to monoalcohols (monools) or polyalcohols (polyols) by means of direct esterification; and (ii) epoxidizing the esterified products. Alternative reaction steps exist. Unlike other bio-based products, the invention provides plasticizers that can be used as a primary plasticizer in PVC applications. | - Plasticizers in PVC resins | Battelle Memorial Institute / PolyOne |  |
| Methanol | Glycerin | New method to produce methanol directly from glycerin. The process uses direct catalytic hydrogenolysis of glycerol under mild conditions | - Methanol production | Oxford University |  |
| Lactic Acid Production | Glycerin | Process to convert glycerin into lactic acid for use in making polylactic acid, a type of biodegradable plastic. | - Biodegradable plastics | Tohoku Electric power Co. / Zosen Corp. |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Polyhydroxyalkanoate (PHA) | Glycerin | Bacterial production of polyhydroxyalkanoates from glycerin | - Biodegradable plastics | Danimer Scientific LLC<br>National Institute of Advanced Industrial Science and Technology<br>State University of New York<br>USDA |  |
| Propylene Glycol | Glycerin | There are several routes to produce propylene glycol using glycerin. Generally, glycerin is hydrogenated in the presence of metallic catalysts and hydrogen under different reaction conditions. | - Antifreeze<br>- Coolant<br>- Emulsifier<br>- Heat transfer fluid<br>- Humectant<br>- Moisturizer<br>- Polyester resin<br>- Solvent<br>- Unsaturated polyester resins (e.g., boat hull) | Archer Daniels Midland<br>Cargill / Ashland Chemical<br>Davy Process Technology<br>Dow Chemical<br>Huntsman Corporation<br>Michigan State University<br>Senergy Chemical |  |
| | | Microbial conversion of glycerol to propylene glycol (1,2-propanediol) has also been evaluated. | | University of Wisconsin |  |
| Epichlorohydrin Production | Glycerin | It has been known for decades that glycerin can be converted to epichlorohydrin. But this chemistry has not been used commercially to any significant extent because of the high cost of glycerin compared to propylene (traditional route). The availability of bio-based glycerin and the tight | - Epoxy resins<br>- Paper reinforcement<br>- Pharmaceuticals<br>- Surfactant<br>- Water purification | Aser SRL<br>Dow Chemical<br>Solvay<br>Spolchemie |  |

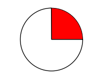
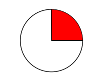
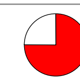
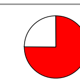
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| | | propylene market has reversed this situation. Several companies have also disclosed technologies that claim improvements to the conventional pathway. | | | |
| 1,3-Propanediol Production | Glycerin | Microbial conversion of glycerol to 1,3-propanediol | - Antifreeze<br>- Building block in the production of polymers (polyester fabric)<br>- Solvent<br>- Wood paint | Institut für Agrartechnologie und Biosystemtechnik (Germany)<br>Dupont<br>Ecole National Supérieure des Industrie Chimiques (France)<br>Iowa State University<br>Michigan State University<br>Shanghai Academy of Agricultural Sciences<br>Universidad Complutense de Madrid<br>Universidade Catolica Portuguesa<br>University of Georgia<br>University of Wisconsin |  |
| Dihydroxyacetone | Glycerin | There are several routes to produce dihydroxyacetone using glycerin. Generally, glycerin is converted in the presence of metallic catalysts under different reaction conditions. | - Food additive<br>- Pharmaceutical<br>- Tanning lotion | Forschungszentrum Jülich GmbH, Institut für Biotechnologie (Germany)<br>Munich University of Technology (Germany)<br>Purdue University |  |

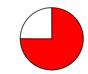
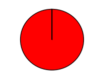
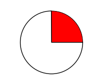
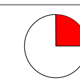
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Acetol | Glycerin | Process that couples copper-chromite catalyst with reactive distillation to convert glycerin to acetol. | - Polyols | University of Missouri |  |
| Succinic Acid | Glycerin | Biobased fermentation processes have been developed to produce succinic using glycerol as a carbon source. | - Cosmetics and personal care products<br>- Chemicals<br>- Food additive (flavoring agent)<br>- Plastics<br>- Pharmaceuticals | Korea Advanced Institute of Science and Technology<br>Rice University |  |
| Glyceric Acid | Glycerin | Bacterial conversion of glycerin to glyceric acid. | - Cosmetics and personal care products<br>- Chemicals<br>- Pharmaceuticals | National Institute of Advanced Industrial Science (Japan) |  |
| Acrolein | Glycerin | Production of acrolein through the dehydration of glycerin. | - Chemicals<br>- Detergent<br>- Plastics | Arkema<br>Chinese Academy of Sciences<br>Tohoku University (Japan) |  |
| Propionic Acid | Glycerin | Biobased fermentation using a strain of Propionibacterium acidipropionici bacteria to produce propionic acid from glycerin to convert glycerin into ethanol. | - Grain and seed preservative<br>- Pharmaceuticals | INRA (France)<br>Ohio State University |  |

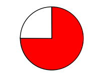
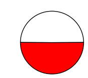
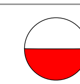
Not an exhaustive list

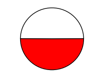
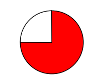
### b) Biodiesel Technologies

**Table 20: Biodiesel Technologies**

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Supercritical Methanol Transesterification | Soybean Oil | Transesterification of soybean oil in supercritical methanol has been shown to increase the chemical reaction speed and yield, while preventing the need for a catalyst. | - Biodiesel production | Beijing University of Chemical Technology<br>Kyoto University<br>Texas A&M University<br>The University of Iowa |  |
| In Situ Transesterification | Soybean | It is possible to have an in situ transesterification, the transesterification occuring directly in the raw soy flakes containing the oil. This method skips the conventional oil-extraction step, hence eliminating the need for hexane. | - Biodiesel production<br>- Oil Extraction | USDA ARS |  |
| Ultrasonic Cavitation | Soybean Oil | Ultrasonic cavitational mixing helps achieve a better mixing in commercial biodiesel processing. It increases the chemical reaction speed and yield of the transesterification of vegetable oils into biodiesel. | - Biodiesel production | Hielscher Ultrasonics GmbH (Germany)<br>Mississippi State University |  |
| Magnetic Pulse Cavitation | Soybean Oil | Magnetic pulse cavitational mixing helps achieve a better mixing in commercial biodiesel processing. It increases the chemical reaction speed and yield of the transesterification of vegetable oils into biodiesel. | - Biodiesel production | W2 Energy Inc. |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Hydrodynamic Cavitation | Soybean Oil | Micro bubbles generated by pressure pulses help achieve a better mixing in commercial biodiesel processing. It increases the chemical reaction speed and yield of biodiesel production. | - Biodiesel production | Arisdyne Systems |  |
| Solid Transesterification Catalyst | Soybean Oil | The solid catalyst process enables a significant reduction in waste streams compared to other processes and leads to the direct production of a very high quality glycerin (98% purity). The catalyst can be reused. | - Biodiesel production | Axens<br>Better Biodiesel<br>New Century Lubricants<br>Süd-Chemie Group |  |
| Enzymatic Transesterification | Soybean Oil | Lipase-catalyzed transesterification of soybean oil and methanol for biodiesel production is more efficient, highly selective, involves less energy consumption (reactions can be carried out in mild conditions), and produces less side products or waste (environmentally favorable). | - Biodiesel production | Donghua University (China)<br>Hongik University (Korea)<br>Indian Institute of Chemical Technology<br>National Chung Hsing University (Taiwan)<br>Seoul National University<br>Songjiang University (China)<br>University of Georgia |  |
| Peroxidation Process | Soybean Oil | A peroxidation technique can be combined to conventional transesterification in order to improve fuel properties (e.g., fuel consumption rate) and reduce the emission pollution (i.e., $CO_2$, CO and $NO_x$) of biodiesel. | - Biodiesel production | National Taiwan Ocean University |  |

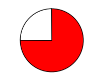
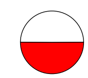
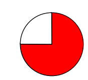
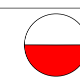
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Mcgyan Process | Soybean Oil | Novel transesterification process using a continuous fixed-bed reactor filled with a sulfated metal oxide catalyst. The process increases the reaction speed and eliminates unwanted side reactions with free fatty acids, thereby reducing the amount of waste. The process also uses no water and only produces traces of glycerin. | - Biodiesel production | Augsburg College / StarTec Corporation |  |
| PermaFlow | Soybean Oil | The PermaFlow process incorporates urea into the traditional transesterification process, which enables the separation of the saturated and unsaturated biodiesel molecules via the mechanism of urea-biodiesel clathration. By separating (fractionating) the saturated and unsaturated oil molecules from each other, the remaining unsaturated oil molecules have much lower cloud points than traditional biodiesel. | - Biodiesel and cold flow properties | Indiana Soybean Alliance Purdue University |  |
| Farm-Scale Biodiesel Production | Soybean Oil | The microreactor consists of a series of parallel channels through which vegetable oil and alcohol are pumped simultaneously. The process is efficient, fast, and portable, and could enable farmers to produce | - Transesterification microreactor | MTEK Energy Solutions / Oregon Nanoscience and Microtechnologies Institute |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| | | biodiesel on their farms using seed crops they grow. | | | |
| Modified Transesterification with Glycerin Conversion into Biodiesel Additive | Soybean Oil | Continuous transesterification process in which the glycerin is converted into glycerol acetal suitable for inclusion in biodiesel as a fuel additive. The acetal additive reduces particulate emissions, particularly from diesel engines and functions like an oxygenate. | - Biodiesel<br>- Biodiesel additive | Michigan State University |  |
| Biodiesel Additives | NA | Important barriers for the expansion of biodiesel use include its poor cold flow properties, low oxidation stability, and high NOx emissions. Numerous additives have been developed to improve biodiesel properties. | - Cold flow improver<br>- Antioxidant<br>- Particulate matter emission reduction | Afton Chemical<br>ARCO Chemical Technology<br>Dawn Chemical Corp.<br>Eastman Chemical Co.<br>Enertch Labs<br>Innospec<br>Institut Francais du Petrole<br>Lubrizol<br>Midcontinental<br>Power Service<br>Schaeffer Manufacturing<br>SVO Specialty Products<br>University of Bologna (Italy)<br>University of Nebraska |  |

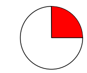
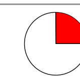
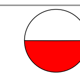
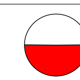
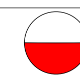
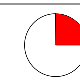
Not an exhaustive list

## c) Fuel / Energy Technologies (other than biodiesel)

**Table 21: Fuel / Energy Technologies (other than biodiesel)**

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Hydroprocessing | Soybean Oil | Catalytic hydrogenation of fats and oil into renewable diesel. The glycerin chain is hydrogenated to produce propane. There is no glycerin sidestream. The resulting renewable diesel is identical to conventional diesel. | - Renewable diesel production | BP<br>ConcoPhillips/Tyson<br>Dynamic Fuels<br>Neste Oil<br>Petrobras<br>Syntroleum Renewable Diesel |  |
| Renewable Diesel Fuel Production Technology | Soybean Oil | Small reactor able to produce renewable diesel from vegetable oil without the need for external inputs other than the feedstock (i.e., no need for methanol or hydrogen). | - Renewable diesel production | Renewable Fuel Products, Inc. |  |
| Emulsification for Fuel Production | Soybean Oil | The process consists of an additive blending process in an emulsion to manage the properties of vegetable oil at the point of combustion. | - Renewable diesel production | New Generation Biofuels |  |
| Soy Oil Biofuel Cell | Soybean Oil or Glycerin | Biofuel Cells create electricity using a wide variety of fuels for power generation such as alcohol, sugar, soybean oil, and glycerol. | - Electricity generation | St. Louis University |  |

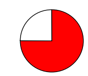
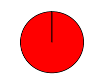
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| GlyClene | Glycerin | Technology capable of converting glycerin into a fuel suitable for use in turbine engines. In this process, the glycerin is cracked and then treated with a chemical and thermal heat process to create the fuel. | - Energy production | XcelPlus Global Holdings Inc. | |
| Glycerin Burner | Glycerin | The system uses a novel spray atomization swirl burner achitecture that overcomes technical and safety issues usual with glycerin burners. | - Energy production | Diversified Energy Corporation<br>North Carolina State University | |
| GlyCoal | Glycerin | Technology capable of converting glycerin into a sulfur-free supplement for large industrial applications. GlyCoal reduces coal emissions and byproducts when used as a replacement fuel. | - Energy production in coal plants | XcelPlus Global Holdings Inc. | |
| BioForming | Glycerin | The technology combines Virent Energy Systems' Aqueous Phase Reforming (APR) process that converts glycerin directly into hydrogen and natural gas with catalytic processing to produce renewable gasoline, diesel, jet fuel, and hydrogen from a wide range of biomass feedstock, including glycerin. | - Hydrogen generation<br>- Renewable fuel generation | Virent Energy Systems Inc. | |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Centia | Soybean Oil | Technology design to convert oils derived from any triglyceride feedstock to high value biofuels. The technology integrates a sequence of four steps to produce biogasoline, jet fuel, and renewable diesel. | - Renewable fuel generation | Diversified Energy Corporation / North Carolina State University |  |
| Hydrogen Generation | Glycerin | Technology uses a bi-functional monolith autothermal reforming catalyst to generate hydrogen from liquid such as glycerin. | - Hydrogen generation | Eden Energy ltd. / Hythane Company |  |
| Glycerin to Renewable Diesel Conversion | Glycerin | The process, IUCT-S50, converts glycerin into biodiesel. | - Renewable diesel production | Institut Universitari de Ciència i Tecnologia (Barcelona, Spain) |  |
| Fuel Oxygenates Production | Glycerin | Solid transesterification catalyst technology that convert glycerin into fuel oxygentates, primarily di- and tri-ethers of glycerin. | - Fuel oxygenates | New Century Lubricants |  |
| Ethanol | Glycerin | Biobased fermentation using a strain of E. coli to convert glycerin into ethanol. | Ethanol production | Rice University / Glycol Biotechnologies |  |
| Butanol | Glycerin | Biobased fermentation using Clostridium pasteurianum bacteria to produce butanol from crude. | - Fuel<br>- Solvent<br>- Coatings: paint, varnish, and inks<br>- Agricultural chemicals: insecticides, pesticides and herbicides<br>- Synthetic resin and adhesives<br>- Textiles (scatter rugs, sets…)<br>- Sealants | German Research Center for Biotechnology University of Alabama |  |

Not an exhaustive list

## d) Oilseed Crushing and Processing

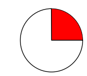
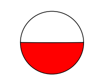
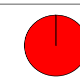
**Table 22: Oilseed Crushing and Processing**

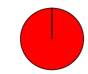
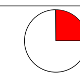
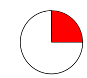
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Supercritical Carbon Dioxide Extraction of Oil | Soybean | Mechanical screw press modified to inject liquid or gases into the internals of the press cage. Currently, liquid CO2 is used in the press, resulting in more efficient removal of oil from the seed and a higher quality press cake. | - Oil extraction process | Crown Iron Works |  |
| Enzymatic Degumming | Soybean Oil | Novel enzymatic degumming process designed to increase the oil yield and reduce low-value byproducts by removing oil phospholipids in the oil refining process. The phospholipase enzyme increases total oil yield by reducing heavy phase entrainment and converting phospholipids into diacylglycerol oil. | - Oil degumming process | Bunge North America<br>Danisco<br>Novozymes<br>Verenium |  |

Not an exhaustive list

### e) Food Technologies

**Table 23: Food Technologies**

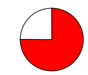
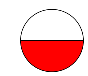
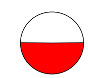
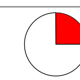
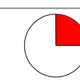
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Flatulence-Free Soybean Products | Soybean | The indigestibility of oligosaccharides is blamed as the causing factor for flatulence associated with the human consumption of soy products. Germinating black soybeans under stress from fungus may reduce flatulence-causing carbohydrates. | - Soy dairy products | National University of Singapore |  |
| Frozen Tofu | Soy Proteins (meal, flour, concentrate or isolate) | Generally, by freezing tofu, the large ice crystals that develop within the tofu results in the formation of large cavities. Furthermore, the tofu takes on a yellowish hue. A new technology was developed to allow the soy-based product to be frozen while maintaining all of its characteristics. Using a patented flash-freezing process, frozen tofu can be stored for up to a year (compared to no more than seven to ten days for the fresh product). | - Food | Battelle Memorial Institute / Ohio Soybean Council |  |
| Enzymatic Interesterification | Soybean Oil | Interesterification rearranges fatty acids, resulting in a product with a higher melting point without forming trans fatty acids as is the case with partial hydrogenation. | - Margarine<br>- Shortening for baking | De Smet/Novozymes<br>Bunge |  |

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Soy Protein Isolation Method | Soy Proteins (meal, flour, concentrate or isolate) | Upfront has developed a new concept for isolating fractions of soluble soy protein. This enables the industry to add a new high value product category to the traditional insoluble soy protein product. | - Food ingredients<br>- Pharmaceuticals | Upfront Chromatography A/S |  |
| Omega-3 Fatty Acids | Glycerin | Glycerin is used as a carbon source to grow microalgae that produce omega-3 fatty acids. | - Food<br>- Animal feed | Battelle Memorial Institute / Ohio Soybean Council<br>Virginia Tech |  |
| Soybean Protein Concentrate Preparation | Soy Proteins (meal, flour, concentrate or isolate) | New process for the preparation of soybean protein concentrate by directly extracting full-fat soy flour with a mixture of hexane and aqueous ethanol. The process saves energy and reduces protein denaturation caused by heat action during solvent recovery. | - Food<br>- Aquaculture Feed | Wuhan Polytechnic University (China) |  |

Not an exhaustive list

### f) Value-Added Soybean Varieties

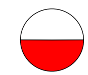
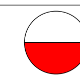
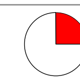
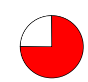
**Table 24: Value-Added Soybean Varieties**

| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| High Stability Oil Soybeans | Soybean | Biotech soybean varieties with a low polyunsaturated fatty acid content. New varieties include low linolenic, high- and mid-oleic, and high stearate soybean. | - Functional food<br>- Frying applications<br>- Industrial applications<br>- Margarine<br>- Shortening for baking | Monsanto<br>Asoyia<br>Pioneer<br>Syngenta |  |
| Omega-3 Fortified Soybeans | Soybean | Biotech soybean variety that provides oil enriched in the omega-3 fatty acid called stearidonic acid (SDA). | - Functional food<br>- Frying applications<br>- Industrial applications | Monsanto<br>Solae (with its majority owner DuPont) |  |
| High Oil Soybeans | Soybean | Biotech soybean variety with a high oil content (19-25% depending on development stage). Protein quality would not be impacted. | - Soybean oil production | Monsanto<br>Pioneer<br>University of Guelph |  |
| Improved Feed Soybeans | Soybean | Pioneer Hi-Bred is working to develop soybean varieties that improve the meal quality and digestible energy in animal feeds. | - Feed | Pioneer |  |
| Soybean with Increased Tocopherol Content | Soybean | Development of soybean varieties with increased tocopherol (vitamin) content through genetic modification or conventional crossing. | - Food | University of Guelph<br>University of Kentucky |  |

Not an exhaustive list

## g) Other Technologies/Processes

**Table 25: Other Technologies/Processes**

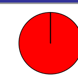
| Technology Name / Product | Soybean Product Used | Description of Technology | Applications | Institutions/Companies Involved (Technology Name) | Stage of Development |
|---|---|---|---|---|---|
| Powder Coating | Soybean Oil | Innovative technology that combines resin composites derived from soybeans to produce a powder coating that has the ability to operate at 130°C (compared to 175°C typically), increasing the range of applications, and lowering energy consumption compared to conventional powder coating. | - Powder coating (e.g., refrigerators, tractor panels…) | Battelle Memorial Institute / Ohio Soybean Council |  |
| Bowman-Birk Inhibitor Extract from Soybeans | Soy Proteins (meal, flour, concentrate or isolate) | The new method includes taking defatted soybean material, removing its fiber, and then using a special ultra filtration process to produce Bowman-Birk inhibitor extract that has chemopreventive activity. | - Pharmaceutical (cancer treatment) | Lolae, LLC |  |
| Candle Making | Soybean Oil | The properties of partially hydrogenated soybean oil in wax applications can be improved through the combination of epoxidation, ring-opening reaction, and esterification. | - Candles<br>- Coating | Iowa State University |  |
| Ambersep BD50 Glycerin purification process | Glycerin | Chromatographic separation process to purify crude glycerin and produce a purified glycerin product with 99.5% purity. The system has low energy requirements and only consumes small quantities of water. | - Glycerin refining | Rohm and Haas / Novasep Process |  |

Not an exhaustive list

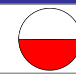
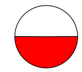
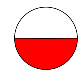
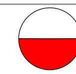
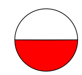
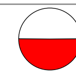
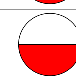
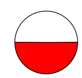
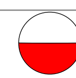
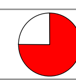
## 2. Soybean Products

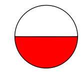
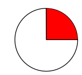
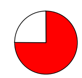
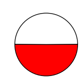
### a) Soy-Based Chemicals

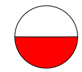
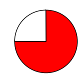
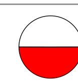
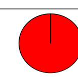
**Table 26: Soy-Based Chemicals**

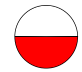
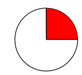
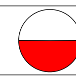
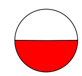
| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Soy Methyl Ester (non-fuel applications) | Soybean Oil | - Methyl ester sulfonate<br>- Epoxidized methyl soyate | - Paints and coatings<br>- Solvent |  | ADM<br>Biospan Technologies<br>Cargill<br>Citrus Oleo<br>Cognis Corporation<br>Columbus Foods<br>Cortec Corporation<br>Diversified Chemical Technologies<br>Eco Safety Products<br>Florida Chemical<br>Gemtek Products, LLC<br>Green Products Inc.<br>IMET Corp.<br>Lambent Technologies Corp.<br>Lubrizol<br>New Century Coatings<br>Soy Technologies, LLC<br>Stepan Company<br>Sun Products Corp.<br>Vertec BioSolvents, Inc.<br>REG |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Polyols | Soybean Oil or Glycerin | - Alkyd resins<br>- Polyurethanes | - Adhesives<br>- Carpet-backing agents<br>- Coatings<br>- Elastomers<br>- Flexible foam cushioning for furniture, bedding and automotive products<br>- Paints and varnish<br>- Plastics<br>- Sealants | | Arkema Inc.<br>Battelle Memorial Institute<br>BioBased Technologies, LLC<br>Cargill<br>The Dow Chemical Company<br>Urethane Soy Systems Co. |
| Epoxidized Soybean Oil | Soybean Oil | - Acrylated epoxidized soybean oil<br>- Alcohols (industrial)<br>- Alkanolamines<br>- Carbonyl compounds<br>- Epoxy resins<br>- Maleinized hydroxylated oil<br>- Olefinic compounds<br>- Polyol<br>- Polyvinyl chloride (PVC)<br>- Polyester resins | - Adhesives<br>- Agricultural and pharmaceutical molecules<br>- Coatings<br>- Fiberglass manufacturing<br>- Flexible foam cushioning for furniture, bedding and automotive products<br>- Pharmaceutical<br>- Plastics<br>- Rubbers<br>- Sealant<br>- Sheet molding composite panels (e.g., covers for tractors)<br>- Surfactants | | Chemtura Corporation<br>Cognis Corporation<br>Cytec Industries<br>ICC Chemical Corporation<br>The Dow Chemical Company<br>University of Delaware<br>USDA ARS |
| Epoxidized Allyl Soyate | Soybean Oil | - Epoxy resin | - Coating (especially metal, plastic or glass surfaces)<br>- Manufacturing of composite materials<br>- Plastics | | University of Missouri |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Maleinized Soy Oil Monoglyceride | Soybean Oil | - Resin | - Composite material with glass fibers |  | University of Delaware |
| Maleinized Hydroxylated Oil | Soybean Oil | - Resin | - Composite material with glass fibers |  | University of Delaware |
| Epoxidized Pentaerythritol Tetrasoyate | Soybean Oil | - PVC resin | - Plastics |  | Battelle Memorial Institute / PolyOne |
| Epoxidized Propylene Glycol Disoyate | Soybean Oil | - PVC resin | - Plastics |  | Battelle Memorial Institute / PolyOne |
| Epoxidized Ethylene Glycol Disoyate | Soybean Oil | - PVC resin | - Plastics |  | Battelle Memorial Institute / PolyOne |
| Epoxidized Sucrose Octasoyate | Soybean Oil | - PVC resin | - Plastics |  | Battelle Memorial Institute / PolyOne |
| Epoxidized Methyl Soyate | Soybean Oil | - Carbonated methyl soyates<br>- Epoxy resin<br>- PVC resin | - Composite material with glass fibers<br>- Lubricant<br>- Plastics |  | Battelle Memorial Institute / PolyOne<br>University of Missouri<br>ASDA ARS |
| Epoxidized Product of Soybean Oil Interesterified with Linseed Oil | Soybean Oil | - PVC resin | - Plastics |  | Battelle Memorial Institute / PolyOne |
| Polyethiol | Soybean Oil | | - Crosslinking / curing agents in epoxy resins (adhesives, coatings) |  | Chevron Phillips Chemical Co. |
| Ethoxylated Soybean Oil | Soybean Oil | | - Surfactant (e.g., fungicide, herbicide) |  | |

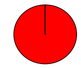
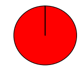
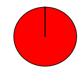
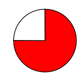
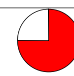
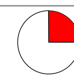
| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Acetol | Glycerin | - Polyols | - Adhesives<br>- Carpet-backing agents<br>- Coatings<br>- Elastomers<br>- Flexible foam cushioning for furniture, bedding and automotive products<br>- Paints and varnish<br>- Plastics<br>- Sealants |  | University of Missouri |
| Acrolein | Glycerin | - Acrylic acid<br>- Acrylonitrile<br>- Polyester resin<br>- Polyurethane<br>- 1,3-propanediol<br>- Propylene glycol | - Antifreeze<br>- Chemical intermediate<br>- Herbicides<br>- Plastics |  | Arkema<br>Chinese Academy of Sciences<br>Tohoku University (Japan)<br>University of Tennessee |
| Propylene Glycol | Glycerin | NA | - Antifreeze<br>- Coolant<br>- Emulsifier<br>- Heat transfer fluid<br>- Humectant<br>- Moisturizer<br>- Polyester resin<br>- Solvent<br>- Unsaturated polyester resins (e.g., boat hull) |  | Archer Daniels Midland<br>Cargill / Ashland Chemical<br>Davy Process Technology<br>Huntsman Corporation<br>Michigan State University<br>Senergy Chemical<br>The Dow Chemical Company<br>University of Wisconsin |
| Epichlorohydrin | Glycerin | - Epoxy resins | - Paper reinforcement<br>- Plastics<br>- Pharmaceuticals<br>- Surfactant<br>- Water purification |  | Solvay<br>Spolchemie<br>The Dow Chemical Company |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| 1,3-Propanediol | Glycerin | - Polyester fibers<br>- Polyurethanes | - Adhesives,<br>- Antifreeze<br>- Composites,<br>- Moldings<br>- Paints and coatings |  | Institut für Agrartechnologie und Biosystemtechnik (Germany)<br>Dupont<br>Ecole National Supérieure des Industrie Chimiques (France)<br>Iowa State University<br>Michigan State University<br>Shanghai Academy of Agricultural Sciences<br>Universidad complutense de Madrid<br>Universidade Catolica Portuguesa<br>University of Georgia<br>University of Wisconsin |
| Rhamnolipids | Soybean Oil or Glycerin | NA | - Cosmetics and personal care products<br>- Enhanced oil recovery (petroleum industry)<br>- Food additives<br>- Pharmaceuticals<br>- Sanitary cleaning products |  | Cargill<br>Rhamnolipid, Inc. |
| Sophorolipids | Soybean Oil or Glycerin | NA | - Cosmetics and personal care products<br>- Pharmaceuticals<br>- Sanitary cleaning products |  | Saraya Co., Ltd<br>Soliance<br>USDA |
| Glyceryl soyate | Soybean Oil or Glycerin | NA | - Cosmetics and personal care products |  | Lubrizol |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Dihydroxyacetone | Glycerin | - Methotrexate (chemotherapie) | - Cosmetics and personal care products<br>- Food additive<br>- Pharmaceutical |  | Forschungszentrum Jülich GmbH, Institut für Biotechnologie (Germany)<br>Munich University of Technology (Germany)<br>Purdue University |
| Methanol | Glycerin | - Denaturing agent<br>- Feedstock in the fabrication of various chemicals | - Chemical industry<br>- Fuel |  | Oxford University |
| Lactic Acid | Glycerin | - Lactide<br>- Polylactic acid | - Food additive<br>- Plastic |  | Tohoku Electric power Co. / Zosen Corp. |
| Polyhydroxyalkanoate (PHA) | Glycerin | NA | - Plastic |  | Danimer Scientific LLC<br>Meredian<br>National Institute of Advanced Industrial Science and Technology<br>State University of New York<br>USDA |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Succinic Acid | Glycerin | - 1,4-Butanediol (BDO)<br>- Tetrahydrofuran (THF)<br>- γ-Butyrolactone (GBL)<br>- 2-Pyrrolidinone<br>- N-Methyl Pyrrolidone (NMP)<br>- Succindiamide<br>- 1,4-Diaminobutane<br>- Succinonitrile<br>- DBE<br>- 4,4-Bionolle | - Cosmetics and personal care products<br>- Chemicals<br>- Food additive (flavoring agent)<br>- Plastics<br>- Pharmaceuticals | | Korea Advanced Institute of Science and Technology<br>Rice University |
| Glyceric Acid | Glycerin | NA | Building block for several chemical compounds | | National Institute of Advanced Industrial Science (Japan) |
| Butanol | Glycerin | - Butyl Acrylate<br>- Methacrylate<br>- Glycol Ethers<br>- Butyl Acetate | - Fuel (gasoline substitute)<br>- Solvent<br>- Coatings: paint, varnish, and inks<br>- Agricultural chemicals<br>- insecticides, pesticides and herbicides<br>- Synthetic resin and adhesives<br>- Textiles: scatter rugs, bathmats, and sets<br>- Sealants | | German Research Center for Biotechnology<br>University of Alabama |
| Propionic Acid | Glycerin | NA | - Grain and seed preservative<br>- Pharmaceuticals | | INRA (France)<br>Ohio State University |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Glycerol Ethers | Glycerin | NA | - Biodiesel / diesel additive (improves cold flow properties and particulate matter emissions) | | ARCO Chemical Technology<br>University of Nebraska |
| Glycerin Acetate Carbonates | Glycerin | NA | - Biodiesel / diesel additive (reduces particulate matter emissions) | | Institut du Petrole<br>University of Bologna (Italy) |
| Glycerin Acetals | Glycerin | NA | - Biodiesel / diesel additive (improves cold flow properties and particulate matter emissions) | | Institut Francais du Petrole |
| Triacetin | Glycerin | NA | - Fuel Additive (improves cold flow properties when added to diesel or antiknocking properties when added to gasoline) | | Rey Juan Carlos UniVersity (Spain) |
| Abietoyl Hydrolyzed Soy Polypeptide | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products | | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |
| Cocodimonium Hydroxypropyl Hydrolyzed Soy Protein | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products | | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |
| Hydroxypropyltrimonium Hydrolyzed Soy Protein | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products | | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Socoyl Hydrolyzed Soy Protein | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products |  | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |
| Soy Stearyl Polypeptide | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products |  | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |
| Undecylenoyl Soy Polypeptide | Soy Proteins (meal, flour, concentrate or isolate) | NA | - Cosmetics and personal care products |  | Arch Chemicals<br>Rita Corporation<br>Sinerga S.p.A. (Italy) |
| Soy Isoflavones | Soybeans | NA | - Nutraceutical |  | ADM<br>Acatris |
| Soy Saponins | Soybeans | NA | - Nutraceutical |  | ADM |
| Citric Acid | Glycerin | NA | - Preservative<br>- Flavoring |  | Andhra University (India)<br>Wroclaw University (Poland) |

Not an exhaustive list

## b) Soy-Based Fuels

**Table 27: Soy-Based Fuels**

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Renewable Diesel | Soybean Oil | NA | - Fuel (diesel substitute) | | BP<br>ConcoPhillips/Tyson<br>Diversified Energy Corporation / North Carolina State University<br>Dynamic Fuels<br>Neste Oil<br>Petrobras<br>Syntroleum Renewable Diesel |
| Direct Soybean Oil Use as Fuel | Soybean Oil | NA | - Diesel (biofuel) | | |
| Turbine Engine Fuel | Glycerin | NA | - Fuel | | Diversified Energy Corporation<br>North Carolina State University<br>XcelPlus Global Holdings Inc. |
| Renewable Diesel | Glycerin | NA | - Fuel (diesel substitute) | | Institut Universitari de Ciència i Tecnologia (Barcelona, Spain)<br>Virent Energy Systems Inc. |
| Renewable Gasoline | Glycerin | NA | - Fuel (gasoline substitute) | | Virent Energy Systems Inc. |
| Hydrogen | Glycerin | NA | - Chemical industry<br>- Fuel | | Eden Energy ltd. / Hythane Company<br>Virent Energy Systems Inc. |

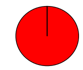
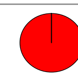
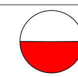
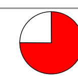
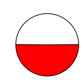
| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Jet Fuel Substitute | Glycerin | NA | - Fuel (jet fuel) | | Virent Energy Systems Inc. |
| Fuel oxygenate | Glycerin | NA | - Fuel | | New Century Lubricants |
| Ethanol | Glycerin | NA | - Gasoline | | Rice University / Glycol Biotechnologies |

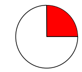
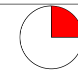
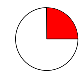
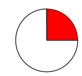
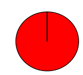
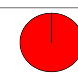
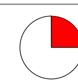
Not an exhaustive list

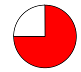
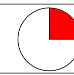
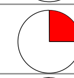
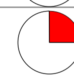
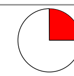
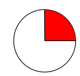
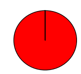
### c) Other Emerging Soy-Based Applications

**Table 28: Other Emerging Soy-Based Applications**

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Lubricant | Soybean Oil | NA | - Bar and chain oil<br>- Crankcase oi<br>- 2-cycle oil<br>- Drip oil<br>- Hydraulic fluid<br>- Metalworking fluid<br>- Transformer oil<br>- Wire rope oil | | ABB<br>Alcoa<br>Bunge/AgriTech<br>Cargill/Cooper Power Systems<br>Chevron<br>ELM<br>Environmental Lubricants Manufacturing, Inc.<br>Exxon Mobil<br>Fuchs<br>Houghton<br>TribSys Inc.<br>Valvodine |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Soy Wax | Soybean Oil | NA | - Candles<br>- Coating |  | Bitter Creek Candle Supply, Inc.<br>Bubbles 'N Lights<br>Cargill<br>Elevance Renewable Sciences<br>Gelluminations<br>Nature's Gifts International, LLC<br>Peter Cremer North America<br>Soyawax<br>SoyLights |
| Drying oil | Soybean Oil | - Polyol | - Intermediate for polyols<br>- Paints, coatings and inks |  | Cargill<br>Degen Oil & Chemical Co.<br>Georgia-Pacific Resins, Inc. |
| Soyscreen | Soybean Oil | | - Cosmetics and personal care products (hair care, sunscreen)<br>- Pharmaceutical (drug delivery) |  | iSoy Technologies<br>USDA ARS |
| Adhesives | Soybean Oil | | - Adhesive |  | Kansas State University<br>University of Delaware<br>W.F. Taylor Co., Inc. |
| Animal Feed | Glycerin | NA | - Animal feed |  | Iowa State University<br>Kansas State University<br>Oklahoma State University<br>Purdue University<br>University of Arkansas<br>University of Missouri<br>University of Wyoming<br>USDA ARS |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Soybean Hulls in Polyurethane Applications | Soybean Hull | - Polyurethane | - Rigid and flexible polyurethane foams |  | University of Missouri |
| Soybean Hulls in Food Applications | Soybean Hulls | NA | - Doughnuts |  | Korea Food Reasearch Institute<br>Korea University |
| Carboxylated Soy Proteins | Soy Proteins (isolate or flour) | NA | - Plastics |  | Dupont<br>University of Missouri |
| Hydrolyzed Soy Proteins | Soy Proteins (isolate or flour) | NA | - Plastics |  | Dupont<br>University of Missouri |
| Wood Adhesive | Soy Proteins (meal, flour, concentrate or isolate) | Alternatives to:<br>- Urea formaldehyde resins<br>- Phenol formaldehyde resins<br>- Phenol-resorcinol-formaldehyde<br>- Blood meal in adhesives | - Oriented strand board<br>- Plywood<br>- Fiberboard<br>- Particleboard<br>- Structural engineered wood products (e.g., finger joints) |  | Ashland Chemicals<br>Battelle Memorial Institute<br>Columbia Forest Products<br>Eka Chemicals<br>Heartland Resource Technologies<br>Hexion Specialty Chemicals<br>Oregon State University |
| Soy Protein Fiber | Soy Proteins (meal) | NA | - Textile |  | Soy silk is currently made in China and is available in the US under the SOYSILK® brand. |
| Hydrogel | Soy Proteins (isolate) | NA | - Personal care products<br>- Pharmaceuticals |  | University of Toronto<br>University of Wisconsin<br>US Agricultural Research Service |

| Biobased Products / Chemicals | Soybean Origin | Derivatives / Utilization | Applications / End Uses (Product and Derivatives) | Lifecycle Stage | Companies/Institutions Involved |
|---|---|---|---|---|---|
| Aquaculture | Soy Proteins (meal and concentrate) | NA | - Feed |  | Archer Daniels Midland Company<br>United Soybean Board |
| Charcoal Briquette | Soybean Stalk | NA | - Food (grill use) |  | USDA ARS |
| Fiberboard | Soybean Stalk | NA | - Furniture |  | USDA ARS |
| TerraMat (soy-based cork) | NA | NA | - Corkboards<br>- Floor mat |  | Purdue / Indiana Soybean Alliance |
| Melt-A-Way Cupcake Liners | NA | NA | - Cupcake liner that disappears after cooking |  | Purdue / Indiana Soybean Alliance |
| Omega-3 Fatty Acids | Glycerin | NA | - Food additive |  | Battelle Memorial Institute / Ohio Soybean Council<br>Virginia Tech |
| Bypass Protein Soybean Meal | Soy Proteins (flour) | NA | - Feed for dairy cows |  | AGP<br>Cargill<br>Grain States Soya<br>West Central Soy |

Not an exhaustive list

## B. Interview List

**Table 29: Interview List**

| Name | Area of expertise | Company/Institution | Position |
|---|---|---|---|
| Bernard Tao | Soybean utilization | Purdue University | Professor of Agricultural & Biological Engineering and Food Sciences |
| Susan Couch | Renewable diesel | UOP | Sales Representative |
| Gerhard Knothe | Biofuel | USDA ARS | Research Chemist |
| Kathleen Warner | Veg oil in food applications | USDA ARS | Research Food Technologist |
| Kenneth Doll | Soybean utilization | USDA ARS | Research Chemist |
| Shailesh N. Shah | Biofuel and glycerol utilization | USDA ARS | Research Chemist |
| Nicole R. Brown | Adhesives and Forest Products | Pennsylvania State University | Assistant Professor of Wood Chemistry |
| Michael Haas | Enzymatic transesterification | USDA ARS | Acting Research Leader |
| Don Lindsey | Soy Protein Concentrates | Solae | |
| Tony Shepherd | Soy Protein Concentrates | Hamlet Protein | Vice president of Sales |
| Kaichang Li | Wood Adhesives | Oregon State University | Associate Professor |
| Catalina Valencia | Soy Protein Concentrates | US Soybean Export Council | Marketing Manager |
| Charles Frihart | Wood Adhesives | US Forest Service | Research Chemist |
| Adam Bratis | General | NREL | Biochemical Program Manager |
| James McMillan | General | NREL | Principal Chemical Engineer |
| Randy Powell | General | Independent | Chemical Consultant |
| Michael Cotta | General | USDA ARS | Supervisory Microbiologist |
| Joseph Rich | General | USDA ARS | Research Leader |
| Cletus Kurtzman | General | USDA ARS | Supervisory Microbiologist |
| Julious Willett | General | USDA ARS | Supervisory Chemical Engineer |
| Mark Berhow | General | USDA ARS | Research Chemist |
| Sean Liu | General | USDA ARS | Research Leader |
| Brian H. Davison | General | Oak Ridge National Laboratory | Chief Scientist for Systems Biology and Biotechnology |