# Growing Pains:

# Exploring the Future of the US Biodiesel Industry

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## Dedication

This research is dedicated to the farmers, scientists, engineers, entrepreneurs, policymakers, and all others working to build a more robust and cleaner renewable energy future. Expanded use of low-carbon fuels such as biofuels pursued in conjunction with aggressive increases in energy efficiency, reduced demand through conservation, and reforms in transportation and land use policies can help to achieve timely reductions in both greenhouse gasses and our dependence on fossil fuels.

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And last but not least, I would like to thank my wife, Dr. Jeanmarie Bantz, for her patience and many insightful comments.

Preface

In the August of 2004, I became interested in biofuels after attending the Southern Energy and Environment Exposition in Asheville, NC and hearing Lyle Estill and his colleagues from Piedmont Biofuels singing the praises of homegrown fuels. I was hooked. A few months later I discovered the Fuels Diversification Program in the Integrated Science and Technology (ISAT) Department at James Madison University. I decided to enroll in the ISAT masters' degree program because I wanted to learn about biofuels and I recognized that this program would give me a broad, balanced approach when addressing the technical issues society faces with regards to energy, the environment, and sustainability. I had the opportunity to work with the program directors to write a grant proposal to Clean Cities for funding of a small-scale biodiesel processor for the university and performed a detailed process hazards analysis of various small-scale processor designs. Participation in this program afforded me to be opportunity to have discussions with entrepreneurs regarding the development of biofuels plants in the Harrisonburg, Virginia area. After hearing the concerns of these various business leaders, I became extremely interested in the broad drivers, limits, and impacts of the rapidly expanding biofuel industries. This has led to my current thesis research exploring the biodiesel industry using system dynamics (SD) modeling to help understand the impacts of current and future industry growth.

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Abstract

The biodiesel industry -- both in the US and globally -- is experiencing explosive growth. Demand for biodiesel in the US is driven by concerns about energy security, climate change, high oil prices, and economic development and supported by state and federal mandates. The US production capacity has grown by a factor of ten in the past two years, and over forty new plants are currently in or near construction phase. Continued strong growth of biodiesel production capacity depends on producer profitability which will be influenced by several factors such as biomass oil feedstock prices, product and co-product prices, production technologies, and government regulations and incentives. This research aims at evaluating how, when, and to what extent the growth of the biodiesel industry will be influenced by these various factors. A system dynamics (SD) model of the US biodiesel marketplace is developed to explore possible answers to these questions. The construction and use of this model provides a framework for understanding the structure and dynamics of this industry and how feedstock availability will impact growth. Simulating industry behavior over the next decade using the SD model with different scenarios, we can gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. A key finding from this study is that many of the scenario runs indicate that industry may experience a plateau of capacity growth over the next few years due to the impact of increasing feedstock prices on profitability. In addition, the industry will only achieve its own goal to reach five percent of diesel market penetration in the most optimum of feedstock and market conditions.

1. Introduction

1.1. Promise for a new energy future

Biofuels have the potential to yield a range of important societal benefits: reducing emissions of greenhouse gases, increasing energy security, decreasing air and water pollution, conserving resources for future generations, saving money for consumers, and promoting economic development. But, there are increasing concerns about the limits to growth and the unintended economic and environmental consequences of expanding biofuel production. Whereas ethanol and biodiesel made from corn and soybean oil feedstocks have been important in building a strong foundation for the industry; these biofuels feedstocks are currently used for many other purposes such as livestock feed, human food products, and a hundreds of other chemicals and consumer products. Based on land availability and other competing demands, corn and soy based biofuels can ultimately only displace a small percentage of the petroleum-based transportation fuels. The increasing demand from biofuel production will present challenges and opportunities for feedstock markets in the coming years.

Recently, many researchers have attempted to understand the long term growth potential and impacts of the biofuel industries (Perlack et al., 2005; English et al., 2006). For the biodiesel industry, the picture is not at all clear. The Department of Energy Information Administration (USDOE-EIA, 2007) forecasts that biodiesel production will only reach 400 million gallons per year by 2030. This forecast contrasts sharply with the current industry capacity, growth rate, and goals. The current industry capacity in operation is estimated to be over 700 million gallons per year (Biodiesel Magazine,

2007). The National Biodiesel Board recently set industry goals at 5% of the diesel market by 2015 or approximately 2500 million gallons per year of biodiesel (Nilles, 2007). Biodiesel Magazine estimates that if all the capacity in the pipeline becomes a reality, three billion gallons of biodiesel production capacity from all feedstocks may be in place in the US by the end of 2008 (Bryan, 2007). This would require three quarters of all fats and oils produced in the country annually.

With all these lofty numbers and conflicting forecasts, one is left to wonder what the future will hold for biodiesel: boom, bust, or somewhere in between? Have previous analyses adequately focused on the short term growing pains that the industry may incur in the next decade? Using SD modeling tools and techniques, this thesis will explore the nascent biodiesel industry in the US and attempt to evaluate the impact of some of the pressing near-term feedstock supply issues on the growth of this industry.

### 1.2. Costs of our addiction to oil

As President Bush stated in his 2006 State of the Union address, we are addicted to oil. Besides providing 97% of the energy to fuel transportation needs in the US (Davis & Diegel, 2006), petroleum also provides us with everyday products such as plastics, lubricants, man-made fibers, asphalt, and heating oil. As seen in Figure 1, the US consumes one quarter of all the oil consumed every day despite having less than 2% of the world's reserves and slightly less than 5% of the world's population. The US imports 60% of our oil (USDOE-EIA, 2007). The costs of our addiction are staggering: our nation spends approximately a half of a million dollars every minute to pay for imported oil.[1]

[1] Calculations based on $60 per bbl oil price and 2005 EIA oil import data.

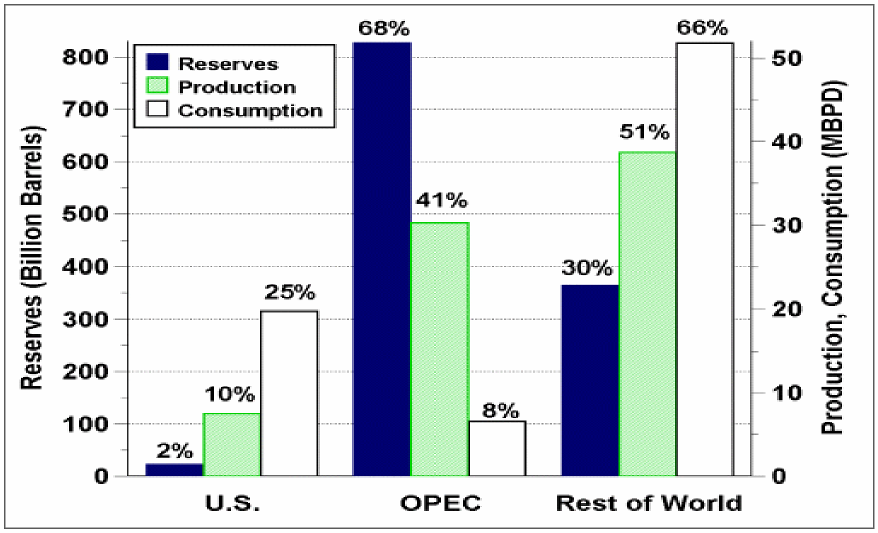


**Figure 1: World oil reserves, production, and consumption 2003**

Source: USDOE Office of Energy Efficiency Renewable Energy [2]

In addition to reducing our dependence on oil, diversifying our energy supply – by including renewable sources of fuel and electricity -- could create tremendous economic opportunities for Americans. And finally, the International Panel on Climate Change, the US National Academy of Sciences, and the scientific academies of ten leading nations have all stated that human activity, especially the burning of petroleum products and other non-renewable fossil fuels, are responsible for the accumulation of heat-trapping gases in the atmosphere, which impacts global climate patterns (IPCC, 2007). Stopping and reversing global climate change may become one of the greatest challenges of our era, and, therefore, we need to measure all energy-related policies by their ability to deliver real and measurable reductions in greenhouse gas emissions. To address the vulnerabilities that result from our oil addiction, we must substantially reduce our demand through efficiency, conservation, and reforms in transportation and land use

[2] Reserves: EIA International Energy Annual 2002, Table 8.1./Production: EIA International Petroleum Monthly, July 2004, Tables 4.1a– 4.1c and 4.3/Consumption: EIA International Petroleum Monthly, July 2004, Table 4.6/ OPEC consumption (2002 data): EIA International Energy Annual 2002, Table 1.2 Data posted at http://www1.eere.energy.gov/vehiclesandfuels/facts/2004/fcvt_fotw336.html.

policies (smart growth), and develop a diverse energy portfolio that emphasizes renewable energy sources such as wind, solar, and biofuels.

1.3. Biofuels- Part of the solution, but no silver bullet

Increasing the use of biofuels -- renewable fuels made from biomass such as ethanol and biodiesel -- can yield a range of important societal benefits, but biofuels alone are not sufficient to remedy the threats that fossil fuels pose to our nation's security, economic health, and environment. Solutions to create a secure and clean energy future must be economically feasible and sustainable, and they must simultaneously address both the supply and the demand sides of the energy equation. Federal and state policy initiatives, consumer demand, high fuel prices and future supply uncertainty, have triggered rapid expansion in the biofuels industries. As seen in Table 1, biofuel production has grown rapidly in response to increasing demand for ethanol and biodiesel, but still only accounts approximately 3% of total US motor vehicle fuel needs. It is estimated that 20% of the 2006/07 US corn crop will be converted to ethanol to supply about 3% gasoline demand (Collins, 2006) and 8% of 2006/07 US soybeans could be converted to biodiesel to supply less than 1% of diesel demand (Conway, 2007).

| | Gasoline (million gals) | Ethanol (million gals) | Pct of gasoline market | Diesel (million gals) | Biodiesel (million gals) | Pct of diesel market |
|---|---|---|---|---|---|---|
| 2000 | 128,662 | 1630 | 0.89% | 37,238 | 0 | 0.00% |
| 2001 | 129,312 | 1770 | 0.96% | 38,155 | 9 | 0.02% |
| 2002 | 132,782 | 2130 | 1.12% | 38,881 | 11 | 0.03% |
| 2003 | 134,089 | 2800 | 1.46% | 40,856 | 18 | 0.04% |
| 2004 | 137,022 | 3400 | 1.74% | 42,773 | 28 | 0.07% |
| 2005 | 136,949 | 3904 | 2.00% | 43,180 | 91 | 0.21% |
| 2006 | | 5450 | | | 225 | |

**Table 1: US motor fuels consumption 2000-2006**

Source: 2000-2005: USDOE-EIA Annual Energy Outlook 2007,
2006: National Biodiesel Board, Renewable Fuels Assoc.

1.4. Limits to growth

In the US, ethanol is predominantly made by fermenting the sugars derived from the starch in the corn kernel, and biodiesel is made by chemically reacting triglycerides (found in plant oils and animals fat feedstocks) with an alcohol and catalyst.[3] Biodiesel feedstocks can come from oilcrops (e.g. soybean, rapeseed, and palm oils), and also from used oils, fats, and greases from rendering facilities and other food processing facilities. The use of corn and soy feedstocks has helped build a strong base for the biofuels industry and has helped to establish a foothold in a transportation fuel marketplace. However, the current feedstocks have many other uses besides fuel production: mainly feed and food for livestock and human consumption, but also products like soy-based ink[4] and plastic from corn.

Ultimately, the limiting factor to growth for today's biofuels will be the availability of feedstocks. For example, if all corn produced in the US in 2005 was converted to ethanol -- with nothing left for food or animal feed -- this would displace less than 15% of the gasoline demand[5]. Biodiesel production from oils and fats may be even more limited. Currently, if we used all the domestically available oil crops, waste fats, and oils to make biodiesel -- with nothing left for margarine, cooking oil, animal feed supplement, or other oil uses -- this would displace less than 10% of the current diesel demand.[6] Moreover, all of the vegetable oil in the world would only make enough biodiesel to supply just over half of the US diesel consumption (Baize, 2006b). Many, like John Sheehan at the National Renewable Energy Laboratory (NREL), agree that corn

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[3] See Appendix B for more details regarding biodiesel chemistry and process.
[4] See Appendix D for a complete listing of edible and industrial soy uses.
[5] Calculations based on data from DOE-EIA (2006) and National Corn Growers Association.
[6] Calculations based on data from Tyson et al. (2004), Soystats, and National Renderers Association.

ethanol and soy biodiesel are not sufficient long-term solutions to breaking our oil addiction (Irwin, 2006).

To capture a greater percentage of the transportation fuel markets and to help realize significant reductions in oil usage and greenhouse gas emissions, we must think outside the kernel and the bean and pursue biofuels that utilize a diverse array of biomass feedstocks. To this end, public and private efforts (and funding) have been has focused on the research, development, demonstration, and deployment of next-generation biofuels. These next-generation biofuels can be produced using a variety of production methods and can be made from corn stalks, wheat straw, woodchips, tree trimmings, switchgrass, municipal wastes, and even algae.

### 1.5. The biodiesel dilemma

Biodiesel has become an attractive alternative for replacement of petroleum-diesel because it is domestically produced, less polluting,[7] and used at any blend percentage with no vehicle modification required. The most common way to produce biodiesel is shown in Figure 2. Reacting biomass oils with a simple alcohol (typically methanol) and a catalyst produces a renewable fuel called Fatty-Acid Methyl Ester (FAME) biodiesel and a co-product, glycerol (or glycerin). Although the renewable diesel market is currently dominated by FAME biodiesel, alternate production pathways are being pursued such as biomass gasification/Fischer-Tropsch diesel and refinery hydrogenation of biomass oils (both are shown in Figure 3).

[7] Emission reduction of greenhouse gases (GHG), Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Particulate Matter (PM) - based on GREET model from Argonne National Lab (Wang, 2007)

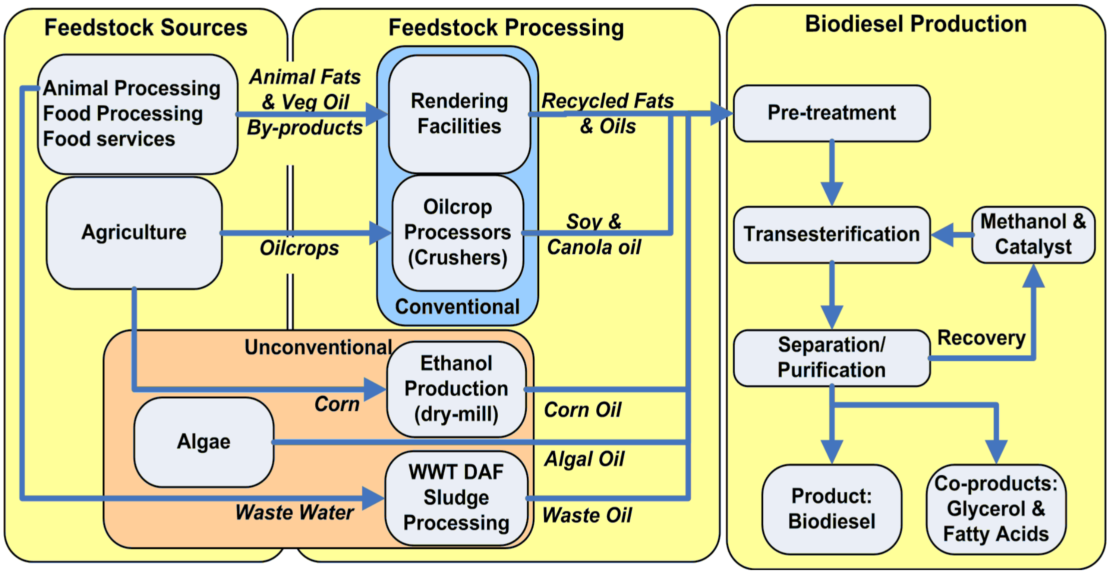

Figure 2: FAME biodiesel feedstocks and production diagram

The biomass gasification process, seen in Figure 3 below, is promising because it enables renewable fuel producers to use a diverse array of feedstocks with an estimated one billion tons of potential feedstock (Perlack et al., 2005). FAME biodiesel and hydrogenation currently have a limited supply of biomass fats and oils as feedstocks.

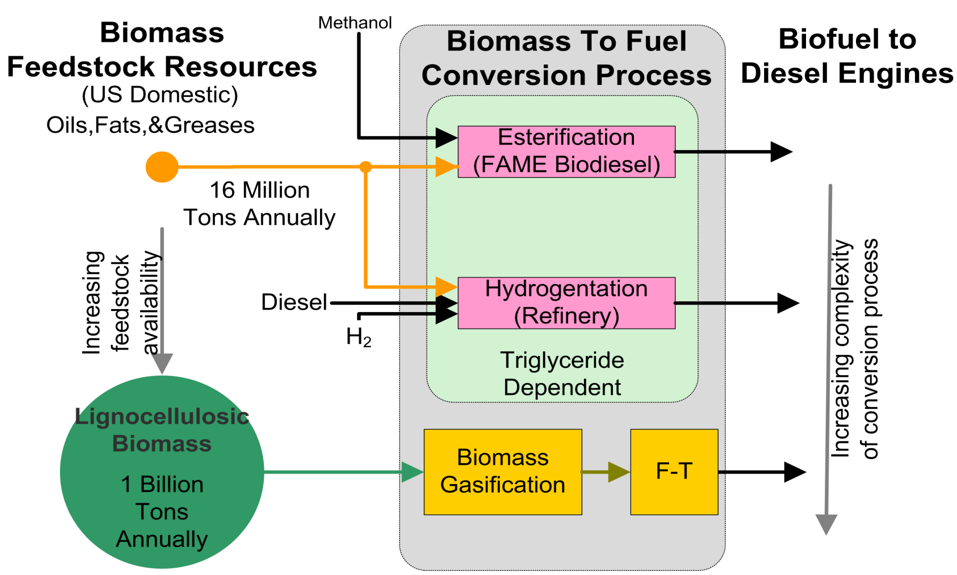

Figure 3: Renewable diesel production pathways

The alternative renewable diesel processes, shown in Figure 3, are currently at various phases of commercialization[8,9] and show great promise. But, due to increased process complexity and capital costs, investors have not yet begun to transition away from FAME biodiesel production to these newer technologies. As the cost of biomass oil feedstocks continues to rise and cut into the profit margins for FAME biodiesel producers, these technologies may soon begin to be more prominent in the biodiesel industry.

The US uses three times more gasoline than diesel (USDOE-EIA, 2006b). Hence, much of the effort to develop renewable transportation fuels has focused on gasoline alternatives such as ethanol. In 2005, the ethanol industry dwarfed biodiesel, producing over 40 times as much fuel. Compared to ethanol which became commercial in 1980's, the US biodiesel industry is in its infancy. Research and development took hold in the early 1990's and commercial production began to appear in the late 1990's. Expanding diesel demand, high oil prices, state and federal environmental mandates, and growing consumer awareness of environmental and energy security issues have fueled the growing demand for biodiesel in the US.

To meet the booming biodiesel demand, US FAME biodiesel production capacity is expanding rapidly. According to Biodiesel Magazine January 2007 online plant listing (see Appendix A), the biodiesel production capacity is approximately 700 million gallons per year and forty eight new biodiesel plants are under construction in the US. Over the next few years, as these new plants become operational, the total capacity will easily

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[8] Conoco-Phillips and Neste Oil are working to commercialize a renewable diesel process unit integrated with oil refineries in which they hydrogenate natural oil. This offers advantages to the large fuel producers to better integrate renewable fuels into the fuel pool (versus blending further downstream).

[9] Choren, a European company, and others are gasifying biomass and then processing this gas into a diesel fuel using the Fischer-Tropsch (FT) process.

exceed one billion gallons per year as illustrated in Figure 4. This is an extraordinary growth rate for an industry that had just 30 million gallons of production in 2004 (NBB, 2007).

The actual biodiesel produced annually is currently far below the design capacity of the US plants. In earlier periods, the low capacity utilization (Actual Production/Design Capacity) could be attributed to low demand and/or profitability issues. Currently, low capacity utilization is most likely due to operational (startup) problems associated with rapid growth in a young industry (Koplow, 2006). As shown in Figure 4, the biodiesel industry only achieved up to 42% capacity utilization in the 2001-2006 time-frame.

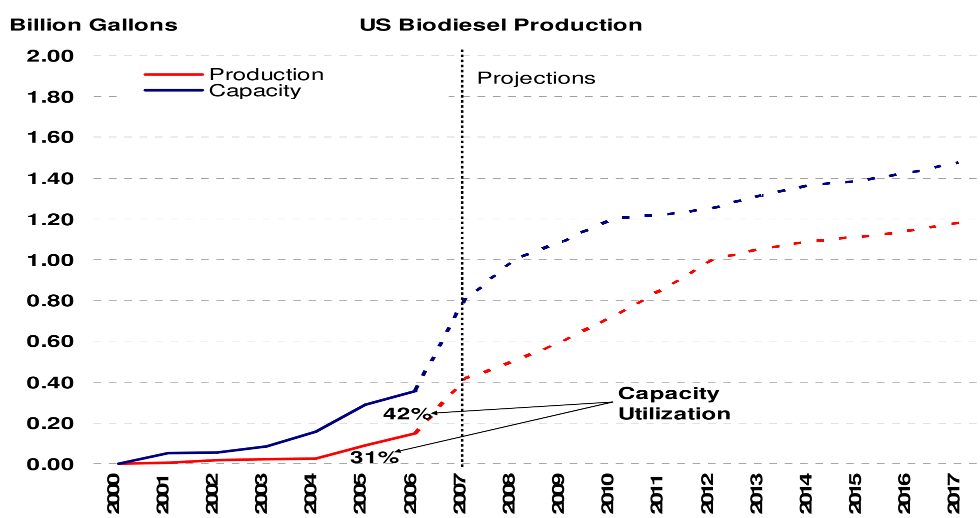



**Figure 4: Biodiesel US production and capacity (historical and projections)**

Sources: Biodiesel Magazine, NBB, Koplow (2006), and production projections used from Ugarte et al. (2006)

As processes improve and the industry builds operational experience, and as the demand and cost pressures on the biofuel producers increase, the productivity (as indicated by capacity utilization) should increase. However, as the industry grows, biomass oil feedstock availability will become a pressing issue. In 2004, US biodiesel

demand consumed less than 1% of the total biomass fats and oils produced in the US (Figure 5). Over the next decade, as new biodiesel plants come online, the biodiesel production crosses one billion gallons per year, the demand could approach one quarter of the total fats and oils the market.

So, the biodiesel dilemma is: production cost are relatively high because the feedstocks compete in high-valued food markets, but the selling price of biodiesel is relatively low because it competes in the fuel market with petroleum diesel which historically has a lower value than animal fats and oil (Duffield, 2006). Uncertainty in the future of biomass oil feedstocks has industry participants worried that new biodiesel production facilities may not have an affordable feedstock supply to make their operations profitable. To be sure, many have recognized this problem and are shifting new plants to multi-feedstock processing capability that enables FAME biodiesel producers to process cheaper, lower quality feedstocks.

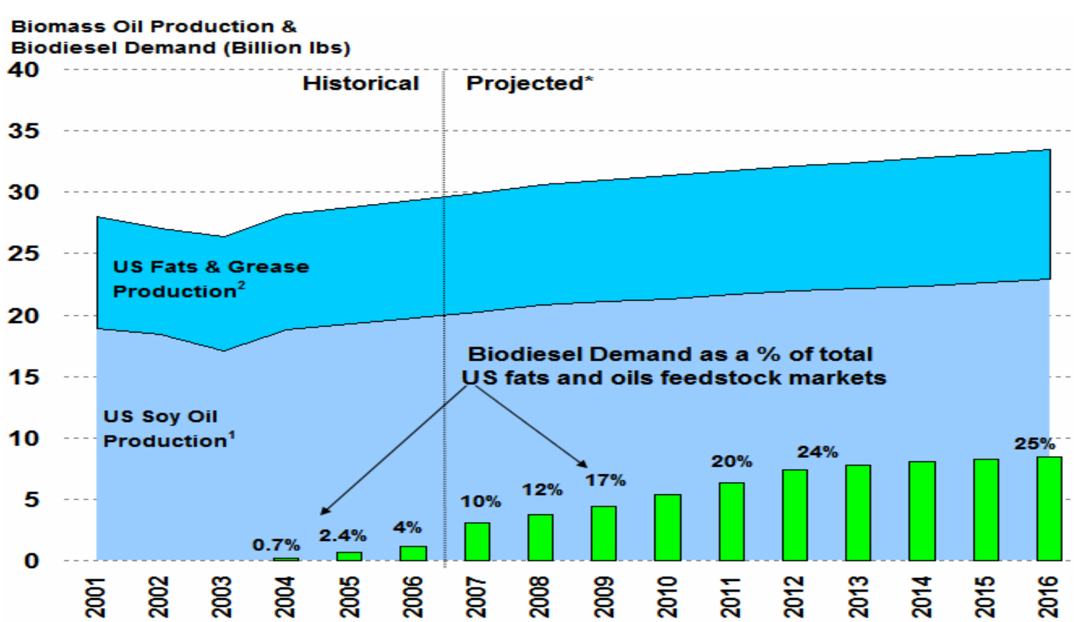



**Figure 5: US biomass oil production (soy oil and fats & greases)**

Sources: Historical data from Soystats (1) and National Renderers Assoc (2)

However, those feedstock supplies are also used in other markets and not expected to grow significantly over the next decade. The potential for a feedstock shortage to impact the growth of the biodiesel market is generally recognized, but it has not seemed to dampen the exuberance for building new FAME production facilities.

1.6. Research objectives, organization, and methodology

**Section 1** articulated the problem of feedstock limitations on the expansion of FAME biodiesel industry. The working hypothesis for this thesis is that feedstock limitations will continue to put pressure on producer profitability, and this will adversely impact the industry growth over the next decade. The main objectives for this research are:

- To investigate the market dynamics of the FAME biodiesel industry
- To build a system dynamics research model to help investigate how growth in this market (as represented by the total production capacity of US biodiesel suppliers) will be impacted by feedstock availability over the next decade

System Dynamics (SD) modeling (e.g. see Forrester, 1961; Meadows, 1970; Sterman, 2000) was preferred over other modeling tools because of the inherent heuristic nature of the SD model building process: illustrating the structure, causal relationships, and feedback loops. The research model constructed for this thesis will be referred to as the Biodiesel Industry Growth Simulator (BIGS).

In **Section 2**, I review the research and methods that have been used to analyze the potential for and the impacts of growth in the biofuel and bioenergy industries. Then,

I discuss how my research draws upon these other areas of research, then uses system dynamic modeling to take a unique look at this problem.

In **Section 3,** I define the model boundaries and structure and provide the background for understanding the growth dynamics of the biodiesel industry over the next decade. I discuss the biodiesel supply chain and build up the model sector-by-sector. Then I assemble the model sectors and discuss the important factors and interactions that could impact growth in the next decade. Finally, I conclude this section with a discussion of methods for testing the model structure and assumptions.

In **Section 4,** I outline how the model can be used to answer the research questions by postulating various scenarios and then simulating industry behavior over the next decade using the SD model. This will help to gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. I explore conditions under which the simulated biodiesel market can be expected to experience healthy growth, and the conditions under which this market might experience decline. The results will help identify conditions under which biodiesel production capacity can be expected to grow smoothly, and those conditions under which it could encounter "boom and bust" cycles.

In **Section 5**, I summarize the findings of this study and makes recommendations regard to policy, further research, and technology and market development.

## 2. Literature Review – Biodiesel Market Dynamics

The basis of this research draws upon four research areas: a) bioenergy assessment modeling; b) regional feasibility studies; c) SD modeling of industrial capacity and production; and d) SD modeling of the bioenergy markets. The rapid expansion of the bioenergy industries has prompted pressing questions such as: How much petroleum can biofuels ultimately displace? How fast can this occur? What will be the impacts of this rapid expansion?

To answer these and other important questions, many researchers from government agencies, academia, non-governmental organizations (NGOs), private consulting firms, and corporations have published assessments and projections for the future potential for biomass to provide transportation fuels, energy, products and power. Many of these assessments such as the often cited joint USDA-DOE Billion Ton Study[10] focus on a "point B" in the distant future -- often decades away – and tend to spend less time examining the dynamics of how we get from point A to point B. To help better understand the near-term transitional dynamics, US DOE Office of Biomass Programs has tasked a team of modelers to build the Biomass Transition Model based on System Dynamics (USDOE-OBP, 2006). This work will be critical for understanding the transition to second generation cellulosic biofuel technologies to displace gasoline, however, this effort does not focus on the specific near-term growth issues that the biodiesel industry is facing.

[10] The USDA-DOE study (Perlack et al., 2005) titled "Biomass as Feedstock for Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion-Ton Annual Supply" assesses the ability of US agricultural and forestry industry to provide sufficient biomass feedstock for transportation fuels, electrical power generation, and bioproducts. Although the report detailed several different land use and biomass production scenarios with a wide variation in results, the optimum scenario which yield 1.3 billion tons of biomass annually is often cited as the ultimate potential to support massive expansion of the bioenergy industries.

## 2.1. Assessing the potential of bioenergy

In recent years, many studies (e.g. see English et al., 2006; Perlack et al., 2005; IEA, 2004) have been performed at the state, national, and international levels to assess the potential for and implications of expanding biofuel production. Much analysis of the biofuels industry potential in the US tends to focus gasoline displacement (with ethanol) and minimizes discussion of renewable diesel. Two earlier assessments of the biodiesel industry were performed by researchers at the NREL (Tyson et al., 2004) and Promar International (Promar, 2005). The NREL study optimistically concluded[11] that biomass oils can displace up to 10 billion gallons of petroleum by 2030 if incentives or mandates are used to promote fuels and bio-based products from biomass oils. In late 2005, the consulting firm Promar International was commissioned by the United Soybean Board (USB) to analyze the impact of the growth of the industrial use of soybean oil (biodiesel) would have on the soybean oil markets through 2012. They used a global econometric model to assess market impacts and their growth projections are shown with the other projections in Figure 6. More recently a study published by Nexant Consultants in December 2006 concludes that FAME biodiesel will “probably be a transition technology, capable of substituting for only a small fraction of global diesel demand” (Clark, 2006). The report also concludes that integrated thermochemical platforms (as discussed in section 1.5) will soon take the lead in renewable diesel production.

The latest ten-year agricultural outlook from the USDA issued in February 2007 (USDA-OCE, 2007) forecast biodiesel production would only rise to 700 million gallons per year and then plateau at this level due to increased price of feedstocks (Figure 6).

[11] In this estimate, NREL assumed a)canola would be planted on 30 million acres of current wheat acreage (wheat exports), b) 30 million acres of CRP and other pasture land would be used to grow oil crops, and c) 30 million acres of soybean land is converted to higher yielding oil seeds.

The USDA assumed that the current government support (tax credits) for biodiesel would continue, but they also modeled an alternative scenario in which the government support was allowed to expire and the biodiesel industry was shown to collapse almost completely. This USDA forecast also provides insight into the impacts of the rapid increase in corn acreage due to ethanol expansion.

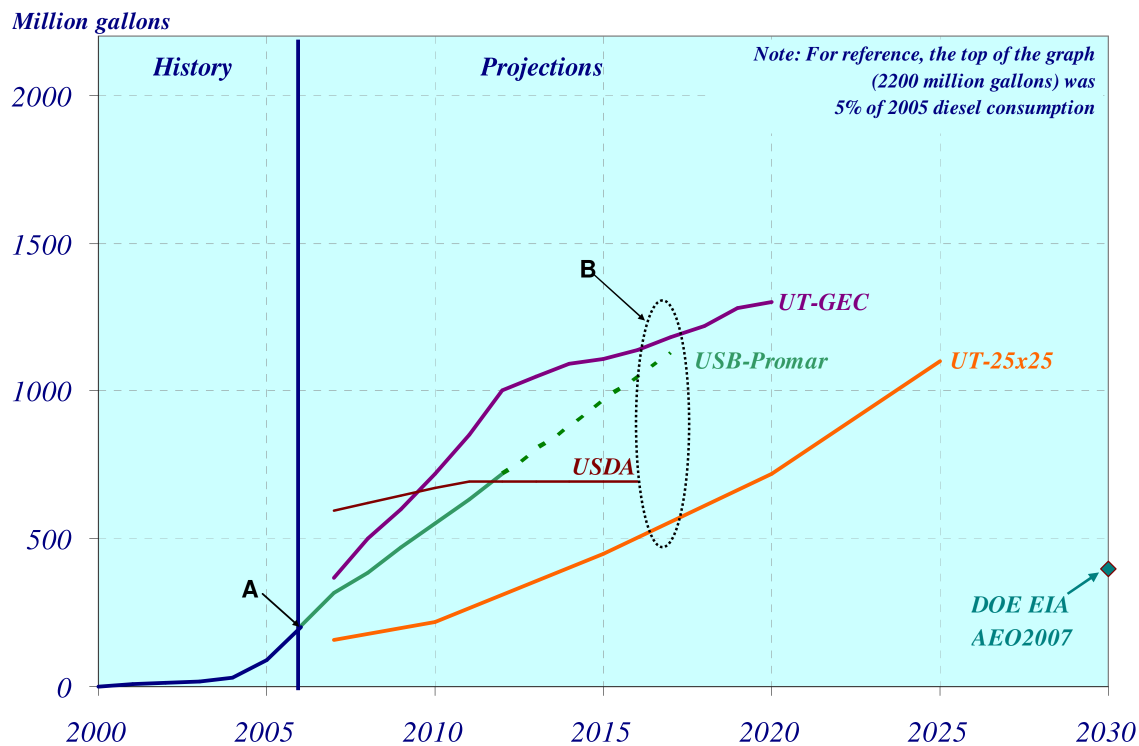



**Figure 6: Projections of biodiesel production compiled from various reports**

Sources: USDA-OCE (2007), Promar(2005), English et al. (2006), Ugarte et al. (2006), USDOE-EIA (2007)

As mentioned previously, the findings from the various biodiesel growth predictions do not give a clear or consistent picture of the industry future as seen in the trends shown in Figure 6. Included are data from the two reports produced by agricultural economists at the University of Tennessee (UT-GEC and UT-25x25). The UT-GEC projection was generated as a part of study commissioned by the Governor Ethanol Coalition that analyzed the agricultural impacts of a 60 billion gallon per year

Renewable Fuel Standard (RFS). The UT-25x25 projection was generated for a report commissioned by the 25 x ’25 Coalition to study the agricultural impacts of a generating 25% of US energy from renewable resources in the year 2025. Both of the University of Tennessee projections were developed for use with extensive national agriculture and energy models designed in coordination with government labs and agencies (English et al., 2006; Ugarte et al., 2006). Notice the AEO 2007 projection (data point shown on the bottom right for biodiesel production in 2030) contrasts dramatically with all the other projections (USDOE-EIA, 2007).

### 2.2. Biofuel feasibility studies

Feasibility studies are performed when companies are considering plant construction in a region and when state or regional authorities are promoting local economic development (e.g. see Carlson, 2006; Fortenberry, 2005; McMillen et al., 2005; Duff, 2004; Bowman, 2003; English et al., 2002; Shumaker et al., 2001). While these studies often provide a good overview of regional markets and economic impacts and are useful for private and public decision making, they do not adequately address the impacts on larger national markets and overall availability of feedstocks. Feasibility studies are valuable to this effort because they help us to build an understanding of the criteria that investors use to make plant investment and operational decisions. Understanding these micromotives will help us to better model the macrobehavior of the marketplace (Schelling, 1978).

### 2.3. System dynamics modeling of commodity markets

Since Jay Forrester published the landmark book Industrial Dynamics (1961), many researchers have used SD modeling to analyze industrial growth and the interactions in commodity markets. The model in this thesis is built upon basic feedback structure for industrial capacity growth and commodity production cycles proposed by Meadows' hogs model (1970) and Sterman's textbook, Business Dynamics (2000). Others researchers like Sandia National Laboratory's Stephen Conrad have also built upon Meadows' work by describing an initial crop model of corn production cycle and how it interacts with other market sectors (Conrad, 2004). Later, Conrad joined with colleagues to adapt this generic crop model structure for soybean production to help better understand the consequences of soy rust to US agriculture (Zagonel et al., 2005). These modeling efforts reinforce the research methodology used in this thesis and validate certain structural assumptions made in constructing the agricultural feedstock (soy oil) sector of the BIGS model.

### 2.4. System dynamics modeling of bioenergy markets

Key researchers at the national government research institutes have seen the potential of SD modeling tools to analyze the transitional dynamics of emerging bioenergy markets. As mentioned above, a team comprised of systems modelers and bioenergy experts from top government research laboratories are currently developing a SD model – named the Biomass Transition Model -- to better understand drivers and constraints on the large-scale deployment of biofuel production.[12] This extensive SD

[12] The Biomass Transition Model is sponsored by the US Department of Energy Office Biomass Programs (DOE-OBP). The initial model development, led by researchers at NREL, began in July 2005.

modeling effort focuses on the transition of the ethanol market from corn to cellulosic feedstock and should be a valuable resource for analysis of current and future policies. The current version of this model will not be completed until the end of fiscal year 2007, hence no official reports have yet been published formally documenting this work.[13] The model description and minutes from the intermediate model review workshops have been posted online for the general public (USDOE-OBP, 2006).

The development of the BIGS research model has drawn from all four research areas: bioenergy assessment modeling; regional feasibility studies; SD modeling of industrial capacity and production; and SD modeling of the bioenergy markets. This understanding has been synthesized with data and information from other biodiesel industry and feedstock market sources to create a working SD model to investigate the near-term growth in the biodiesel industry. While these simulated behaviors are not a "crystal ball" into the future, this unique SD perspective may provide insights to industry leaders and policy-makers to improve understanding of the biodiesel industry.

[13] Version 1.0 of the model was peer-reviewed at a group session of industry experts in Washington DC in October 2006. The results of this modeling workshop are posted online at http://www.30x30workshop.biomass.govtools.us/documents/061106ScenarioModelWorkshopReport.pdf

3. Modeling the Biodiesel Industry

3.1. Biodiesel market overview

Recall that the purpose of this thesis is to investigate how biodiesel industry growth will be impacted over the next decade through its interaction with the feedstock markets. The purpose of this chapter is to define the boundary and structure of the Biodiesel Industry Growth Simulation (BIGS) SD model and then to explore the dynamic behavior and the causal relationships between the main actors in the market. A high level overview of the biodiesel supply chain (see Figure 7) highlights the important market sectors and interactions.

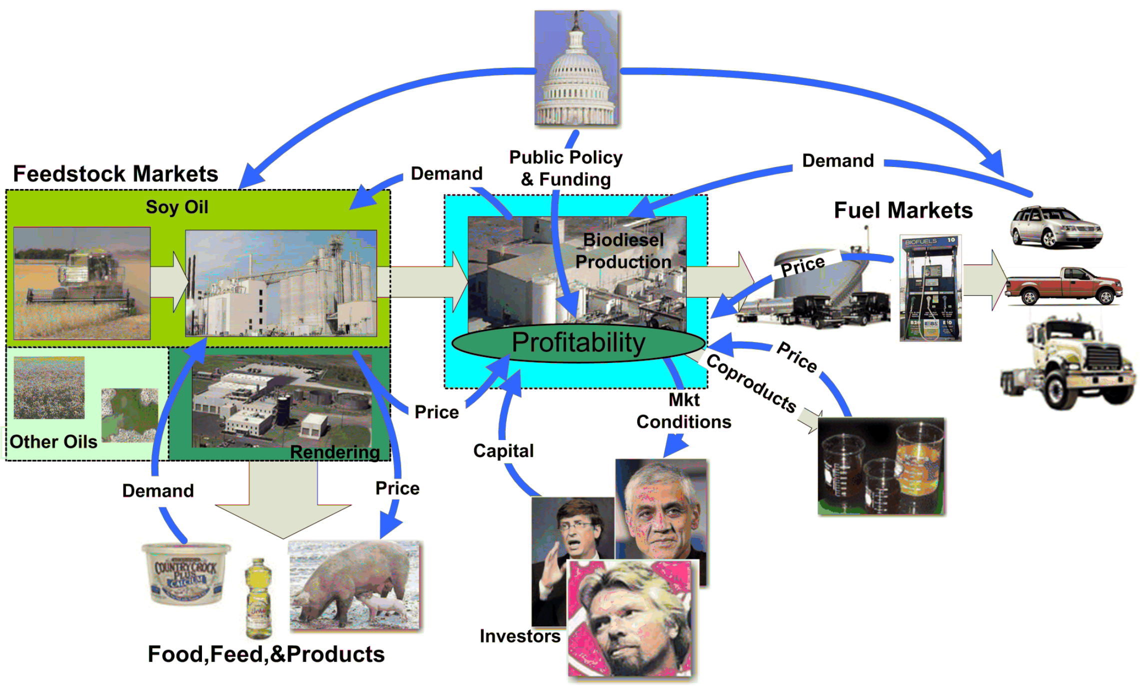


Figure 7: Biodiesel Market Overview

Beginning at the left, the feedstock markets provide oils and fats to the production facilities where it is converted into biodiesel fuel. Biodiesel fuel is then blended with petroleum diesel and sold as a transportation fuel (alternatively it also can be used to

displace heating oil or in industrial boilers). The growth of the biodiesel industry has been driven by state and federal public policies such as renewable fuel mandates and tax credits, high oil prices, and consumer awareness of energy security and environmental issues. The stock and flow diagram presented in Figure 8 shows the ***Exuberance*** reinforcing loop (R1) that has driven the industry growth in recent years and has been dominated by ***Perceived Future Profitability.*** The working hypothesis of this research is that the balancing feedback loops, ***Build*** and ***Produce*** (B1 and B2) will limit industry growth as ***Profitability*** is impacted by rising feedstock prices. In the model, ***Profitability*** is influenced endogenously by feedstock prices and exogenously by crude oil prices (reflected in the diesel price), co-products prices, and government interaction in the market (e.g., tax credits).

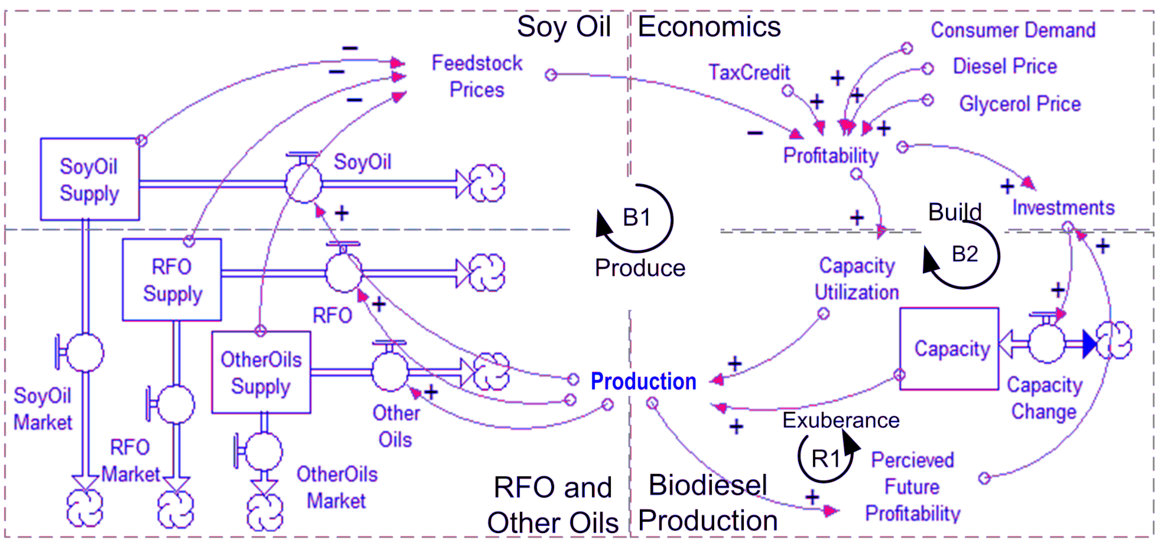



Figure 8: Biodiesel Model Main Feedback Loops

An increase in biodiesel ***Production*** will increase the demand for fats and oils. This will put upward pressure on ***Feedstock Prices*** as biodiesel demands an increasing market share. Increasing feedstock prices, in turn, will negatively impact ***Profitability.***

Decreasing ***Profitability*** will impact the decisions that investors and producers make with regards to capacity utilization and capital investments. The aggregated, high level SD stock-and-flow model diagram (Figure 8) is divided into sectors. In the following sections, these sectors are further examined, focusing on the important variables, causal relationships, and dynamic behavior.

### 3.2. Biodiesel production sector

Investors have been attracted to the biodiesel industry because they have seen an opportunity to make a profit and to enter a market where there is a high probability that demand will far exceed supply for the foreseeable future. Hence, industry players are investing in capacity that could produce ten times the demand seen in 2005 (Irwin, 2006). To help understand the dynamics of capacity growth, the biodiesel production capacity stock and flow diagram, based on the industrial capacity structure in Sterman (2000), is presented in Figure 9.

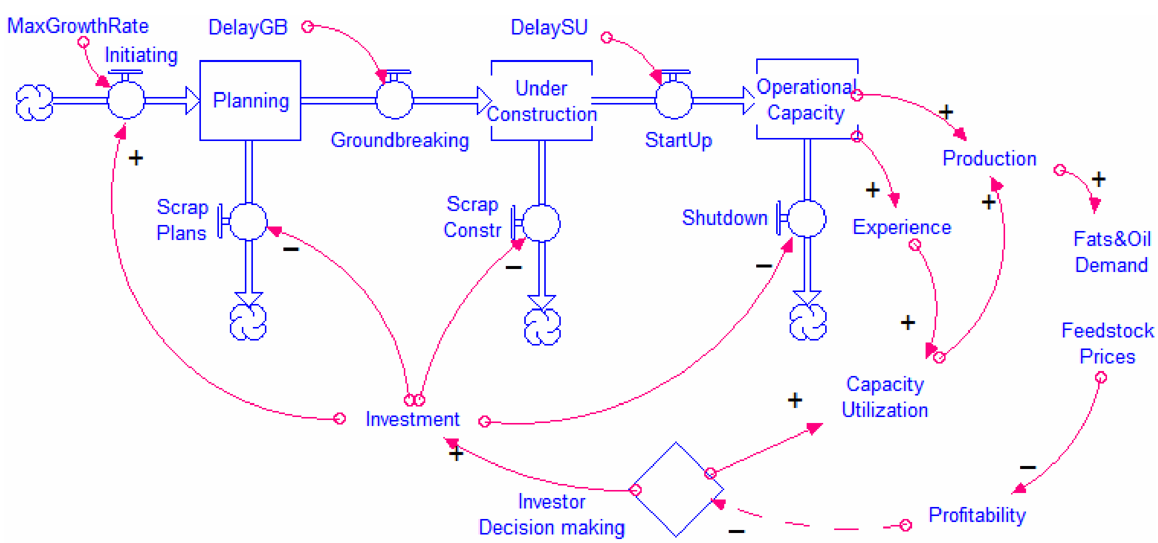



Figure 9: Stock and Flow Diagram – Biodiesel Production Sector

The three main stocks in this sector represent the aggregate industry production capacity at various stages in the "capacity pipeline" -- ***Planning***, ***UnderConstruction***,

and ***OperationalCapacity*** -- in millions of gallons of biodiesel per year. The investor decision-making process is modeled by using the current and anticipated profitability to determine the rate new capacity is added (***Initiating***). In an attempt to model real-world plant limitations such as construction/engineering bottlenecks, the ***Initiating*** rate is limited to a maximum growth rate. Investors also use this same profitability information when making decisions to shut down existing operating capacity or to scrap facilities that are under construction or in the planning phase. In the model, time delays were added to represent real-world market information and management decision-making delays. These delays in the system create an important dynamic during periods of rapid growth, as they allow the possibility that the investment in new biodiesel capacity can overshoot the actual long-term demand. This overcapacity could eventually lead to contraction (or possibly collapse) of the biodiesel production capacity. This is somewhat analogous to the boom and bust cycles in the electric power industry (discussed in Ford, 2002). In addition to the capacity stocks, the model variable ***CapacityUtilization*** (%) is adjusted endogenously by profitability and exogenously by accumulating operating experience. ***Production*** of biodiesel is modeled as the product of ***CapacityUtilization*** and ***OperationalCapacity.***

### 3.3. Biodiesel economics sector

In the real world, the profitability of individual biodiesel plants will be affected by many other factors such as plant size, location, capital installed cost, financing, and other operating costs (fixed and variable). But to simplify the modeling of industry profitability, I use the margin (as defined in Eq.1) as an aggregate indicator of overall industry profitability. For biodiesel production, the margin is:

**Margin = (Biofuel Price + Co-Product Price) – (Feedstock Price + Other variable costs) Eq. 1**

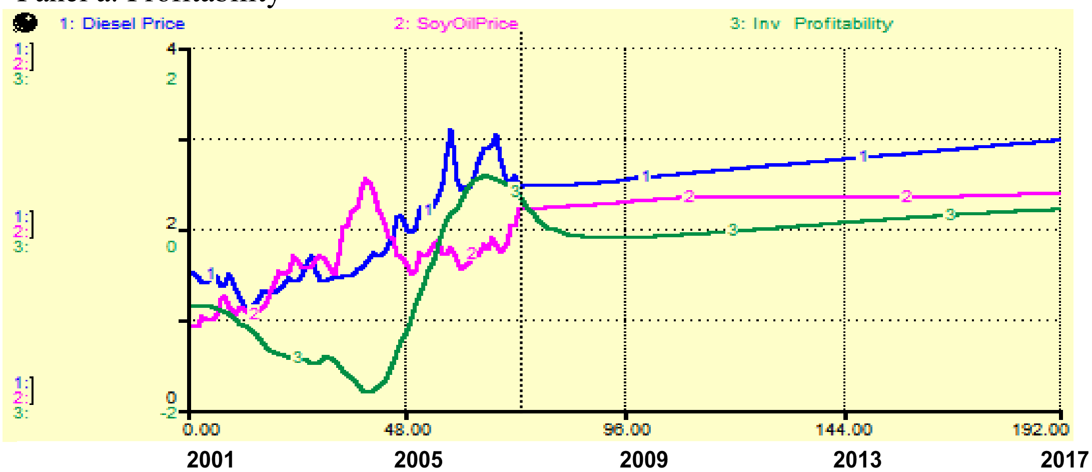
The feedstock makes up 70-80% of costs on average (vanGerpen et al., 2005). The other variable costs are much less significant and the model assumes them to stay relatively constant. The glycerol co-product assumptions are discussed in more detail in section 3.6.4. Simplified, the aggregate indicator of profitability is dominated by the difference between the biofuel price and the oil feedstock price.

Biodiesel is typically priced similar to that of a petroleum diesel blend component in order to be attractive in the blend component market. For that reason, in the model, I assume biodiesel will track diesel prices (plus an offset) for the calculation of the margin. Diesel price will be calculated from the AEO crude oil price projections (USDOE-EIA, 2007). The historical nationwide average price of biodiesel is difficult to track, but according to the sparse data compiled from quarterly price reports from the Alternative Fuel Data Center (USDOE-EERE, 2007) the price of biodiesel has been approximately $0.80 to $1.00 above the price of diesel over the past year and a half.

Since investors use current margin and anticipated future margin in the decision-making process, these two variables are combined in the composite variable ***InvProfitability***. To be profitable, this composite margin must exceed an aim or an acceptable minimum margin (***MarginMin)***. As the deviation from aim increases, the more attractive the market to potential investors and the greater the rate of growth in biodiesel production capacity. The investor decision making details are encapsulated the ***Investor Decision Block*** (Figure 9). The investor propensity to add or to decrease production capacity in is modeled through the use of a Proportional-Integral-Derivative (PID) controller, which acts on the difference between the Margin and the Minimum

Acceptable Margin (White et al., 2002). In addition, if the rate at which this difference is changing is positive, then higher margins are expected in the future, thereby further enhancing the attractiveness of the market. Under such conditions (high margins and higher anticipated margins), the rate at which investors enter the market can be very high indeed.

Panel a: Profitability




Panel b: Capacity stocks and Production

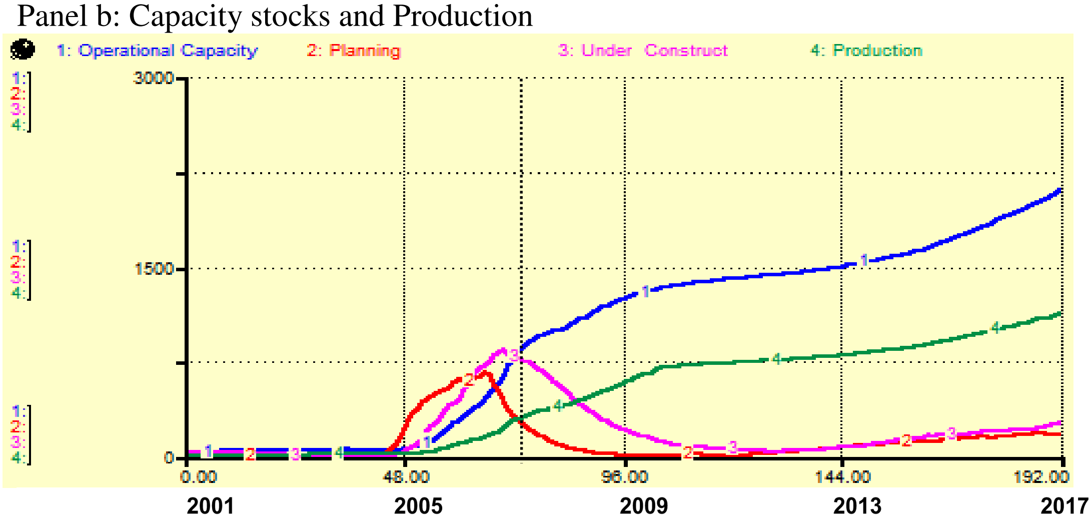



Figure 10: Biodiesel Industry Production and Capacity Dynamics

This mental model is supported by investor behavior in the market since 2004. The BIGS model behavior was calibrated using the industry data aggregate profitability and capacity data from 2001 through December 2006. Figure 10 shows both historic and simulated time trends that illustrate the response of the investor community to change in

biodiesel profitability. Panel (a) presents the historic and forecasted ***Diesel Price*** (1), ***SoyOilPrice*** (2), and the calculated aggregate ***InvProfitability*** (3)**.** Panel (b) presents the simulated impact that changes in ***InvProfitability***, panel (a), have on the industrial capacity stocks ***Planning***(2), ***UnderConstruction***(3), and ***OperationalCapacity***(1). Note that the rapid growth in capacity in the past two years fueled by the long, steep climb in ***InvProfitabiltity,*** panel (a). Also note, as it peaks in 2006 and then falls below zero in 2007/2008 timeframe the market attractiveness to investors diminishes. This is evident in the simulation as investors stop building new plants and/or scrap existing plans (see the simulated ***Planning***(2) and ***UnderConstruction***(3), curves in Figure 10, Panel (b)). As market conditions further deteriorate, new plant startups curtail and eventually existing plants are shuttered or production is scaled back. While it is too early to have confirmatory data to validate the dampened exuberance shown in the simulated trends in panel (b), these results are corroborated in anecdotal evidence in recent trade journal publications (Roberson, 2007).

3.4. Oil feedstock sectors

The choice of feedstock impacts operating costs (as discussed in the previous section) and the capital investment decisions that business leaders make when deciding to build a plant. Lower quality feedstocks require more processing equipment and, therefore, more investment. Having the option to process lower quality, cheaper feedstock may give the producer more flexibility, but the additional processing could increase the potential for yield or quality problems. Moreover, the use of lower quality feedstocks could reduce the amount of sale-able glycerol co-product produced (Kortba, 2006) -- decreasing a potential revenue stream for biodiesel producers. Capital

investment and operational decisions regarding feedstock usage are important to the profitability of each individual plant, but the BIGS model of aggregated industry decision-making focuses primarily on the impact that feedstock prices have on the margin. It is our working hypothesis that this balancing feedback presented as loops B1 and B2 in Figure 8 will limit the growth of the biodiesel industry.

Data from two studies (Eidman, 2006; Tyson et al., 2004) (shown in Table 2) indicate between 22 - 25 billion pounds of plant oils and between 9 - 13 billion pounds of animal fats, greases, and recycled cooking oils are produced annually in the US. These feedstocks could yield between 4.2 to 5.8 billion gallons per year of biodiesel which could displace approximately 11 - 15% of the current on-road diesel consumption (USDOE-EIA, 2006b). For reference, Figure 11 shows the prices for various fats and oils in mid-2006.

| | Eidman Estimate[14] 2000-2004 | | NREL Estimate[15] 2001 | |
|---|---|---|---|---|
| | Feedstock (billion lbs) | Biodiesel (million gals) | Feedstock (billion lbs) | Biodiesel (million gals) |
| Soybean Oil | 18.3 | 2378 | 18.9 | 2454 |
| Other Vegetable Oil | 4.5 | 588 | 6.0 | 780 |
| Rendered Fats& Oils | 9.3 | 1212 | 12.7 | 1645 |
| Other Sources | | | 6.9 | 898 |
| Total | 32.2 | 4178 | 44.5 | 5778 |

**Table 2: Estimates of US total domestic fats and oil production**

[14] Eidman (2006b) Table 8 - Pounds of oil are a five year average (2000-2004) from Bureau of the Census and Agricultural Marketing Service, USDA. The pounds of yellow grease and inedible tallow are a two-year averagefor 2002-2003 from US Department of Commerce, US Census Bureau. Current Industrial Report, M311K (03)-13, March 2005.

[15] Tyson et al. (2004) Table 11 -USDA ERS OCS and Outlook, October 2002. Bureau of Census, M311K-Fats and Oils: Production, Consumption and Stocks, 2002, July 2003. USDA ARS, Agricultural Statistics, 2003, Chapter III. Pearl, Gary. Biodiesel Production in the US, Australian Renderers Association 6th Int'l Symposium, July 25-27, 2001. Est from Wiltsee, G., "Urban Waste Grease Resource Assessment," NRELSR-570-26141. USDA ARS, Agricultural Statistics, Chapter XV. Render, Apr 2002, pg. 12.

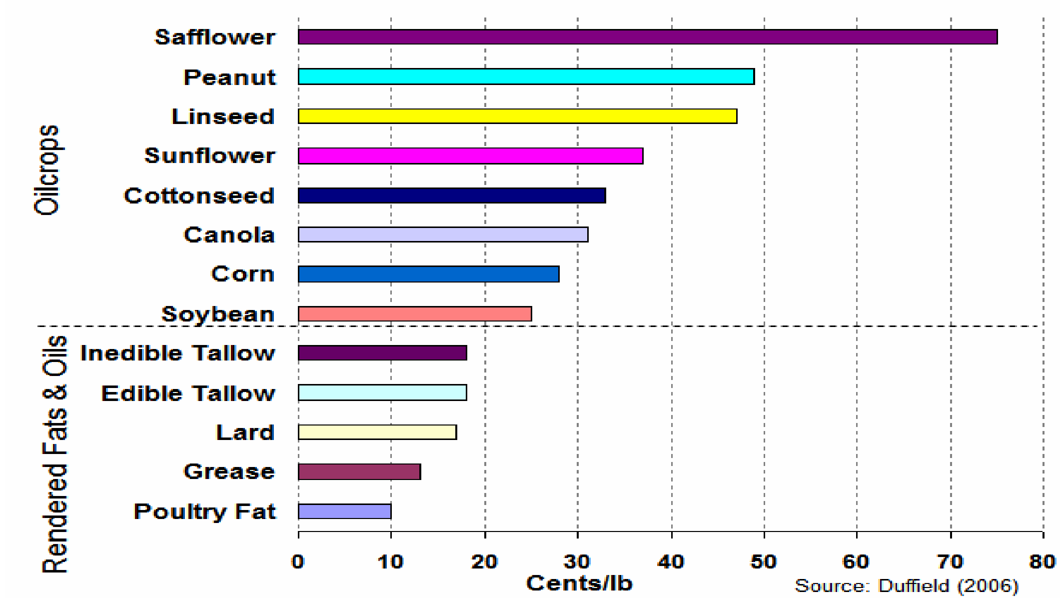



Figure 11: US Biodiesel feedstock prices (2006)

While it is theoretically possible that all the fats and oils in Table 2 could be converted to biodiesel, it is highly improbable because vegetable oils and animal fats are important ingredients for many other products such as baking and frying fats, animal feed, cooking and salad oils, margarine, and other edible products. In 2006, biodiesel demanded less than 5% of the entire US fats and oils market. How will these markets respond as demand from the biodiesel market rapidly increases and begins to demand a much greater percentage of the market for these feedstocks? Currently about 68% of biodiesel producers use soybean oil as a feedstock, but as seen in Table 3, biodiesel producers are shifting from soy oil to canola, other fats and oils, or multi-feedstock processing capabilities (Nilles, 2006). In the model, the percentage of biodiesel plants using soy only is ramped down over time, and this ramp rate is adjusted endogenously by the relationship between the soy and other oil prices.

| Fall 2006 | % of US Biodiesel Plant Capacity | |
|---|---|---|
| **Feedstock** | **Operational Capacity** | **Under Construction or Expansion** |
| Soy | 62.9 % | 51.5 % |
| Canola/Rapeseed | -- | 11.9 % |
| Multi-Feedstock | 20.2 % | 24.8 % |
| Animal Fats | 12.8 % | 10 % |
| Other | 4.1 % | 1.5 % |

**Table 3: US biodiesel capacity by feedstock**

Source: Biodiesel Magazine US & Canada Plant Map (Fall 2006)

### 3.4.1. Soybean oil market sector

Soybean oil has historically been available in large quantities at relatively low prices because it was considered a surplus product of the soybean meal crushing industry (USDOE-EIA, 2007). The stock and flow diagram modeling the planting, harvesting, crushing, and disposition of soybeans and soy oil are presented in Figure 12. Soybeans harvested in the US are exported, sold domestically as whole beans, or crushed to produce soy meal and soy oil. The amount of soybeans harvested each year in the US is dependent on many variables such as acres planted, yield, weather, and disease.

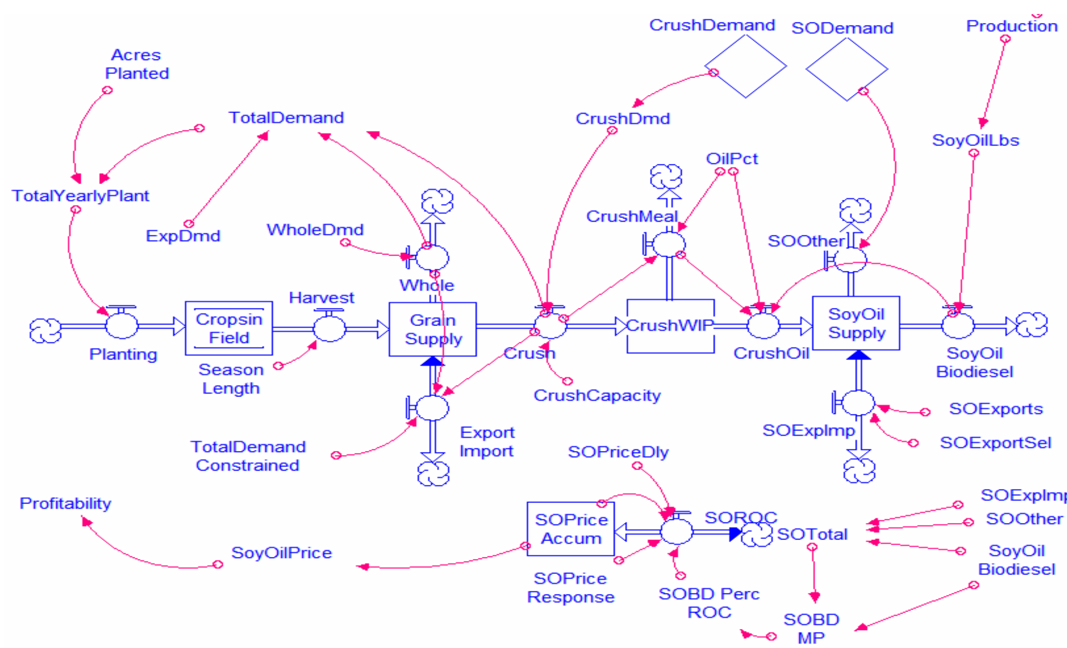



Figure 12: Stock and flow diagram – Soy oil production

Sectoral model testing results in Figure 13 how the behavior of the ***CropsinField*** and ***GrainSupply*** stocks in the soy oil production supply chain. The model structure shown in Figure 12 was verified using USDA data and was helpful in understanding the seasonal dynamics of the soybean and soy oil production supply chain. However, subsequent model testing confirmed that the seasonal harvest dynamics in Figure 13 occur over too short of a time span to impact the longer-term dynamics of interest in this research. Hence, a decision was made to simplify this structure by eliminating the planting and disposition of soy beans and focusing only on the crushing and soy oil disposition.

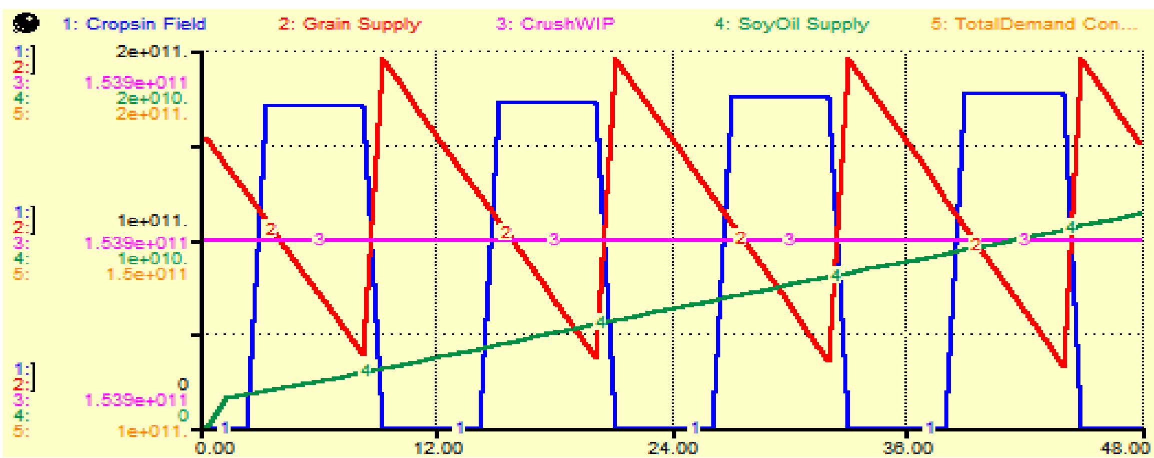


Figure 13: Soy production planting and harvesting dynamics

The simplified Soy Oil Sector stock and flow diagram finally used in BIGS model is presented in Figure 14. The biodiesel demand for soy oil (***SoyOilLbs)*** comes from the Biodiesel Production model sector, and the ***SoyOil Price*** completes the loop by providing feedback to the Biodiesel Production sector through its impact on ***Profitability***. The ***SoyOil Price*** is determined using the price setting stock and flow structure (discussed in Sterman, 2000; Whelan & Msefer, 1996) in which the price is adjusted by the ratio of

actual to perceived inventory coverage. The flow to biodiesel, ***SoyOilBiodiesel,*** is fed from the ***SoyOilSupply*** stock which also feeds the other users of soy oil (***SoyOilOthe***r and ***SoyOilExportImport***). Note that ***SoyOilExportImport*** flow is bi-directional which allows either export or import if desired.

In Figure 14, the ***Crush*** flow and the percentage of oil in the soybeans (***OilPct***) determine the amount of soy oil produced (***CrushOil*****).** Depending on the future of soy meal and soy oil demand relationship, increasing the oil component of soybeans -- which historically average 18–19 % by weight (Ash et al., 2006) -- could be a alternative solution to provide more biodiesel feedstocks from soy. In all the scenarios explored, ***OilPct*** is kept constant, but further research could explore this option. Other important exogenous variables for determining the amount of soybeans crushed are ***Acres***, ***Yield, Crush Capacity***, and ***SoyExports.***

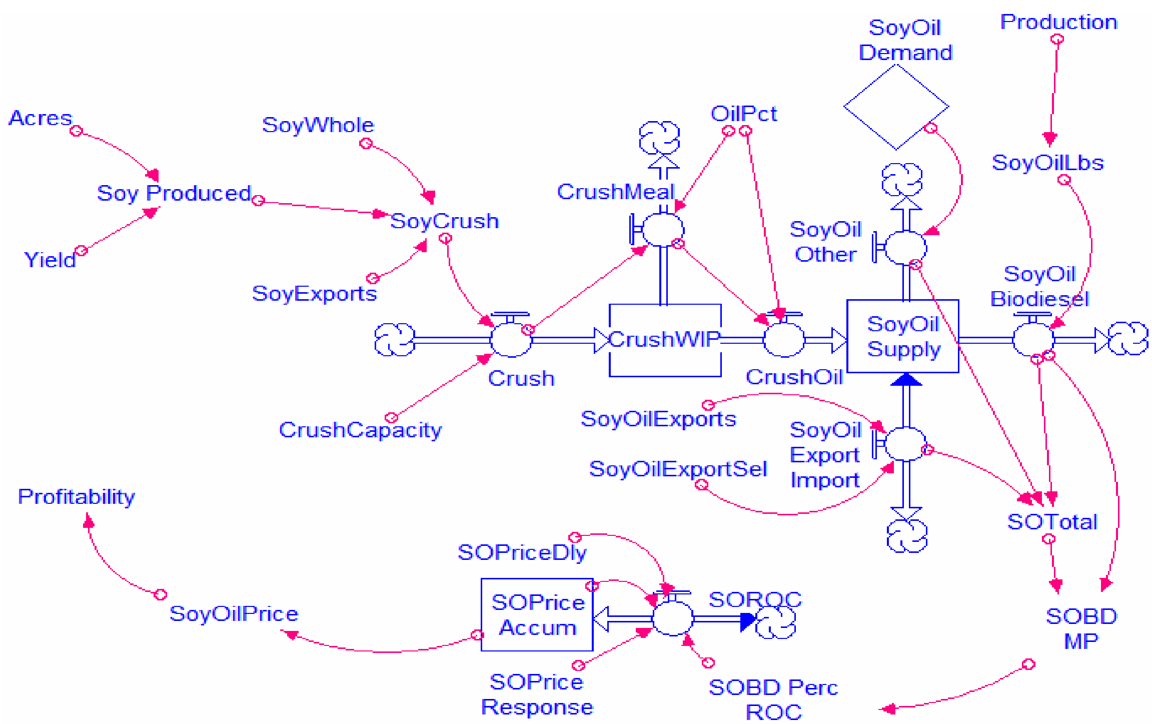



Figure 14: Stock and Flow Diagram – Simplified Soy Oil Sector

The percentage of the acreage for soybean planting will most likely be impacted by competition from other crops – corn in the short term and possibly energy crops such as switchgrass in the longer term -- as demand for ethanol continues to expand rapidly. In the model, the ***Acres*** variable will be an exogenous variable that can be set by the user to constrain the amount of soybean acreage in the US.

The average soybean yield, shown in Figure 15, is increasing at an accelerated rate due to improved cropping practices and technological advances. Increased yields allow farmers to harvest considerably more soybeans without significantly increasing acreage. These yield gains will be important to offset the downward trend in soybean acreage. US soybean growers set a new yield record in 2005 with 43.0 bushels per acre (USDA-OCE, 2007). In the model, it is assumed that yields continue to increase along a 25-year trend line (1980-2005) shown in Figure 15, but the user will be able to set yield trend through a graphical input block. Based on this trend, the average yield is projected to be approximately 46 bushels per acre by 2016.

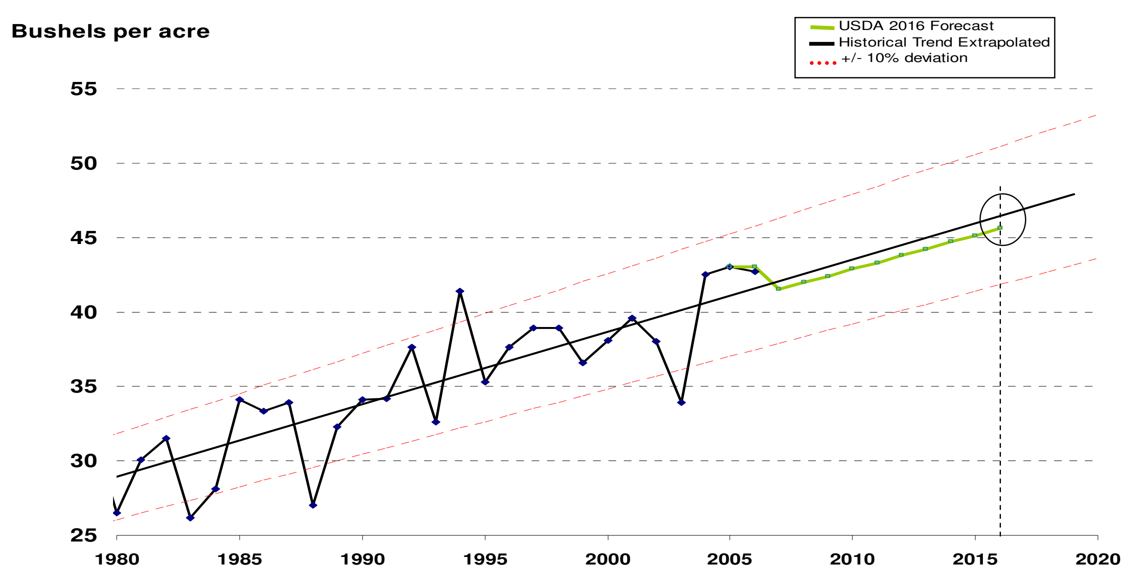



Figure 15: Soybean Yield US Average Historical and Trend
Source: USDA-OCE (2007), Soystats

To illustrate the impact of incremental yield growth, consider that an increase of just one bushel per acre from one year to the next results in an additional 68 million bushels of soybeans. After crushing, the soybean oil from an additional 68 million bushels of soy beans could be used to produce just over 100 million gallons of biodiesel. To better understand the magnitude of the flows in the soy sector, the historical (Soystats) and USDA forecast amounts (USDA-OCE, 2007) are presented in Figure 16.

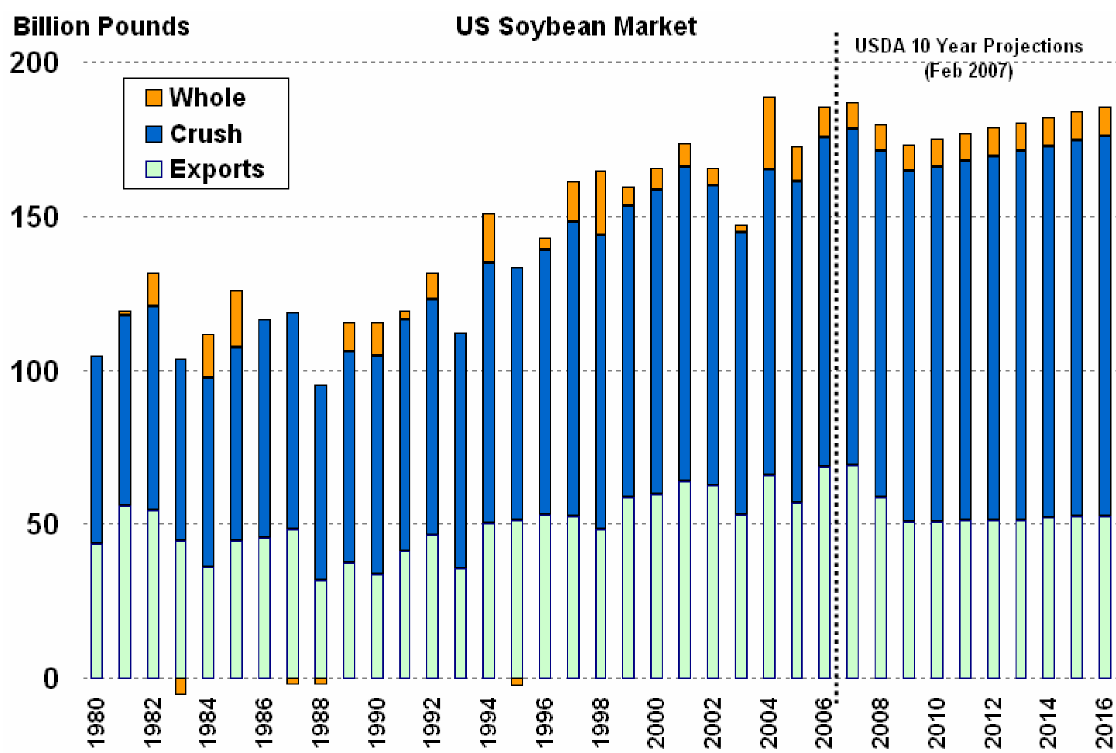



Figure 16: US Soybean Market Historical and Projections
Source: Soystats, USDA Agricultural Projections to 2016

In Figure 14, the ***SoyOilSupply*** stock feeds biodiesel, other (food, feed, and chemicals), and export markets. In the model, the ***SoyOilOther*** flow will be set to increase at historical growth rates and the ***SoyOilExportImport*** flow will be exogenously manipulated in the scenario testing.

### 3.4.2. Rendered fats and other oils market sector

The rendering industry produces fats and oils from byproducts of the food and animal processing industries. Products such as tallow, choice white grease (lard), poultry fat, and yellow grease are cheaper than virgin vegetable oil – selling for about half the price of soybean oil historically (Radich, 2001). Although they offer an economic advantage compared to soy oil, there is a limited supply of these oil feedstocks, and consumption is not limited to use as biodiesel feedstocks. Rendering industry products are important ingredients in animal feed, fatty acids, chemicals, and lubricants (Meeker, 2006), as seen in Figure 17. Domestically, sixty percent of rendered fats and oils go into animal feed and less than two percent is used for industrial uses such as biodiesel.

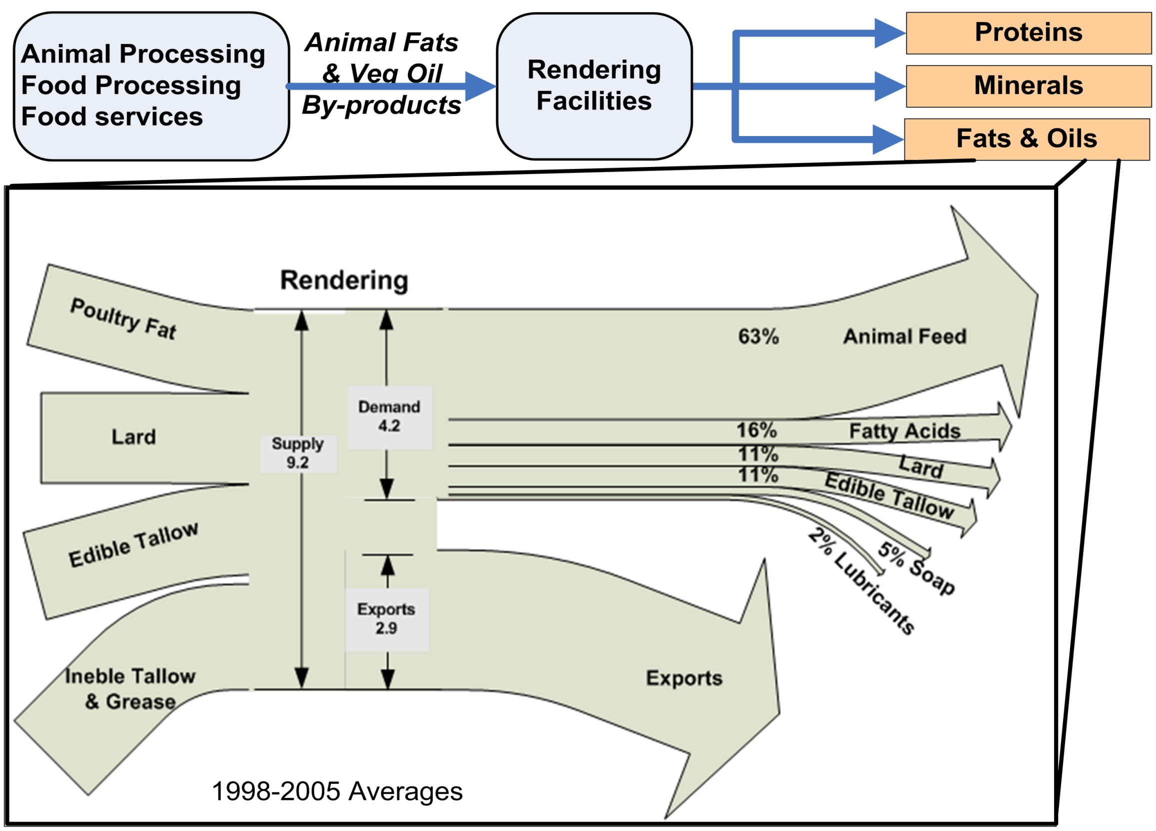



Figure 17: US Fats and Oils Overview
Source: Data compiled from the National Renderers Association

As seen in Figure 18, from 1998-2005, the domestic rendering industry produced nine billion pounds of inedible tallow and greases, edible tallow, lard, and poultry fat on average and has not demonstrated significant industry growth. The assumptions in the model are based on the industry continuing this minimal growth rate through the time period simulated.

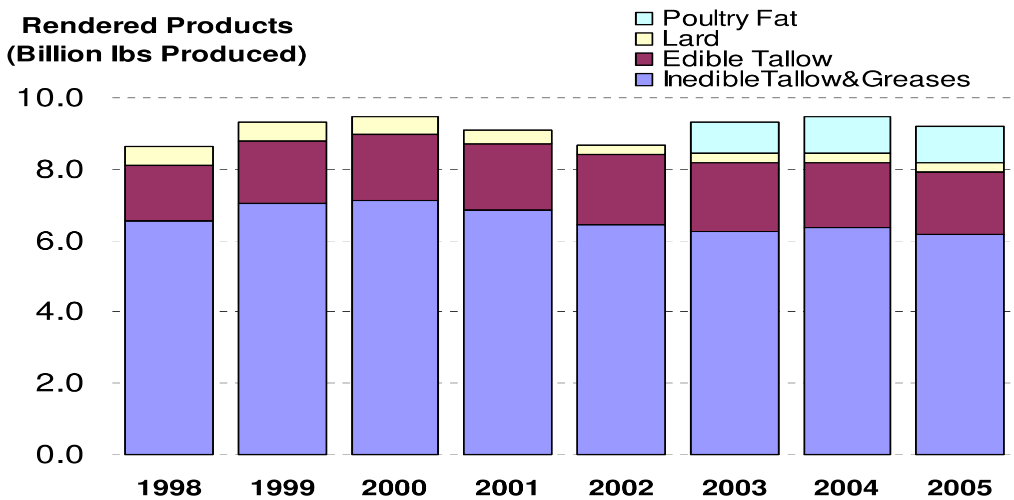



Figure 18: US Rendering Fats and Oils Production
Source: National Renderers Association

The stock and flow diagram modeling the rendered fats and other oils industry sector is presented in Figure 19. The biodiesel demand for rendered fats and other oils (***RFOLbs***) comes from the Biodiesel Production model sector. The ***RFOPrice*** completes the loop by providing feedback to the Biodiesel Production sector through it influence on ***Profitability.*** In the BIGS model, the model users will be able to set the industry growth rate, but in all scenarios I assume the industry growth rate will continue to grow at historical rates. In the BIGS model, the percentage of biodiesel plants using fats and oils (determined by the ***SoyUsage*** variable) is increased over time but is adjusted endogenously by the relationship between the ***SoyOilPrice*** and ***RFOPrice***.

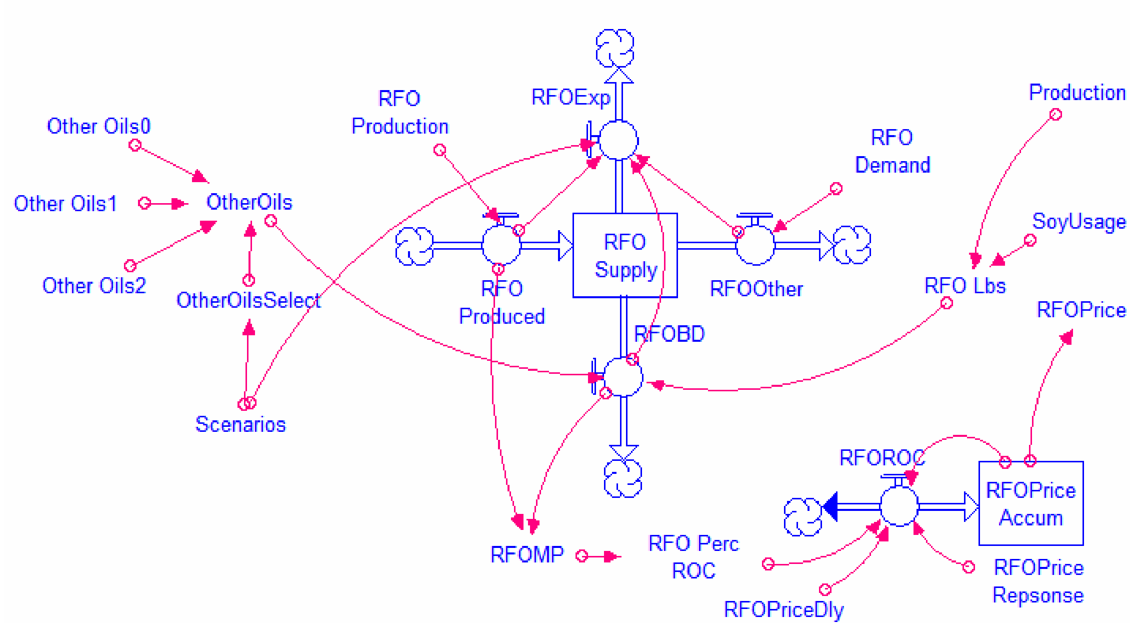



Figure 19: Stock and Flow Diagram – Rendered Fats and Other Oils

### 3.4.3. Other oil feedstocks

In addition to soybean oil and rendered fats and oils, there are other sources of natural oils that could be tapped to increase the supply of potential biodiesel feedstocks. Many in the industry, such as National Biodiesel Board president, Joe Jobe, cite “the availability of other oil sources” as one of the many factors that will support continued growth of this industry in the next decade (Bryan, 2007). In the sections below, I briefly review alternative triglyceride sources that could potentially provide additional FAME biodiesel feedstocks. Since there are many uncertainties around future availability, the total supply of these other alternate oil sources are aggregated in the ***OtherOils*** variable in the model (Figure 19). Alternate ***OtherOil*** scenarios can be selected using the ***OtherOilSelect*** variable, or the supply curves can be changed through the graphical input device to determine the overall impact on the system. As the amount of ***OtherOils***

increases, the price pressure will decrease on both ***SoyOilPrice*** and ***RFOPrice***. This will help to boost overall biodiesel industry profitability.

### 3.4.4. Other domestic oilcrops

Although soy is the dominate oil crop in the world (as seen in Figure 20) six other major oilseeds crops are produced around the world canola/rapeseed, cottonseed, peanut, sunflower seed, palm kernel, and copra (Pahl, 2005). Rapeseed is the favored biodiesel feedstock in Europe and Canola -- a genetic variation of rapeseed -- is gaining popularity in the US. Many US farmers are planting non-traditional oil crops such as Canola and camelina, but Canola currently only makes up one tenth of one percent of the oilseeds market in the US (Nilles, 2007). Ninety percent of this crop is grown in North Dakota. The recent construction of a ADM crushing facility and biodiesel plant in North Dakota is enticing farmers to grow more Canola, but it is estimated that demand at this one plant will not be satisfied entirely by domestic production.

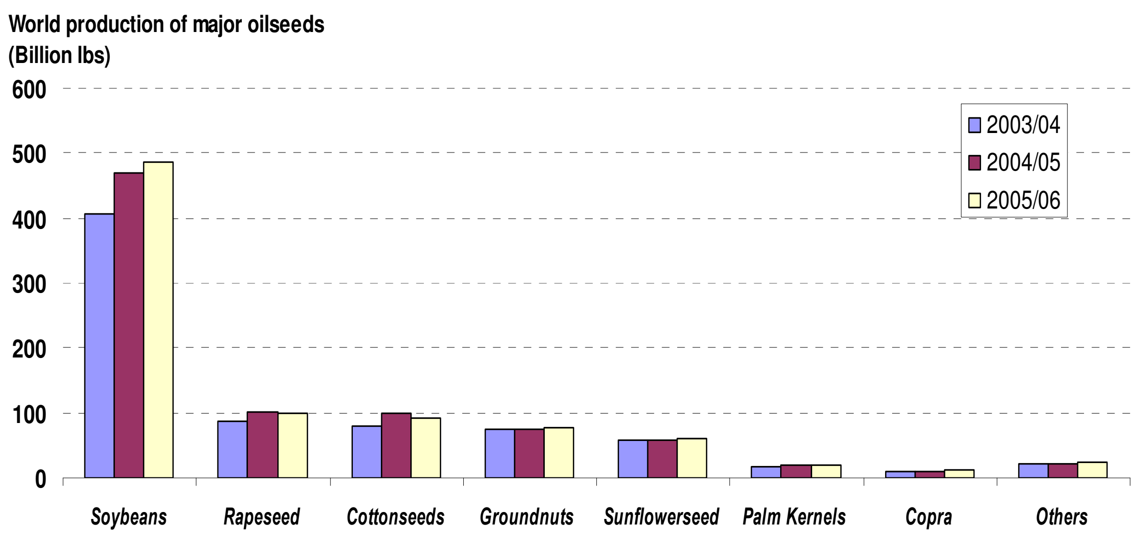



Figure 20: World Production of major oilseeds
Source: Food and Agriculture Organization (FAO) of the United Nations

Another hopeful domestic oil crop candidate is camelina. Farmers in the Midwest and plains states are considering camelina for a winter cover crop in place of winter wheat (Weber, 2007). The potential of these domestic oil crops will also be determined by acreage competition with the other major domestic crops.

#### 3.4.5. Imported oils

Palm Oil -- mainly imported from the Southeast Asian countries of Malaysia and Indonesia -- is rapidly becoming the biodiesel feedstock of choice throughout many regions of the world. Biodiesel production fed mainly by palm oil is beginning to take off throughout Asia – not only in Malaysia and Indonesia, but also India and China. In addition to feeding the Asian biodiesel demand, European and US producers are beginning to consider palm oil. Although it is attractive because of the price, concerns about deforestation and sustainable production methods have combined with cold weather quality issues to dampen some of the North American and European enthusiasm.

#### 3.4.6. Corn oil from ethanol production

At ethanol production facilities, corn oil can be extracted before processing or after fermentation and distillation (Bryan, M., 2006). One company, Greenshift, with a patent on this technology has proposed installing oil extraction equipment in dry mill ethanol production facilities at no charge to client ethanol producers in exchange for first rights of refusal for the oil extracted. Greenshift (2005) estimates that a 50 million gallon per year ethanol plant could extract enough corn oil support a 20 million gallons per year biodiesel plant. Hypothetically, if one quarter of the 60 to 80 ethanol plants being built

today were to install this capability, this could provide enough feedstock for 400 million gallons per year of biodiesel.

### 3.4.7. Waste fats and oils

About 10.5 billion animals are slaughtered and processed each year in the US (Meeker, 2006) and meat-processing facilities are required to use large volumes of water to rinse the meats as during processing. The waste water from this process contains about 5-20% fat and it is estimated that the concentrated Dissolved Air Flotation ("DAF") sludge from the poultry industry alone could provide 2.5 billion pounds per year of additional feedstock to the biodiesel industry (GreenShift, 2005). These 2.5 billion pounds of fat could be converted to 325 million gallons of biodiesel if it could be processed economically with good yields. Another potential source of feedstock is trap grease, which is collected, treated, and disposed of via land-filling, burning, composting, or anaerobic digesting (typically by waste water treatment facilities). According to researchers at NREL, approximately 13 lbs per person per year of trap grease is created in the US (Tyson et al., 2004). Theoretically, 3.8 billion pounds could be converted to 495 million gallons of biodiesel if it could be collected and processed economically with good yields. A few companies that are pursuing these waste feedstock options, but due to the difficulties involved in producing high quality biodiesel fuel from a low quality, highly variable, feedstock stream, the future for this feedstock option remains uncertain.

### 3.4.8. Algal oil

From 1978 through 1996, the Aquatic Species Program at NREL investigated algae with oil-content that could be grown specifically for the purpose of biofuels

production (Sheehan, 1998). In recent years, several companies such as GreenFuel Technologies (www.greenfuelonline.com), along with those in government and academia, have been trying to make large-scale bioenergy algae production a reality. Although the potential is promising -- estimates range up to 10,000 gallons of biodiesel per acre – nobody has scaled this technology to support a commercial size biodiesel facility. Due to the uncertainty in the future of this technology, it is not assumed that algal oil will contribute significantly to the amount of triglycerides available for biodiesel production in the next decade.

### 3.5. Diesel fuel market

Although diesel prices have recently been higher than gasoline prices, the demand for diesel fuel is growing at an annual rate of 2.5%, and vehicles in the US will consume approximately 65 billion gallons of diesel by 2030 (USDOE-EIA, 2007). Diesel fuel powers most of the medium and heavy duty on-road vehicles and most of the heavy duty off-road vehicles such as bulldozers and farm tractors. Light-duty diesel vehicles have been popular in Europe for a long time and they are making a comeback in the US. In addition to highway vehicles, diesel is also used in farm tractors, trains, boats, generators, and other heavy duty equipment. In the BIGS model, diesel fuel price is derived from the price of crude oil which is set exogenously. The model user will be able to select alternate crude oil forecasts – Low, High and User determined -- to determine the impacts on the biodiesel industry. The Low and Hi forecasts are based on the 2007 AEO crude oil price projections shown in Figure 21.

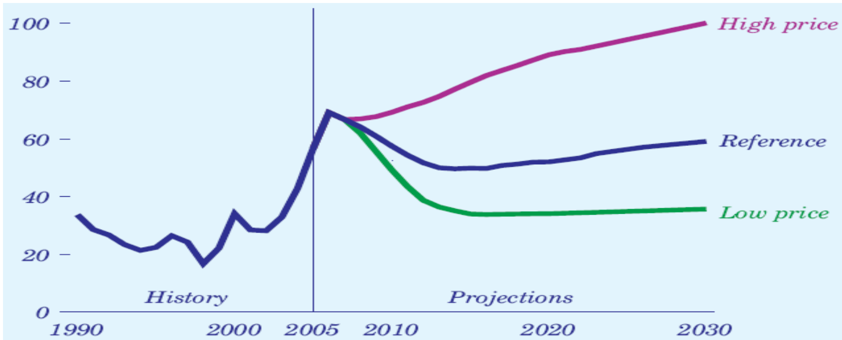



Figure 21: Crude oil prices in three AEO2007 cases
Source: EIA AEO 2007 (2005 $/bbl)

3.6. Putting it all together – Interactions and market dynamics

In the previous sections, the overall model boundaries, structure, and sectoral details including various feedstock, production, and product markets (shown in Figure 22) were described. Now, it is important to discuss the market interactions and other external factors that could impact behavior of the biodiesel market in the next decade.

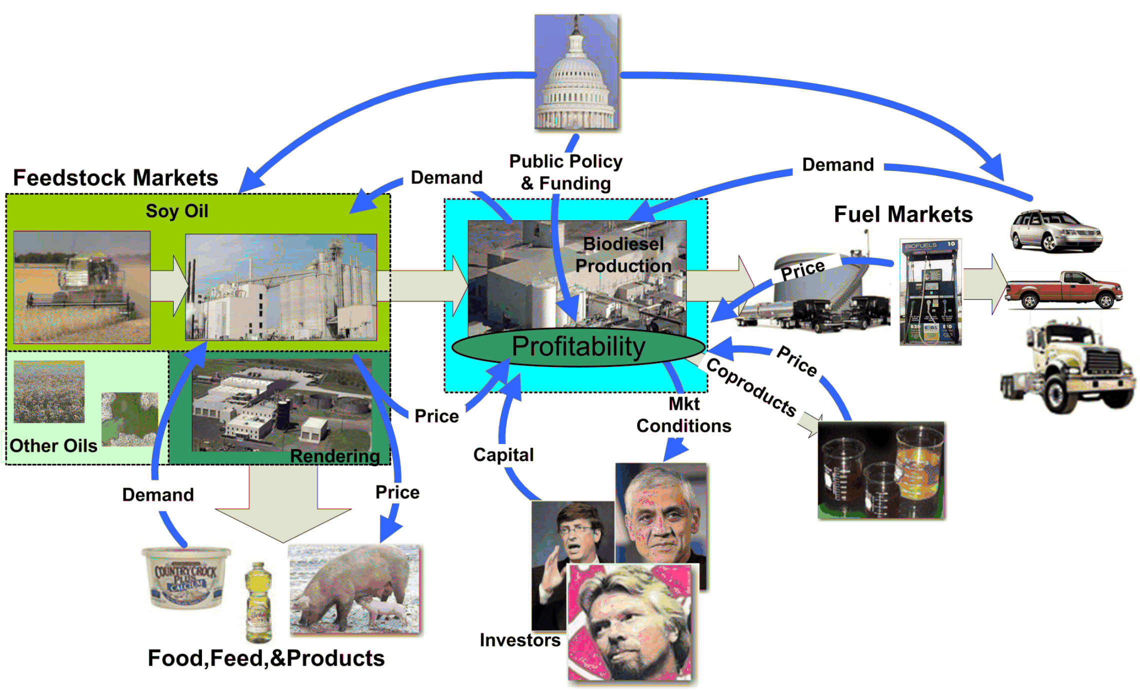



Figure 22: Biodiesel Market Overview

### 3.6.1. Ethanol competition

USDA forecasts that US farmers will plant more corn and less soy over the next decade to meet increasing demand from fuel ethanol (USDA-OCE, 2007). The USDA and University of Tennessee agricultural economists' alternate forecasts (English et al., 2006) are presented in Figure 23. The 2007 spring plantings intentions reported by the USDA on March 30, 2007, indicated corn acres will rise 15% from 2006 plantings to 90.4 million acres and soybean planted acres may drop 11% to 67 million acres (Wilson, 2007). This significant shift of acreage away from soy will most likely affect the price of soy oil and negatively impact the profitability of biodiesel producers.

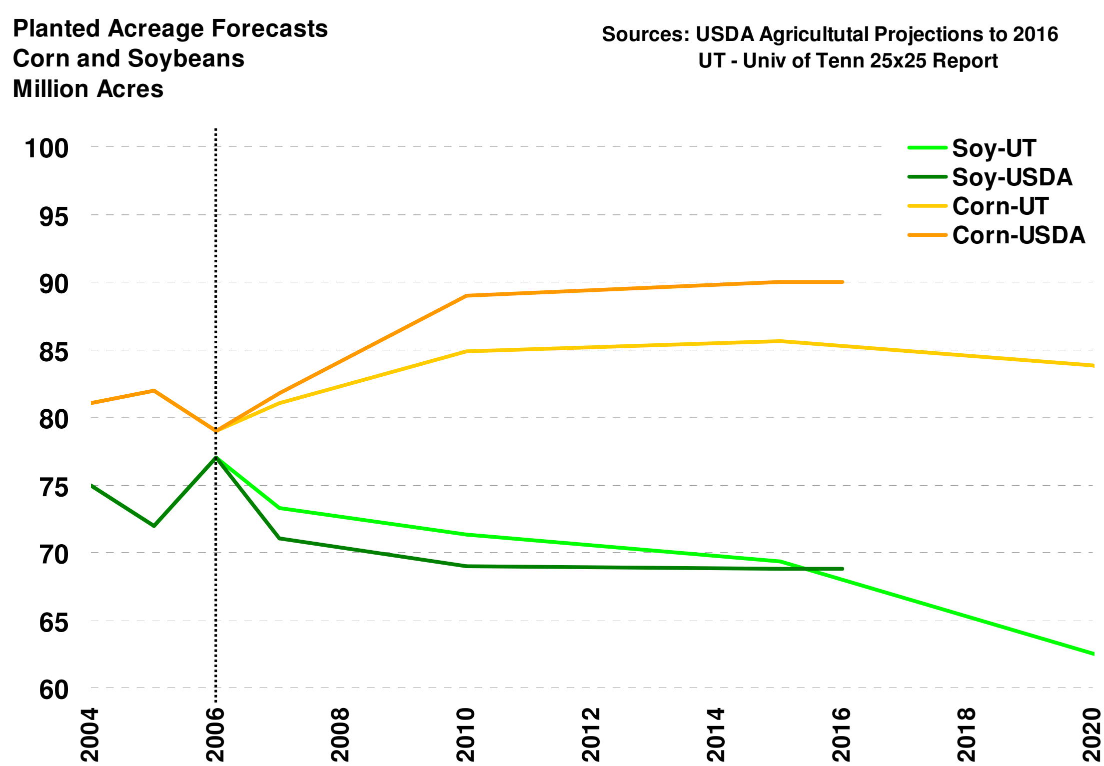



Figure 23: Decreasing US soy acreage
Source: USDA (2007), Univ of Tenn 25x25 report (2006)

Moreover, distillers grains, a co-product from the dry mill ethanol production process can be used as a substitute for soy meal in some animal feeding operations

(Davis, 2001). As ethanol production increases, the expanding supply of DDG will increasingly compete with soy meal and other protein oilseed meals. This is likely to result in lower oilseed meal prices and a possible decline in domestic soy meal consumption. The combined effects of decreased soy acreage and decreased demand for soy meal could have negative impacts on FAME biodiesel production. These impacts could possibly be partially offset by developing new technologies for the production of corn oil from the dry-mill ethanol process to be used for biodiesel production, as discussed earlier in Section 3.4.6. In addition, the acreage loss to corn can be offset by displacing wheat with soybean plantings and by bringing more land into production, but the impacts of these changes could also have unintended consequences.

### 3.6.2. Exports and imports

When introducing the 5 x ‘15 plan, the National Biodiesel Board stated that decreasing biomass oil exports would be a key factor for biodiesel growth (Bryan, 2007). More oil can be made available for domestic biodiesel production by decreasing the exports of both soy beans and soy oil and/or increasing imports. The US exports around one billion pounds of vegetable oil and approximately 2.5 billion pounds of rendered fats and oils annually (Soystats, 2005; Meeker, 2006). These feedstock exports could have some impact if redirected into the domestic market.

Biodiesel producers may begin to import more palm, canola, coconut, and other oils if the economics are favorable, but concerns about deforestation and sustainable production methods have combined with cold weather quality issues and domestic protectionism to dampen some of the enthusiasm in the US.

#### 3.6.3. Crushing capacity and oil content

Both the domestic capacity to extract the oil from oilseeds – called crushing capacity – and the percentage of oil in the oilcrops will affect the amount of oil available in the market. The US exports about a third of its soybean crop annually (USDA-ERS, 2007), and crushing these soybeans domestically would produce enough soybean oil to produce 1.5 billion gallons of biodiesel. This would be beneficial for the biodiesel industry, but not for the soy bean crushers' margins as it would also produce a 67% increase in domestic meal. The industry crushing capacity was typically expanded based on the demand from the oilseed meal market. For soy, only 18.5% of seed by weight is oil, the remainder is sold into meal and other markets and has traditionally been the most valuable part of the bean. The demand for soy oil -- driven up by biodiesel production -- may pressure the industry to change their business models and add new crushing capacity.

#### 3.6.4. Glycerol glut

Glycerol (also called glycerin) is a co-product of biodiesel production and can be sold in a crude or refined form. Refined glycerol is a commodity used in the production of hundreds of other products. Chemical industry analysts forecast the glycerol price to continue its current downward slide, and a serious overcapacity problem (Figure 24) is likely to develop as the biodiesel industry continues at its current growth rate (McCoy, 2001). If the overcapacity problem continues, biodiesel producers may soon be faced the problem of disposing of glycerol instead of selling it (Hamilton, 2007).

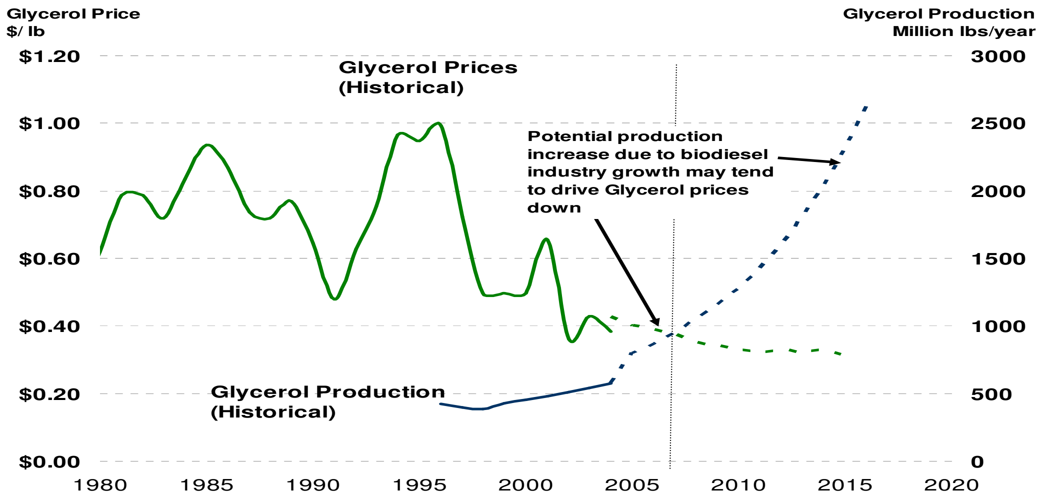



Figure 24: Glycerol Production and Prices – Historical and Projected
Source: Historical data - Bondioli (2003) and Tyson (2004)

The Department of Energy has recognized this issue and has created initiatives -- such as the "top 12" bio-based chemicals that may help new glycerol markets develop which help offset this price decrease (Gerard, 2006). Glycerol sales account for a small percentage of the revenues in the biodiesel industry. Therefore, their impact on the aggregate industry profitability is small compared to the other factors we are exploring. Although this will not be the primary focus in the simulation runs, the model does incorporate an exogenous glycerol price variable that will allow the user to explore this variable.

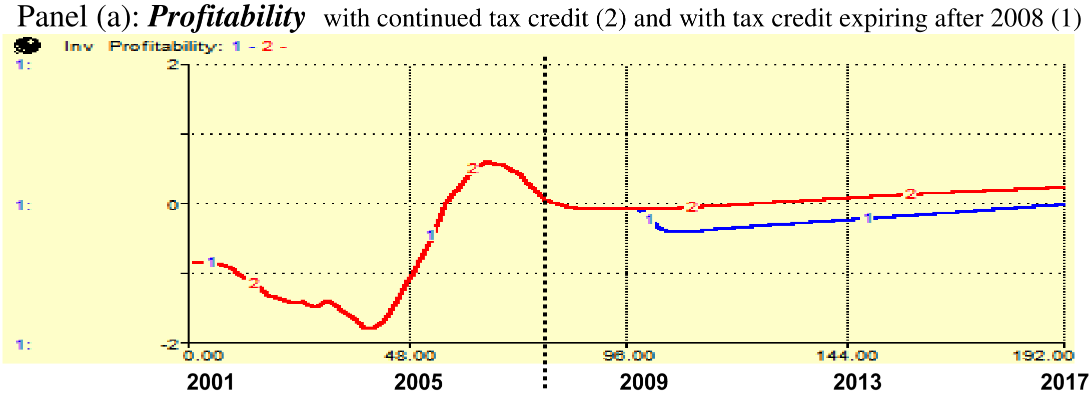
### 3.6.5. Government intervention in the markets

Effective, targeted public investments and policies at the federal and state level -- in the form of research funding, market-creating purchases and mandates, and producer price supports -- have helped to build a strong base for the biodiesel industry. The most well known of these market interactions is the biodiesel tax credit, which was enacted into law as part of the American JOBS Creation Act of 2004 and extended to end of 2008

by the Energy Policy Act of 2005 (Koplow, 2006). Fuel blenders received $1.00 credit for every gallon of soy biodiesel and half that amount for biodiesel produced using other oil sources. Market-based advocates are debating the efficacy and cost of biofuel subsidies, but these government subsidies have helped the industry develop and flourish and are still necessary for profitability. Although the future is not guaranteed, it is likely that the biodiesel tax credits will be extended.

The tax credit has been included in the model as an exogenous variable that can be manipulated to simulate the effects it has on the profitability of producers. The USDA (2007) in its most recent forecast to 2016 also assumed the current biofuel subsidies would remain in place but did run an alternate scenario in which the subsidies were not extended. In that scenario, the biodiesel industry almost entirely collapsed.

Panel (a): ***Profitability*** with continued tax credit (2) and with tax credit expiring after 2008 (1)




Panel (b): ***Operational Capacity*** with cont'd tax credit (2) and with tax credit expiring after 2008 (1)

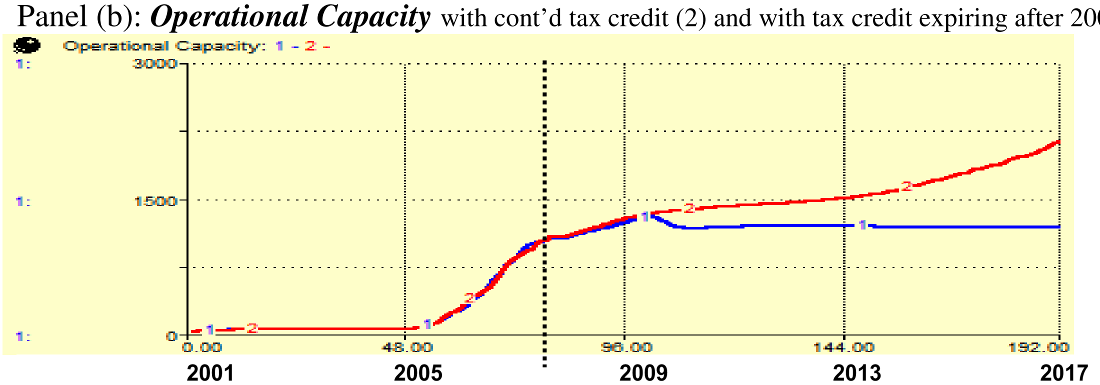


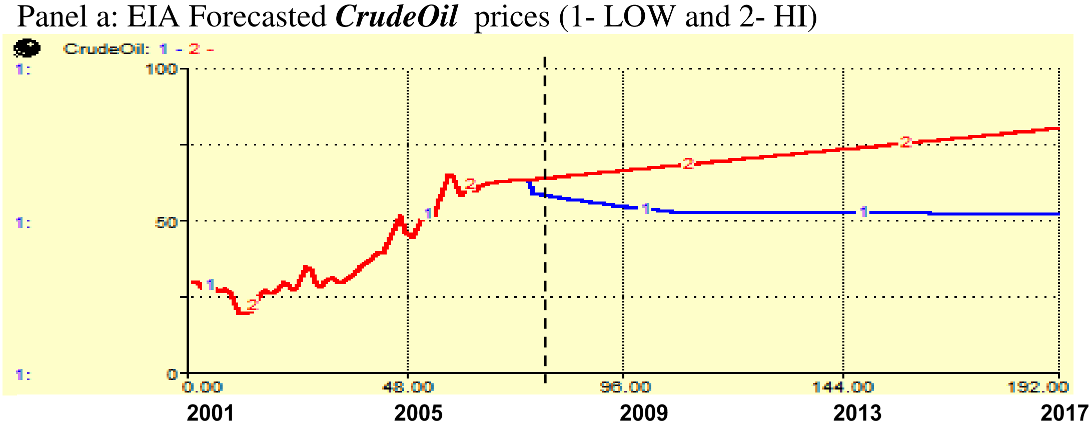

Figure 25: Impact of not extending the tax credit after 2008

The trends presented in Figure 25 are typical of many of the simulated scenarios in which the biodiesel tax credit was not extended after 2008. The ***Profitability*** (Panel (a), Trend line “1”) drops off leading either to stagnation or to deflation in the industry ***Capacity*** (Panel (b), Trend line “1”).

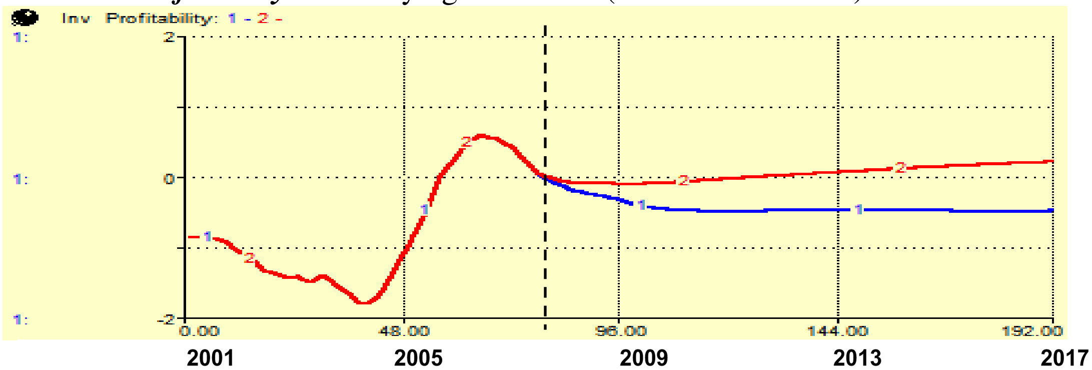
3.6.6. World oil prices

As discussed in Section 3.5, diesel prices which are dependent on crude oil prices have a direct impact on the biodiesel profitability. Elevated diesel prices over the past two years have sparked the current boom in the biofuels industry. Before the scenarios are developed and assumptions are made regarding crude oil prices, the system sensitivity to crude oil needs to be explored. The ***Profitability*** and ***Capacity*** trends in Panel (b) and (c) of Figure 26 are typical of most of the scenarios tested using the low ***CrudeOil*** price forecast. The ***Profitability*** would drop off and this would ultimately lead to the industry ***Capacity*** (and ***Production***) deflating.

Panel a: EIA Forecasted ***CrudeOil*** prices (1- LOW and 2- HI)



Panel b: ***Profitability*** with varying ***CrudeOil*** (1- LOW and 2- HI)




Panel c: ***Operational Capacity*** under the Baseline Scenario is shown here impacted by ***Profitability*** with different ***CrudeOil*** prices

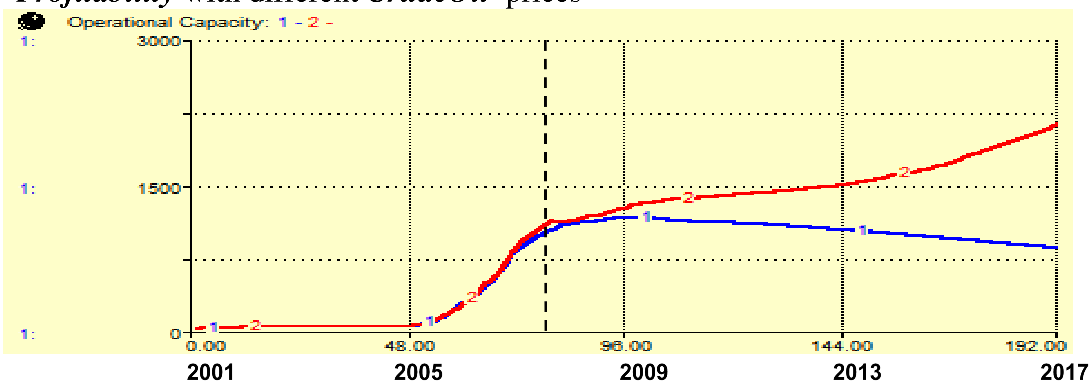



Figure 26: Impact of varying Crude Oil prices

### 3.6.7. Global biofuels growth

Although this thesis focuses on the US biodiesel industry, it is important to put it in context of the global biofuel industry growth. Although the EU biodiesel industry is larger and more mature than most regions, it is still exhibit strong growth behavior. These other global markets are excluded from this analysis, biodiesel industry expansion in Brazil, Argentina, China, India, Malaysia and Indonesia has driven global vegetable oil and fats inventories -- as indicated by the stocks-to-use ratio -- to thirty year lows (Baize, 2006a) and will continue to keep upward pressure on global vegetable oil prices for the near future.

## 3.7. Putting it all together – Testing and using the model

Above I defined the model scope and boundaries and examined the structure of the biodiesel industry and the interaction between sectors. Now I use the model to help answer the original research questions. Keeping in mind that models are simplifications of the real world and that "all models are wrong" (Sterman, 2001), one must demonstrate that this model is at least "right enough" to be useful for its stated purpose. For the young biodiesel industry, little historical data are available. Therefore, one must rely heavily on an understanding of the underlying industry structure and decision-making process and on sectoral testing using analogies provided by similar industries. Model assessment is often done with prescribed sets of tests, but in many cases, model testing becomes an iterative process of building, testing, using, sharing, explaining, and then updating based on the feedback one receives.

### 3.7.1. Face validity and structural assessment testing

In the process of building the BIGS model, I had numerous discussions with biofuel industry analysts that validated many parametric and structural assumptions made. These interactions with industry experts helped to qualitatively test the fit between the structure of the model and the essential characteristics of the real system. This is referred to as face validity testing (Sterman, 2000). Structural assessment testing, to verify whether the model is consistent with the real system relevant to the purpose (Sterman, 2000), was accomplished through discussion and interactions with key modelers from NREL. This interaction with system modelers responsible for the development of the Biomass Transition Model validated the methodology and much of the structure of the model. Finally, I was able to test dimensional consistency and other

hypothesis and key assumptions through extensive sectoral testing and sensitivity analysis.

### 3.7.2. Behavior reproduction tests

As an important part of the model building and testing process, I calibrated the biodiesel capacity and production sector using the historical prices of soybean oil and diesel to calculate the profitability as discussed in sections 3.2 and 3.3 and in Figure 10. This helped to validate the model by comparing the simulation results to historically observed conditions. Also, sensitivity analyses were used to determine which variables in the model have a major influence on the behavior when they are changed. In this way the modeler can identify which variables must be most carefully researched to confirm their numeric values. Moreover, sensitivity analysis is invaluable for analyzing various scenarios.

The price response of the soy oil sector was calibrated against the price projection in the USDA ten year forecast. In the latest ten year projections, in the USDA ten year projection (USDA-OCE, 2007), they modeled the impacts of the soy oil prices with and without the biodiesel tax credits. Using these projections, I was able to further calibrate the model by adjusting the parameters that impact the rates at which investors decide to build (or not to build) biodiesel plants and also the rate at which biodiesel producers ramp back production rates due to decreasing profitability. The recent investor behavior in the biodiesel market could be compared to behavior in a speculative bubble market. It is often hard to model this type of investor behavior, so calibrating the model against other projections (such as those from the USDA) is very helpful in building confidence in the model.

4. Dynamic Analysis of the Biodiesel Industry

In this section, the BIGS SD model described in Section 3 is used to investigate the impact of different market conditions on the biodiesel industry through 2016 and to gain insight into the original research questions. In Section 4.1, the STELLA™ user interface will be briefly reviewed enabling model users to interact with model and to run the various simulation scenarios. Section 4.2 establishes assumptions underlying a set of "core" scenarios including such features as availability of feedstock and other variables affecting profitability. Section 4.3 then presents results for the scenarios including production, capacity, and feedstock prices and market percentages.

4.1. User interface

The STELLA™ SD modeling program consists of four views (or layers) – *Equation, Model, Map,* and *Interface.* To interact with the Biodiesel Industry Growth Simulation, users will start at the main page on the Interface layer provided in Figure 27.

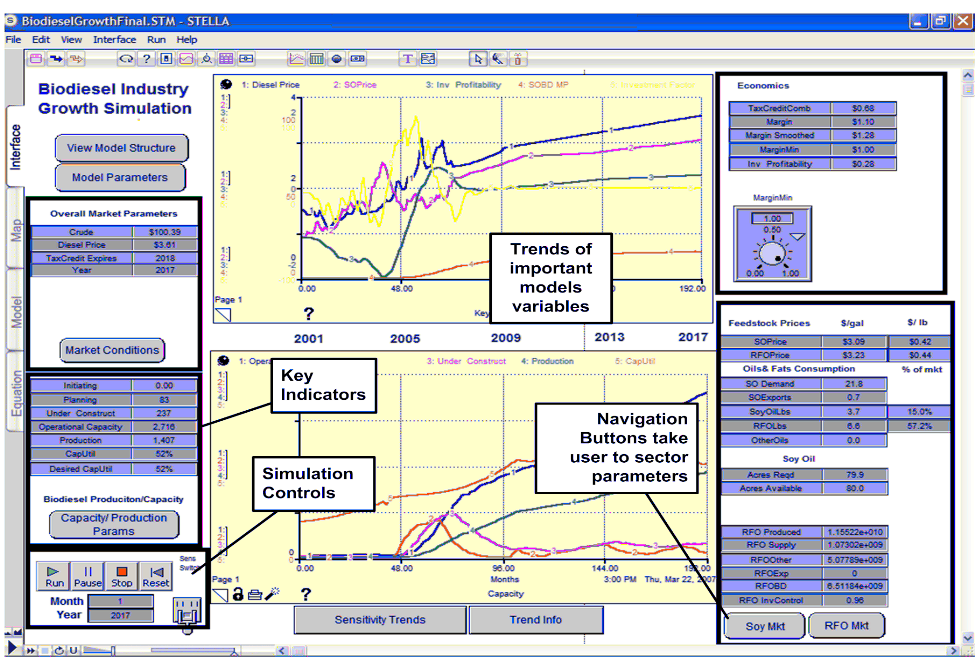
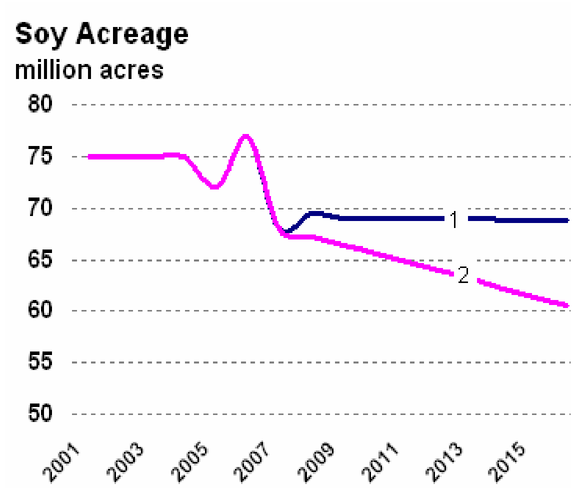


Figure 27: STELLA$^{TM}$ Biodiesel Industry Growth Simulation User Interface

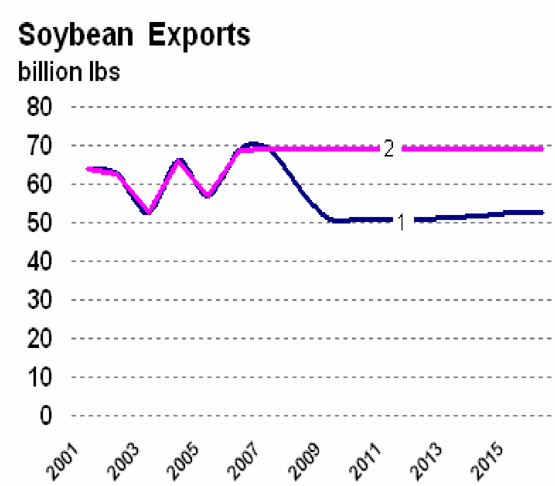
From this "flight simulator" display, the user can run scenarios, and view the model inputs and outputs or navigate to other displays and layers to view the model structure, set model parameters, and perform sensitivity analysis.

4.2. Scenario discussion

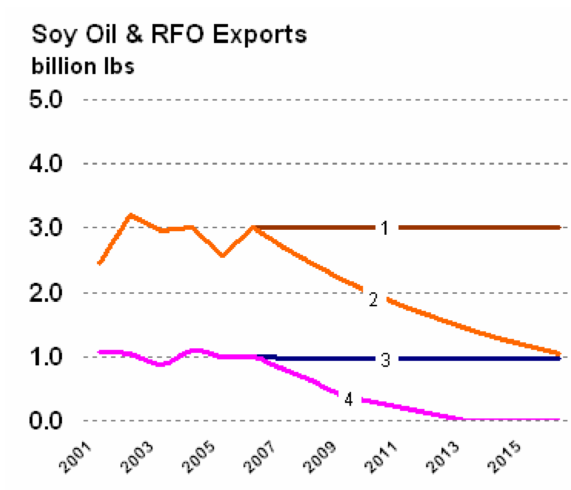
By simulating different scenarios, we can gain a better understanding of how realistic the current growth predictions are and how sensitive the industry is to changing various parametric and structural changes. Hence, I defined market conditions that would affect producer profitability by varying constraints on the availability of fats and oil feedstocks. The main exogenous variables manipulated in the scenarios impact the supply of oils and fats in the market. The first two variables impact soybeans available for crushing: soy acres planted (***Acres***) and soybean exports (***SoyExports***). The historic and future scenario trends for these two variables are shown in Figure 28. Panel (a) shows the USDA (USDA-OCE, 2007) ten year forecast (trend (1)) and University of Tenn 25x25 (English et al., 2006) soy acreage (trend (2)). Both forecasts show decreasing soy acreage but trend (2) drops significantly due to competition from energy crops such as switchgrass. Soybean exports are shown in panel (b) the USDA 2016 Forecast (trend (1)) and in trend (2) exports are held constant at current levels. The other exogenous variables that affect the amount of fats and oils supply are the exports (or imports) of soy and RFO oils (in panel (c)) and the availability of other oils in the market place (panel (d)). In panel (d) trend (2), it is assumes that other oils come into the market as imports, new oil crops, corn oil (ethanol), or through waste stream utilization with an 33% annual growth rate and will increase the supply up to 5 billion pounds per year in 2016. Panel (d) trend (2) assumes only a 5% annual growth rate in other oils.



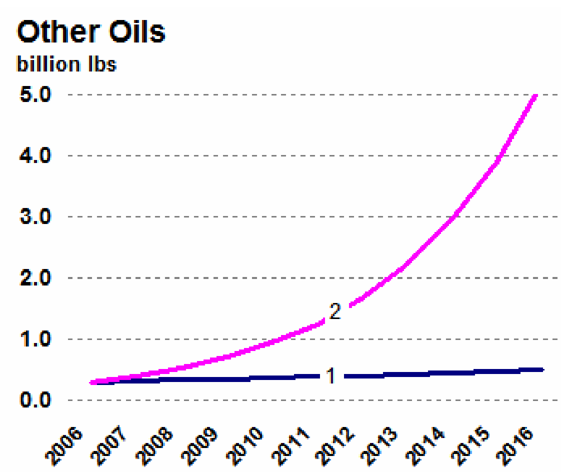

Panel a
(1 - USDA baseline, 2 – UT-25x25)




Panel b
(1 - USDA baseline, 2 – 2006 level)




Panel c
(1&3 – 2006 levels, 2&3 - Decreasing)




Panel d
(1 – 5% growth rate , 2 – 33% growth rate)

Figure 28: Variables affecting Biodiesel Oil Feedstock Supplies

The inputs for the key exogenous variables for three scenarios analyzed are summarized in Table 4. Based on discussions above, for all the scenarios, it is assumed that crude oil prices will continue to trend high and the federal biodiesel tax credit is extended through 2016.

| Scenario | Exogenous Variables Adjusted in each Scenario (see panels in Fig 27) | | | |
|---|---|---|---|---|
| | Soy Acres Planted (Panel a) | Soybean Exports (Panel b) | Fats and Oil Exports (Panel c) | Other Oils (Panel d) |
| Baseline | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Held at 2006 levels | Increasing at 5% per year |
| Five by Fifteen | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Decreasing per trends in Fig.27 | Increasing at 33% per year |
| Constrained Oil | Decreasing (11% reduction by 2016) | Held at 2006 levels | Held at 2006 levels | Increasing at 5% per year |

**Table 4: Scenario Overview Table**

#### 4.2.1. Baseline scenario

The reference or business-as-usual scenario is based on the assumption that existing trends in the biodiesel market will continue on their current trajectories with no major shifts in the feedstock markets. This essentially represents the assumptions currently held by many investors interested the business of producing biodiesel. By examining this scenario, we can gain insight whether the growth of biodiesel industry can be sustained even if these assumptions are correct. The soy acreage is set per USDA 2016 forecast (USDA-OCE, 2007) and soy exports are fixed at 2005 levels. The exports of soy oil and RFO are also set at historical levels. The demand for soy oil and RFO are assumed to grow at historical growth rates. Other oils exhibit a small 5% annual growth.

#### 4.2.2. Five by fifteen Scenario

This scenario evaluate the assumptions underlying the National Biodiesel Board 5 by ‘15 goal (i.e. achieve 5% market share for diesel market by 2015). Most importantly, the

NBB projections postulate a sufficient growth in “other oil” feedstocks to support the 5% market share goal. Assuming the decline in soy oil production as projected by USDA, the model analysis suggests that a roughly 33% annual growth rate in “other oils” is required to achieve this goal (see Figure 28, Panel (d), Trend (2)). Hence, this scenario employs such an increase. The results are useful in evaluating how realistic the NBB 5 x ‘15 goal actually is. Exports of soy oil and RFO oils will also be decreased as shown in the trends in Figure 28. Although the NBB assumes additional soy acreage may come from CRP and pasture lands, this scenario assumes soy acreage will more closely follow the USDA 2016 baseline. The other oils in this scenario may come from corn, canola and palm oil as they enter the market through new technologies, increased domestic production and increased oil feedstock imports to meet the increasing demand from biodiesel. Also other waste streams fat sources will be tapped.

#### 4.2.3. Limited biomass oil scenario

In this scenario, it is assumed that soy acreage will significantly decrease due to increased corn and switchgrass planting for ethanol production and other bioenergy uses. This scenario (shown in Figure 28 Panel a) uses the acreage assumptions developed by the agricultural economists at the University of Tennessee as a way to meet 25% of the nation’s transportation and electricity needs with renewable energy (English et al., 2006). Also in this scenario, it is assumed that exports are maintained at 2006 levels and no significant increases in other oils occur.

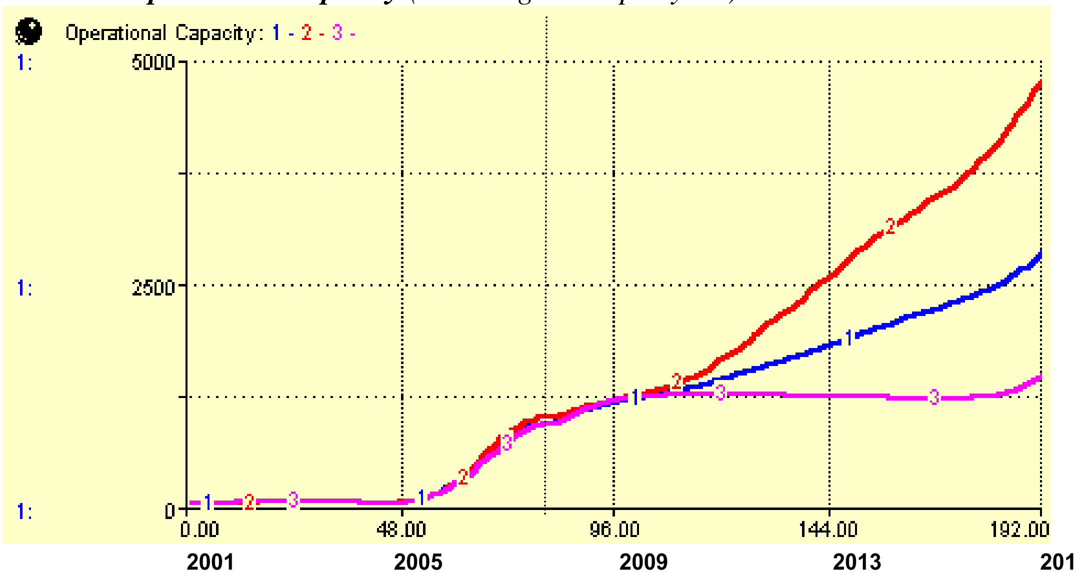
4.3. Scenario results

The projections presented in this section are dependent on assumptions about the availability of FAME biodiesel feedstocks discussed in the section above. The core assumptions are intended to set a reasonable context for assessment of the various growth behaviors in the US biodiesel industry as indicated by biodiesel industry capacity and production and soy oil and rendered fats and oils prices and market share. Capacity and production projections for the three core scenario are depicted in panels (a) and (b) in Figure 29. These projections suggest that biodiesel production, could possibly hit the industry goals of 5% market share (panel (b) trend (2)) by 2015 but, only under ideal conditions. In the Limited Biomass Scenario, the production plateaus at approximately 700 million gals per year (Figure 29, panel (b) trend (3)) which is consistent with the USDA model results (USDA-OCE, 2007). The Baseline scenario in Figure 29 trend (1) shows production capacity is slightly over 2.5 billion gallons per year wh production at approximately 1.5 billion gallons per year. This production level is consistent with the UT-GEC report (Ugarte et al., 2006), discussed in section 2, and possibly the Promar study, if extrapolated to 2016.

In all cases, there will be a slowing of growth in the next three years as production comes on line and rising feedstock prices cut into producer profitability (seen in Figure 30). Soy and rendered fats & oils prices and their impact on the investor profitability for the three core scenario are depicted in panels (a) and (b) in Figure 30. As expected, the acreage constraints in the Limited Biomass Oil scenario have a major impact on soy prices as seen in (Figure 30, panel (a) trend (3)).

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: ***OperationalCapacity*** *(million gallons per year)*




Panel b: ***Production*** *(million gallons per year)*

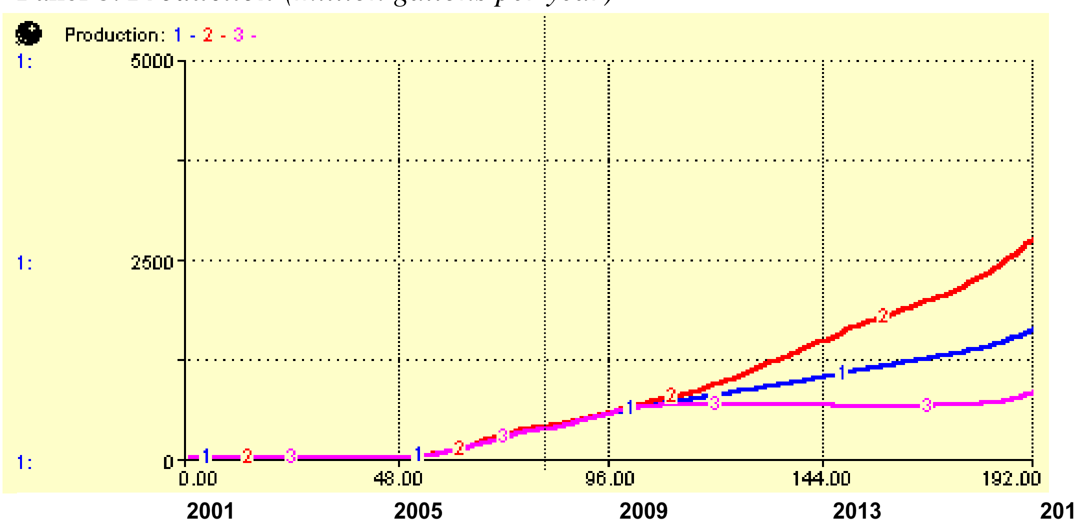
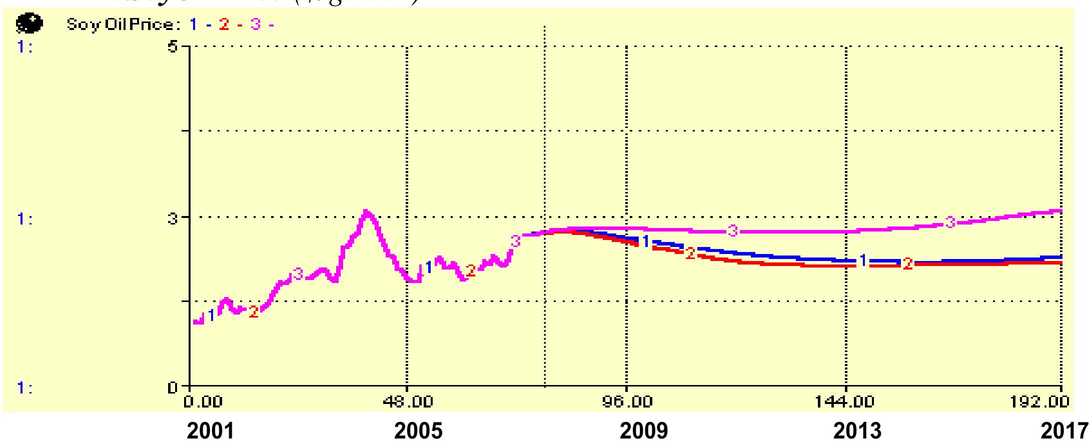


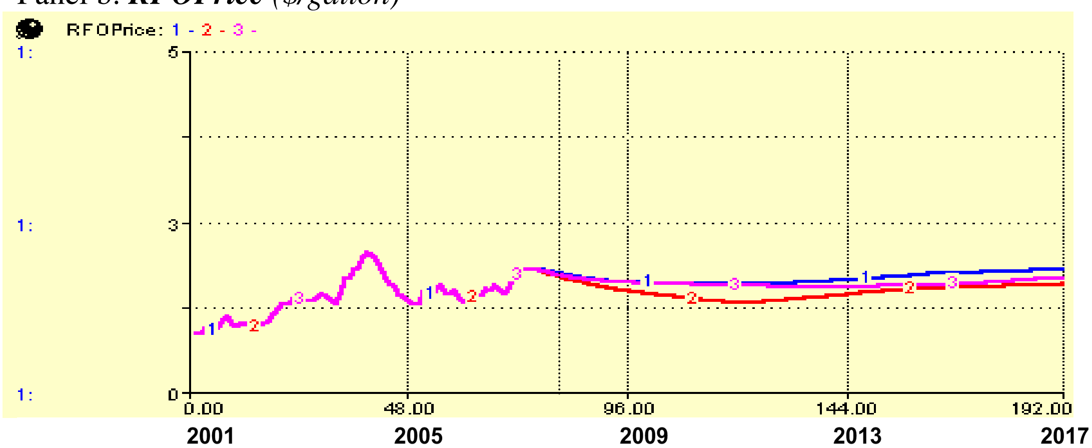

Figure 29: Biodiesel Capacity and Production under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: ***SoyOilPrice*** *($/gallon)*




Panel b: ***RFOPrice*** *($/gallon)*




Panel c: ***Inv Profitability****($/gallon)*

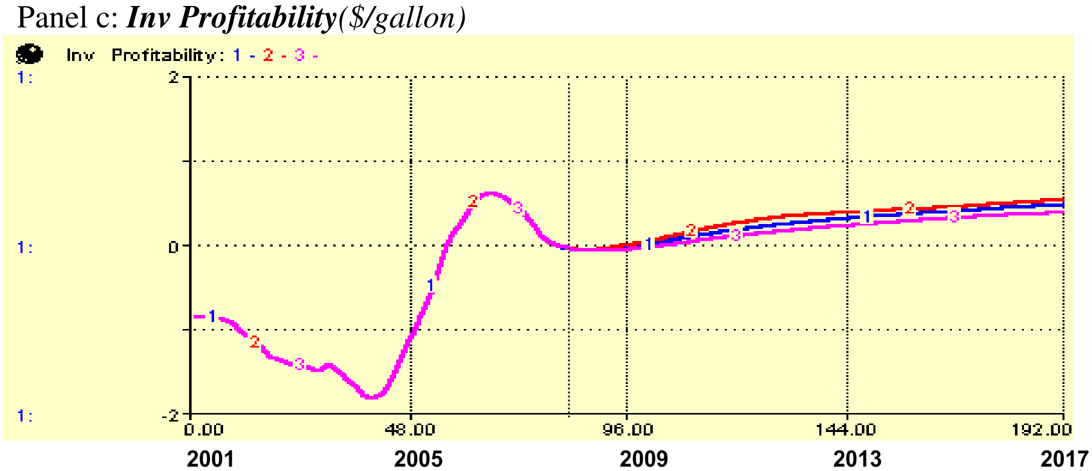
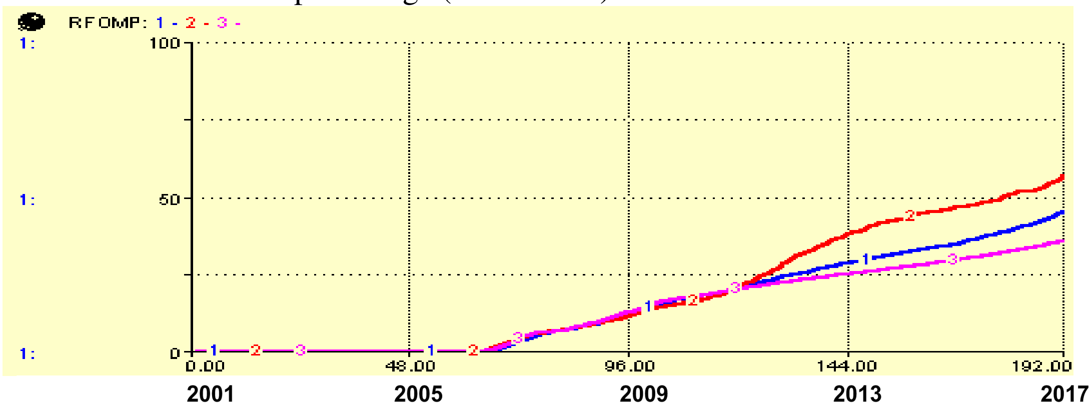



Figure 30: Feedstock prices and profitability under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: RFO market percentage (to biodiesel)




Panel b: Soy Oil market percentage (to biodiesel)

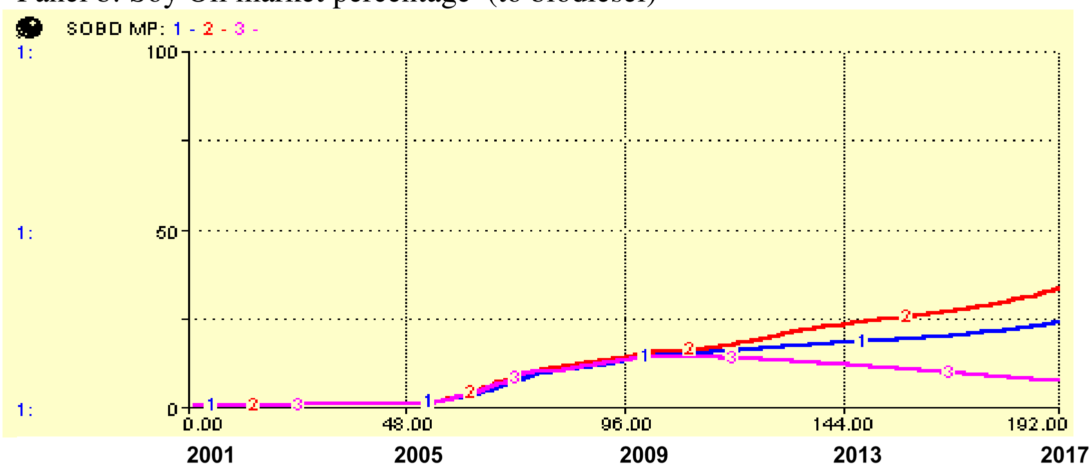



Figure 31: Feedstock Market Percentage under alternative scenario assumptions

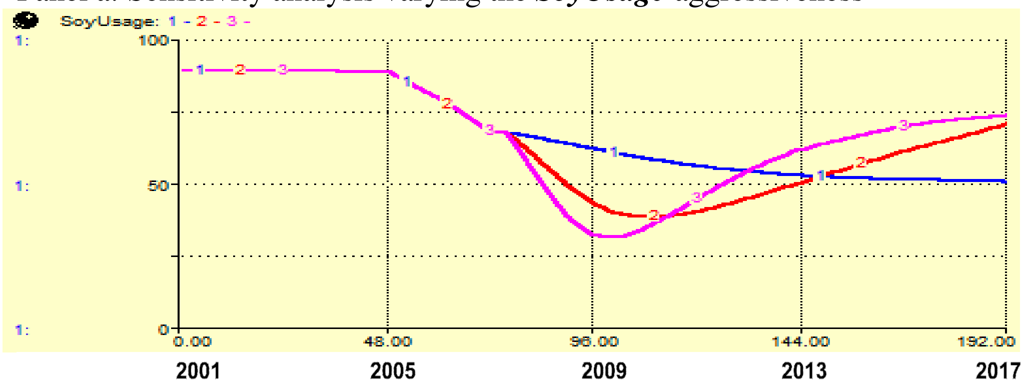
The share of the feedstock markets that biodiesel demand is claiming is show in Figure 31 (soy oil-panel (b), rendered fats and oils-panel (a)). When soy oil supply is impacted by soy acreage constraints in the Limited Biomass Scenario, the amount of soy used for biodiesel feedstock drops off significantly (panel (b), trend (3)) due to high prices. In the other two scenarios, the soy biodiesel market percentage gradually increases to 25-35% of the market. In panel (a), biodiesel takes from 35-60 % of the RFO market share. In reality, this may not be practical, given the elasticities of the other markets.

As these scenarios are evaluated, other factors come into play and other assumptions are also plausible. For example, the industry has been gradually diversifying its feedstock sources and by shifting away from dependence on soy to multi-feedstock facilities. To explore the effect that this shift has on the industry growth, a sensitivity analysis was performed under the baseline scenario and varying the aggressiveness of the ***SoyUsage*** variable. The trends in Fig 31 panel (a) show the varying rate of aggressiveness at which producers are shift from using soy to other feedstocks. The results of the sensitivity analysis shown in Figure 32, reveal that if the industry aggressively moves away from soy in the next three to four years (trend lines (2) and (3) in Panel (a), Figure 32), then a rapid increase in rendered fats and oils market share (***RFOMP***) trend lines (2) and (3) in Panel (b) will occur. The will cause the RFO price to increase and the SoyUsage will be adjusted endogenously as seen when trend lines (2) and (3) in panel (a) reverse direction and begin to increase the soy usage. The simulation indicates that these lower soy oil prices could trigger another boom in construction and more capacity growth towards the end of the simulation run as seen in panel (c) trend lines (2) and (3).

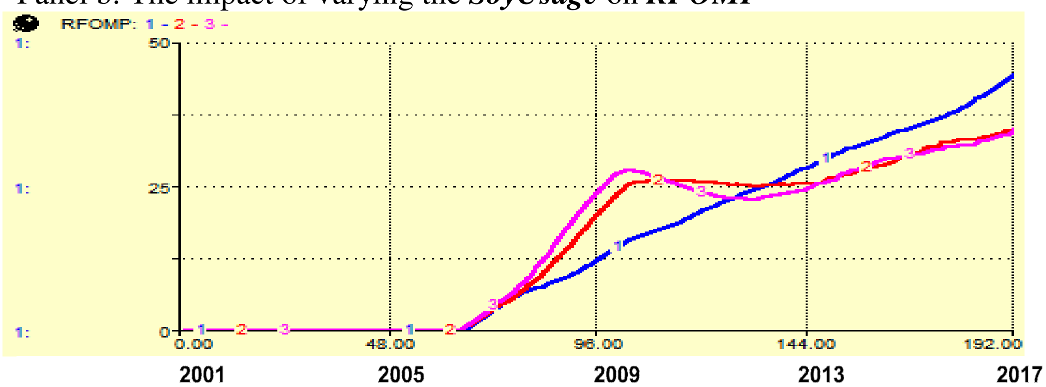
By developing scenarios that affected producer profitability by varying constraints on the availability of fats and oil feedstocks and then using BIGS model to simulate the industry grow, we have gained a better understanding of how realistic the current growth predictions. The sensitivity analyses above provide examples of how the BIGS model can be used to explore the dynamics interactions between different factors that affect growth in the biodiesel industry and help better understand how sensitive the industry is to changing various parametric and structural changes.

**Index:** **SoyUsageChg(3%/yr) (1), Soy UsageChg (13%/yr) (2), Soy Usage Chg(20%/yr)(3)**

Panel a: Sensitivity analysis varying the ***SoyUsage*** aggressiveness




Panel b: The impact of varying the ***SoyUsage*** on ***RFOMP***




Panel c: The resultant effect on industry ***OperationalCapacity***

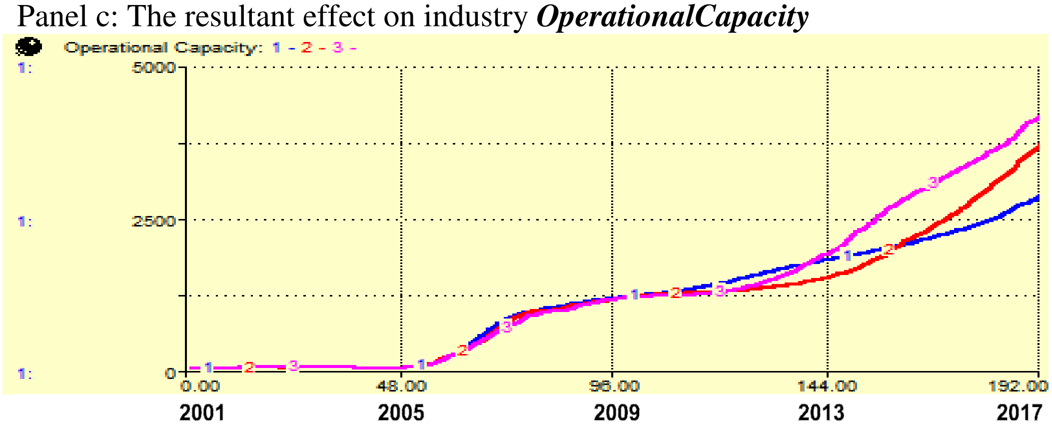



Figure 32: Baseline Scenario- varying the Soy Usage Parameter

5. Recommendations and Conclusions

The objective of this study is to investigate the market dynamics of the FAME biodiesel industry through the use of a SD research model. Conceptualization of the model structure, key parametric assumptions and relationships between them was informed by literature review and discussions with key personnel in the biodiesel industry. Simplifications and assumptions to model structure and parameters are integrated by means of these discussions. Simulation of various scenarios helped to help explore the bottlenecks in feedstock availability and sensitivity of industry growth to various parameters over the next decade. The future of FAME biodiesel is, indeed, not clear and could take many different routes depending on market conditions, government actions, and as we thoroughly investigated, on the availability of affordable oil feedstocks.

A key finding from this study is that many of the scenarios run indicate that industry may experience a plateau of capacity growth in the next few years because of decreased profitability. In fact, only in the most optimum of feedstock and market conditions -- high oil prices, extension of tax credits, reduced exports and 33% annual growth rate of new sources of fats and oils – will the market reach five percent of diesel market penetration. Realistically, growth of the FAME biodiesel industry beyond that in the ten year period studied is not likely. As hypothesized, the dampening of the industry growth is influenced heavily due by increases of feedstock prices. The price increases are brought about by the rapid increase in the feedstock market share of biodiesel and influenced also by agricultural pressures from corn ethanol. Analysis of the various scenarios also finds that decreasing soy usage by increasing multi-feedstock capability

may temporarily delay the pending feedstock squeeze but unless significant amount of other oils become available in the short term the industry will be severely limited.

## 5.1. Recommendations

### 5.1.1. Explore other renewable diesel alternatives

Although the scope of this thesis does not include exploring the transition of the renewable diesel industry to non-FAME alternatives, it is important that this task be addressed urgently. To raise the low feedstock ceiling that will soon limit FAME biodiesel to somewhere less than one tenth of the diesel market, the biodiesel industry must embrace change and quickly expand to production technologies that are not solely dependent on fats and oils. These technologies -- such as biomass gasification/Fischer-Tropsch diesel -- can open the door to a broader and more diverse array of feedstock choices. Although diesel is a smaller piece of the transportation fuel pie, the growth of the diesel market combined with the potential for other non-renewable alternatives to displace petroleum diesel demand appropriate attention to this matter. The EIA projects that by 2030, fuels derived from coal (Coal-To-Liquids or CTL) will account for 93% of non-petroleum diesel alternatives (USDOE-EIA, 2007a) -- making up 7 percent of the total distillate pool.  Liquid coal is produced from domestic feedstocks but only the fuels produced from renewable resources give us real energy security by significantly reducing our greenhouse gas emissions.

SD modeling efforts could be used to help policy makers and industry leaders envision a renewable diesel future with multiple production pathways. As discussed previously, several government agencies and labs are collaborating to develop a SD-based Biomass Transition Model (USDOE-OBP, 2006) to help simulate the evolution of

the ethanol industry to lignocellulosic feedstock sources. The learnings from this model will help to inform policy makers and industry players in their decision making process. It is important that similar modeling efforts include the future of renewable diesel pathways.

#### 5.1.2. Maintain government interaction in the markets

As demonstrated in the model testing, if the current biodiesel tax credit is not extended the production of biodiesel may drop off quite rapidly because producers will have difficulty being profitable. These businesses will not continue production for long if they are losing money. The results of the simulation in this thesis concurred with the USDA industry collapse simulated in the most recent ten year outlook (USDA, 2007a). Therefore, until alternative renewable diesel pathways become established and renewable feedstock supplies markets are stable, effective, targeted public investments in the form of research, market-creating purchases and mandates, and tax credits should be provided for emerging biodiesel technologies and industries. However, these government policies should promote and support the production and uses of biodiesel that meet appropriate performance standards -- such as lifecycle greenhouse gas emissions -- not just specific feedstock types.

#### 5.1.3. Promote sustainable development of new oilcrops

There are possible benefits to producing a diverse array of oil crops that can be used for biodiesel production. For example, planting camelina as a winter cover crop will reduce soil erosion and give the farmers a crop that has a higher value in the market. The need for further research into these matters is recognized by the government and industry.

Researchers at the Danforth Center in St. Louis (Hamilton, 2007) are trying to understand what is needed to achieve a 5% market share for biodiesel.

Increasingly, oil palm could begin to play a major role in US biodiesel industry development. In addition to palm oil, new oilseed crops such as the perennial Jatropha can provide income for rural farming communities in India while providing another valuable source of biomass oil that can be turn in to fuel. Many in the US and Europe are concerned that oilcrops from the tropics, may not be grown in a sustainable manner. To avoid replacing unsustainable fossil fuels with unsustainable biofuels, the international community must act quickly to establish global sustainability standards for biofuels.

#### 5.1.4. Understand the dynamics of the domestic oilseed industry

The domestic crushing industry – which extracts oil from oilseeds – is undergoing a rapid transition driven by international competition in China and Argentina. It is also by the changes of the end use of its products (soy meal and soy oil) domestically which are influenced by the rapid growth of the biodiesel and ethanol industries. Many of the old business models for soybean crushing are being “flipped on their head” by a rapidly changing market environment where soybean meal is losing value and soy oil is gaining. One recent industry trend is to locate crushing facilities at or near biodiesel production facilities to reduce costs for the biodiesel producers. This issue is ripe for analysis using SD modeling methods similar as performed in this thesis.

#### 5.1.5. Develop other non-conventional sources of oil

There are many exciting possibilities for sources of new biomass oil to raise the FAME biodiesel feedstock ceiling such as corn oil, oil from algae, and other under-

utilized waste oils. Research, development, and deployment should be supported at appropriate levels.

## 5.2. Conclusion

Understanding current and future growth in the biodiesel industry requires taking a holistic view of the industry and analyzing key factors that influence profitability. Exploring various scenarios using SD modeling and simulation can be extremely helpful in developing a deeper understanding of the rapidly changing biofuels industry. This thesis described the formulation of a SD model to simulate the behavior of the FAME biodiesel industry and as hypothesized the industry will most likely hit a feedstock ceiling in the next decade and remain only a small fraction (less than 10%) of the non-petroleum diesel replacement market.

# Appendix A: US Biodiesel Plant Listing

**Table 5: US biodiesel plant listing - Jan 2007**

(Source: Biodiesel Magazine online plant listing, last updated 3-Jan-2007)

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Independence Renewable Energy Corp. | Claiborne | AL | soy oil | 40 | Under Construction | |
| Alabama Biodiesel Corp. | Moundville | AL | soy oil | 10 | Operational | N/A |
| Alabama Bioenergy | Bridgeport | AL | soy oil | 10 | Operational | Nov-06 |
| Arkansas Soy Energy Group LLC | Dewitt | AR | soy oil | 3 | Under Construction | |
| FutureFuel Chemical Co. | Batesville | AR | soy oil | 24 | Operational | N/A |
| Patriot BioFuels | Stuttgart | AR | soy oil/animal fats | 3 | Operational | N/A |
| Bay Biodiesel LLC | San Jose | CA | virgin oils/yellow grease | 5 | Under Construction | |
| Energy Alternative Solutions Inc. | Gonzales | CA | tallow | 1 | Under Construction | |
| Simple Fuels LLC | Vinton | CA | yellow grease | 2 | Under Construction | |
| Bio-Energy Systems LLC | Vallejo | CA | virgin oils/yellow grease | 2 | Operational | N/A |
| Biodiesel Industries-Port Hueneme | Ventura | CA | multi-feedstock | 3 | Operational | N/A |
| Imperial Western Products | Coachella | CA | yellow grease | 7 | Operational | N/A |
| LC Biofuels | Richmond | CA | canola oil | 1 | Operational | N/A |
| American Biofuels Corp. o | Bakersfield | CA | soy oil/tallow/waste vegetable oil | 5 | Not Producing | N/A |
| American Agri-Diesel | Burlington | CO | soy oil | 6 | Operational | N/A |
| BioEnergy of Colorado | Denver | CO | soy oil | 10 | Operational | N/A |
| BioFuels of Colorado | Denver | CO | soy oil | 5 | Operational | N/A |
| Rocky Mountain Biodiesel Industries | Berthoud | CO | multi-feedstock | 3 | Operational | N/A |
| Bio-Pur Inc. | Bethlehem | CT | soy oil | 0.4 | Operational | N/A |
| Mid-Atlantic Biodiesel | Clayton | DE | multi-feedstock | 5 | Operational | N/A |
| Purada Processing LLC | Lakeland | FL | multi-feedstock | 18 | Operational | N/A |
| Renewable Energy Systems Inc. | Pinellas Park | FL | recycled vegetable oil | 0.5 | Operational | N/A |
| Middle Georgia Biofuels | East Dublin | GA | soy oil/poultry fat | 2.5 | Operational | Sep-06 |
| US Biofuels Inc. | Rome | GA | multi-feedstock | 10 | Operational | N/A |
| Pacific Biodiesel Inc. | Honolulu | HI | yellow grease | 1 | Operational | N/A |
| Pacific Biodiesel Inc. | Kahului | HI | yellow grease | 0.2 | Operational | N/A |
| Central Iowa Energy LLC | Newton | IA | multi-feedstock | 30 | Under Construction | |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| East Fork Biodiesel LLC | Algona | IA | soy oil/animal fats | 60 | Under Construction | |
| Freedom Fuels LLC | Mason City | IA | soy oil/animal fats | 30 | Under Construction | |
| Iowa Renewable Energy | Washington | IA | soy oil | 30 | Under Construction | |
| Riksch Biofuels | Crawfordsville | IA | multi-feedstock | 9 | Under Construction | |
| Sioux Biochemical Inc. | Sioux Center | IA | corn oil/animal fats | 1.5 | Under Construction | |
| Western Dubuque Biodiesel | Farley | IA | soy oil | 30 | Under Construction | |
| Ag Processing Inc. | Sergeant Bluff | IA | soy oil | 30 | Operational | N/A |
| Cargill Inc. | Iowa Falls | IA | soy oil | 37 | Operational | N/A |
| Clinton County Bio Energy | Clinton | IA | soy oil | 10 | Operational | N/A |
| Mid-States Biodiesel LLC | Nevada | IA | multi-feedstock | 0.5 | Operational | N/A |
| Renewable Energy Group | Ralston | IA | soy oil | 12 | Operational | N/A |
| Soy Solutions | Milford | IA | soy oil | 2 | Operational | N/A |
| Tri-City Energy | Keokuk | IA | multi-feedstock | 5 | Operational | N/A |
| Western Iowa Energy | Wall Lake | IA | soy oil-animal fats | 30 | Operational | N/A |
| Blue Sky Biodiesel LLC | New Plymouth | ID | multi-feedstock | 12 | Operational | N/A |
| Biofuels Company of America LLC | Danville | IL | soy oil | 45 | Under Construction | |
| American Biorefining Inc. | Saybrook | IL | soy oil | 10 | Operational | N/A |
| Columbus Foods Co. | Chicago | IL | soy oil | 3 | Operational | N/A |
| Incobrasa Industries Ltd. | Gilman | IL | soy oil | 30 | Operational | Dec-06 |
| Stepan Co. | Joliet | IL | multi-feedstock | 21 | Operational | N/A |
| e-Biofuels LLC | Middletown | IN | soy oil | 25 | Under Construction | |
| Louis Dreyfus Agricultural Industri | Claypool | IN | soy oil | 80 | Under Construction | |
| Evergreen Renewables LLC | Hammond | IN | soy oil | 5 | Operational | N/A |
| Integrity Biofuels | Morristown | IN | soy oil | 5 | Operational | N/A |
| Owensboro Grain Biodiesel | Owensboro | KY | soy oil | 50 | Under Construction | |
| Griffin Industries | Butler | KY | soy oil/tallow/yellow grease | 2 | Operational | Dec-98 |
| Allegro Biodiesel Corp. | Pollock | LA | soy oil | 15 | Operational | N/A |
| Maryland Biodiesel | Berlin | MD | soy oil | 0.5 | Operational | N/A |
| Bean's Commercial Grease | Vassalboro | ME | waste vegetable oil | 0.25 | Operational | N/A |
| Ag Solutions Inc. | Gladstone | MI | soy oil | 5 | Operational | N/A |
| Michigan Biodiesel | Bangor | MI | soy oil | 10 | Operational | N/A |
| FUMPA Biofuels | Redwood Falls | MN | soy oil/animal fats | 3 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Minnesota Soybean Processors | Brewster | MN | soy oil | 30 | Operational | N/A |
| SoyMor | Glenville | MN | soy oil | 30 | Operational | Aug-05 |
| Ag Processing Inc. | St. Joseph | MO | soy oil | 28 | Under Construction | |
| Great River Soy Co-op | Lilbourn | MO | multi-feedstock | 5 | Under Construction | |
| Natural Biodiesel Inc. | Braggadocio | MO | multi-feedstock | 5 | Under Construction | |
| Prairie Pride Inc. | Nevada | MO | soy oil | 30 | Under Construction | |
| Mid-America Biofuels LLC | Mexico | MO | soy oil | 30 | Operational | N/A |
| Missouri Better Bean LLC | Bunceton | MO | soy oil/animal fats | 4 | Operational | N/A |
| Missouri Bio-Products Inc. | Bethel | MO | soy oil | 2 | Operational | N/A |
| Scott Petroleum Corp. | Greenville | MS | multi-feedstock | 20 | Under Construction | |
| CFC Transportation Inc. | Columbus | MS | soy oil | 1 | Operational | N/A |
| Channel Chemical Corp. | Gulfport | MS | soy oil | 5 | Operational | N/A |
| Earth Biofuels | Meridian | MS | multi-feedstock | 2 | Operational | N/A |
| Evans Environmental Energies | Wilson | NC | multi-feedstock | 3 | Under Construction | |
| Filter Specialty Inc. | Autryville | NC | soy oil/yellow grease | 1 | Under Construction | |
| Blue Ridge Biofuels | Asheville | NC | multi-feedstock | 1 | Operational | N/A |
| Foothills Bio-Energies LLC | Lenoir | NC | soy oil | 5 | Operational | N/A |
| Piedmont Biofuels | Pittsboro | NC | yellow grease/animal fats | 1 | Operational | Sep-06 |
| All-American Biodiesel | York | ND | soy oil/canola oil | 5 | Under Construction | |
| Archer Daniels Midland | Velva | ND | canola oil | 85 | Under Construction | |
| Magic City Biodiesel LLC | Minot | ND | canola oil | 30 | Under Construction | |
| Beatrice Biodiesel LLC | Beatrice | NE | soy oil | 50 | Under Construction | |
| Northeast Nebraska Biodiesel | Scribner | NE | soy oil | 5 | Under Construction | |
| Horizon Biofuels Inc. | Arlington | NE | animal fats | 0.4 | Operational | Sep-06 |
| Fuel:Bio One | Elizabeth | NJ | undeclared | 50 | Under Construction | |
| Environmental Alternatives | Newark | NJ | soy oil | 13 | Operational | N/A |
| Biodiesel of Las Vegas | Las Vegas | NV | multi-feedstock | 30 | Under Construction | |
| Infinifuel Biodiesel | Wabuska | NV | multi-feedstock | 5 | Under Construction | |
| Bently Biofuels | Minden | NV | multi-feedstock | 1 | Operational | N/A |
| Biodiesel of Las Vegas Inc. | Las Vegas | NV | soy oil | 3 | Operational | N/A |
| GS Fulton Biodiesel | Fulton | NY | soy oil | 5 | Under Construction | |
| North American Biofuels Company | Bohemia | NY | trap grease | 1 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Alternative Liquid Fuel Industries | McArthur | OH | multi-feedstock | 6 | Under Construction | |
| Jatrodiesel Inc. | Dayton | OH | multi-feedstock | 5 | Under Construction | |
| American Ag Fuels LLC | Defiance | OH | soy oil | 3 | Operational | N/A |
| Peter Cremer | Cincinnati | OH | soy oil | 30 | Operational | N/A |
| Earth Biofuels | Durant | OK | multi-feedstock | 10 | Operational | N/A |
| Green Country Biodiesel Inc. | Chelsea | OK | soy oil | 2 | Operational | N/A |
| OK Biodiesel | Gans | OK | soy oil | 10 | Operational | N/A |
| Sequential-Pacific Biodiesel LLC | Salem | OR | yellow grease | 1 | Operational | N/A |
| Lake Erie Biofuels | Erie | PA | multi-feedstock | 45 | Under Construction | |
| Agra Biofuels Inc. | Middletown | PA | soy oil | 3 | Operational | N/A |
| Biodiesel of Pennsylvania Inc. | White Deer | PA | multi-feedstock | 3.6 | Operational | Jan-07 |
| Keystone Biofuels | Shiremanstown | PA | soy oil | 2 | Operational | Jan-06 |
| United Biofuels Inc. | York | PA | soy oil | 1 | Operational | N/A |
| United Oil Co. | Pittsburg | PA | multi-feedstock | 2 | Operational | Dec-04 |
| Southeast BioDiesel LLC | North Charleston | SC | multi-feedstock | 6 | Under Construction | |
| Carolina Biofuels LLC | Taylors | SC | soy oil | 5 | Operational | N/A |
| Midwest Biodiesel Producers | Alexandria | SD | soy oil | 7 | Operational | N/A |
| Freedom Biofuels Inc. | Madison | TN | multi-feedstock | 12 | Under Construction | |
| Agri Energy Inc. | Lewisburg | TN | soy oil | 5 | Operational | N/A |
| Memphis Biofuels LLC | Memphis | TN | multi-feedstock | 36 | Operational | N/A |
| Milagro Biofuels | Memphis | TN | soy oil | 5 | Operational | N/A |
| NuOil Inc. | Counce | TN | soy oil | 1 | Operational | Nov-05 |
| Big Daddy's Biodiesel | Hereford | TX | multi-feedstock | 30 | Under Construction | |
| BioSelect Galveston Bay | Galveston Island | TX | multi-feedstock | 20 | Under Construction | |
| Global Alternative Fuels LLC | El Paso | TX | multi-feedstock | 5 | Under Construction | |
| Green Earth Fuels LLC | Houston | TX | multi-feedstock | 43 | Under Construction | |
| Biodiesel Industries of Greater Dal | Denton | TX | multi-feedstock | 3 | Operational | N/A |
| Brownfield Biodiesel LLC | Ralls | TX | multi-feedstock | 2 | Operational | Jul-06 |
| Central Texas Biofuels | Giddings | TX | vegetable oils | 1 | Operational | N/A |
| GeoGreen Fuels | Gonzales | TX | soy oil | 3 | Operational | N/A |
| Huish Detergents | Pasadena | TX | tallow/palm oil | 4 | Operational | N/A |
| Johann Haltermann Ltd. | Houston | TX | soy oil | 20 | Operational | N/A |
| Momentum Biofuels Inc. | Pasadena | TX | soy oil | 20 | Operational | N/A |
| Organic Fuels LLC | Houston | TX | multi-feedstock | 30 | Operational | Apr-06 |
| Pacific Biodiesel Texas | Carl's Corner | TX | multi-feedstock | 2 | Operational | Aug-06 |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Safe Fuels Inc. | Conroe | TX | soy oil | 10 | Operational | N/A |
| Smithfield Bioenergy LLC | Cleburne | TX | animal fats | 12 | Operational | Jan-06 |
| SMS Envirofuels Inc. | Poteet | TX | soy oil | 5 | Operational | Jun-06 |
| South Texas Blending | Laredo | TX | beef tallow | 5 | Operational | N/A |
| Sun Cotton Biofuels | Roaring Springs | TX | cottonseed oil | 2 | Operational | N/A |
| Better BioDiesel | Spanish Fork | UT | multi-feedstock | 3 | Operational | Sep-06 |
| Reco Biodiesel LLC | Richmond | VA | soy oil | 10 | Under Construction | |
| Chesapeake Custom Chemical | Ridgeway | VA | soy oil | 5 | Operational | N/A |
| Virginia Biodiesel Refinery | New Kent | VA | soy oil | 2 | Operational | N/A |
| Biocardel Vermont LLC | Swanton | VT | soy oil | 4 | Under Construction | |
| Imperium Grays Harbor | Grays Harbor | WA | multi-feedstock | 100 | Under Construction | |
| Seattle Biodiesel | Seattle | WA | virgin vegetable oils | 5 | Operational | N/A |
| Best Biodiesel Cashton LLC | Cashton | WI | multi-feedstock | 8 | Under Construction | |
| Sanimax Energy Biodiesel | De Forest | WI | multi-feedstock | 20 | Under Construction | |
| Walsh Biofuels LLC | Mauston | WI | multi-feedstock | 5 | Under Construction | |
| Renewable Alternatives | Howard | WI | soy oil | 0.365 | Operational | N/A |
| A C & S Inc. | Nitro | WV | soy oil | 3 | Under Construction | |

Appendix B: Biodiesel Chemistry and Process Diagram

*Transesterification* is the process of reacting a triglyceride molecule with an excess of alcohol in the presence of a catalyst (KOH, NaOH, $NaOCH_3$, etc.) to produce glycerol and fatty esters. The chemical reaction with methanol is shown schematically below.

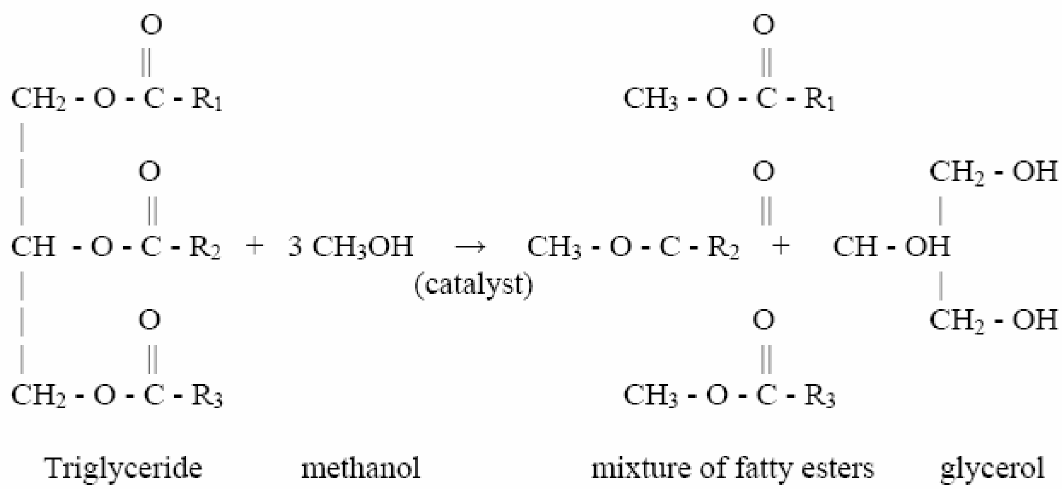



Figure 33: FAME biodiesel chemistry
Source: van Gerpen et al. (2004)

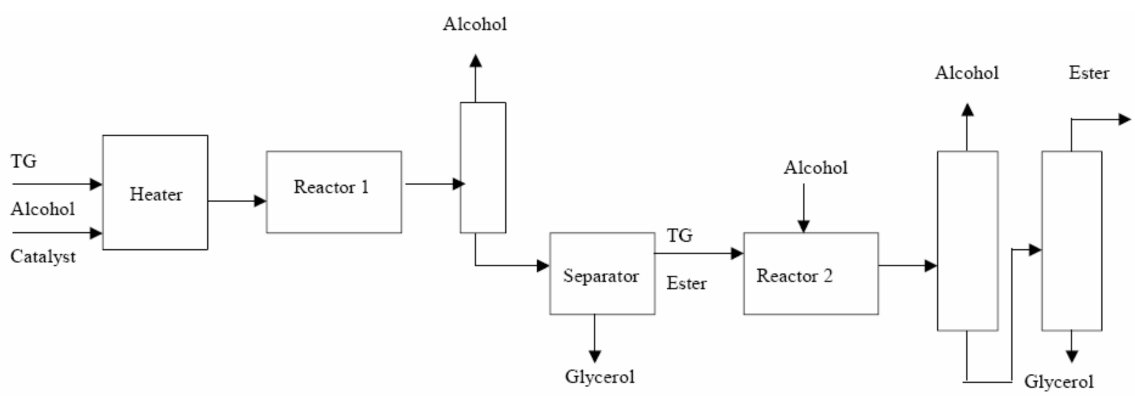
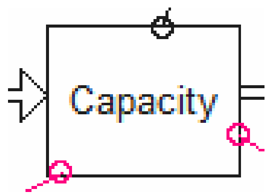
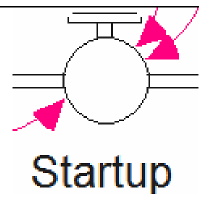
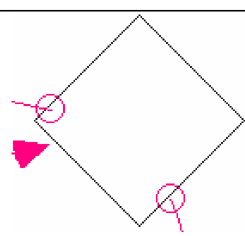
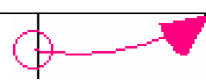



Figure 34: Process flow diagram - Plug flow reactor (typical)
Source: van Gerpen et al. (2004)

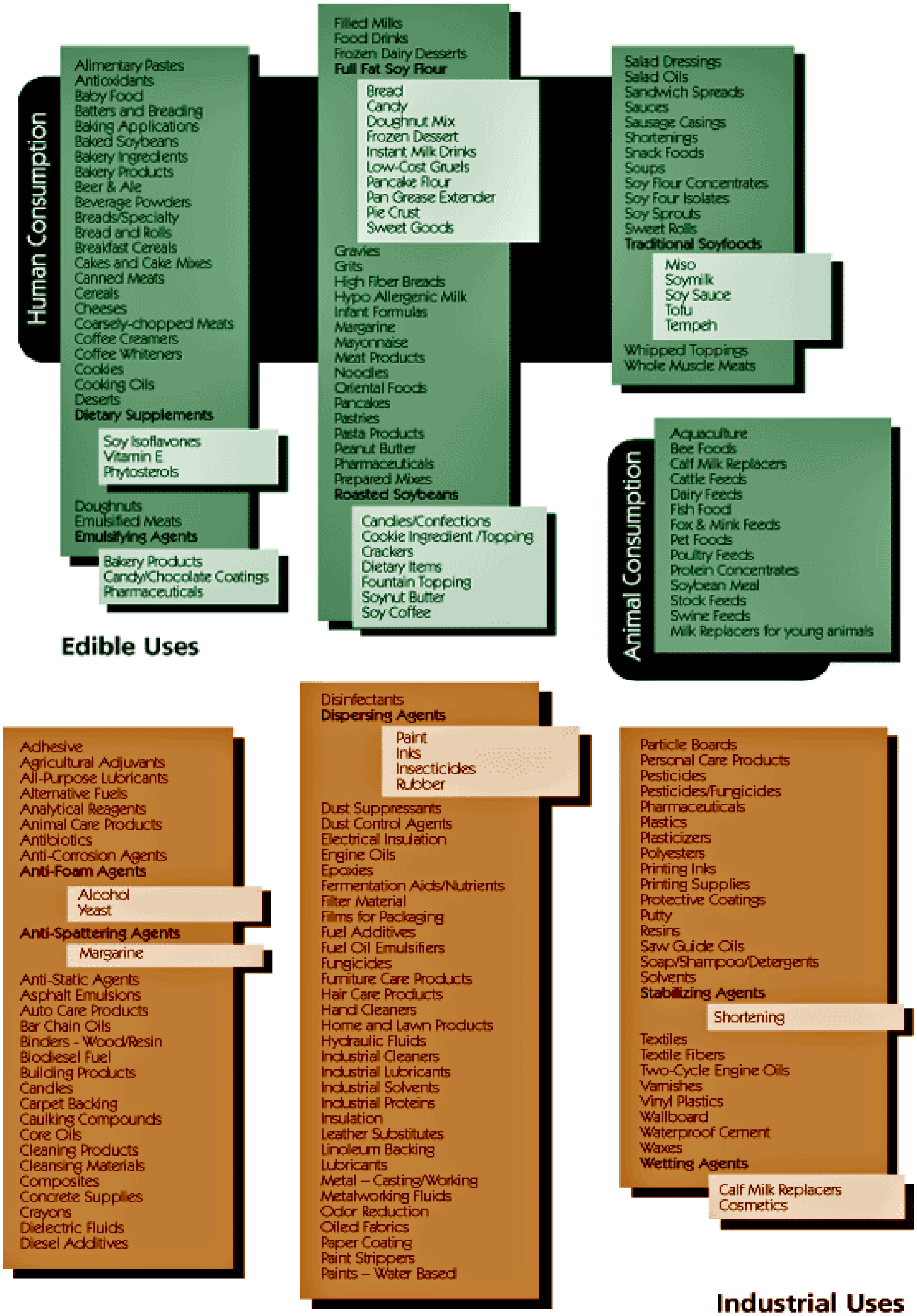
Appendix C: STELLA™ Stock and Flow Symbology

**Table 6: STELLA™ stock and flow overview**

| Name | Symbol | Use |
| --- | --- | --- |
| **Stocks** |  | Accumulates the "stuff" you are modeling such as money, materials, capacity, energy, etc. (flows in – flows out). Stocks can also be linked to other model components using connectors. |
| **Flows** |  | Defines the rate at which the "stuff" moves in and out of the Stocks |
| **Converters** |  | Variables and constants that are all the other model variables that are not Stocks or Flows. STELLA™ provides a large library of built-in calculations and graphical user input. |
| **Decision Blocks** |  | Used to encapsulate important decision making processes in the model. |
| **Connectors** |  | Links model components |

Appendix D: Soybean Uses

Figure 35: Soybean Usage
Source: American Soybean Association



References

American Soybean Association (ASA) Web site. Accessed on Feb 14, 2007. http://www.asa.org

Ash, M., Livezey, J., & Dohlman, E. (2006, April). *Soybean Backgrounder*. Outlook Report No. (OCS-200601). Retrieved August 23, 2006, from US Department of Agriculture, Economic Research Service Web site: http://www.ers.usda.gov/publications/OCS/apr06/OCS200601/

Baize, J. (2006a, February 17).*The Outlook and Impact of Biodiesel on the Oilseeds Sector*. Presented at USDA Outlook Conference in Arlington, VA. Retrieved January 25, 2007 from http://www.usda.gov/oce/forum/2006_speeches.htm

Baize, J. (2006b, October 18). *The global biodiesel industry: A road to riches or an impending train wreck?* Presented at the 2006 American Fats & Oils Association Annual Meeting in New York. Retrieved March 18, 2007 from http://www.afoaonline.org/annualmeeting/slides/AFOA_keynote_presentation_10-18-06.ppt

Biodiesel Magazine. (2007). *Online US biodiesel plant list.* Retrieved Feb 14, 2007 from Biodiesel Magazine Web site. http://www.biodieselmagazine.com/plant-list.jsp

Blondeau, J., Pon, G., Bresciani, S., & Reaney, M. (2006). *Bio-Oils Market Study-Executive Summary*. Retrieved February 18, 2006 from http://res2.agr.ca/saskatoon/result/biooils-biohuile_e.htm#glycer

Bondioli, P. (2003, May 15). *From oilseeds to industrial products: present and next future of oleochemistry*. Presented at International South Europe Symposium Non-Food Crops: From Agriculture to Industry, Bologna, Italy. Retrieved February 20, 2006 from http://www.ienica.net/italyseminar/oils/bondiolipresentation.pdf

Bonnardeaux, J. (2006). *Glycerin Overview*. Retrieved March 25, 2007, from Government of Western Australia Department of Agriculture and Food Web site: http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/SUST/BIOFUEL/GLYCERINOVERVIEW.pdf

Bowman, M. S. (1999). *Applied Economics Analysis*. Upper Saddle River, NJ: Prentice Hall.

Bowman, K. (2003). *Economic Impact of Soy Diesel in Kentucky.* Retrieved February 12, 2006 from http://www.biog-3000.com/PDFs/NEW%20files/biodieselstudy.pdf

Broehl, J. (2006, February 17). The US biodiesel industry matures. *RenewableEnergyAccess.com*. Retrieved February 20, 2006 from http://www.renewableenergyaccess.com/rea/news/story?id=43614

Bryan, M. (2006, Feb 2006). Corn oil extraction can help sustain biodiesel industry growth. *Biodiesel Magazine,* 3 (2).70.

Bryan, T. (2007, Mar 2007). Will 2 billion gallons be a floor or a ceiling? *Biodiesel Magazine,* 4 (3). 8.

Caparella, T. (2005, October 2005). Minnesota mandate takes effect, and IRS clarifies tax incentive issues. *Render Magazine.* Retrieved March 20, 2006 from http://www.rendermagazine.com/October2005/BiodieselBulletin.html

Carlson, R. (2006). *Prospects for Expansion of the Soy-based Biodiesel Industry in Minnesota*. Agricultural Utilization Research Institute. Marshall, Minnesota. Retrieved February 14, 2007 from http://www.auri.org/research/diesel/pdfs/Executive%20Summary%20Bio-Diesel%20Study%20December%2006.pdf

Clark, G. (2006, December 31). Biodiesel is transitional technology says Nextant. *Biofuel Review*. Retrieved from http://www.biofuelreview.com/content/view/705/

Collins, K. (2006, August 26). *Economic Issues Related to Biofuels*. Written testimony to U.S. Senate Committee on Appropriations Subcommittee on Agriculture, Rural Development, and Related Agencies. Retrieved October 26, 2006, from the USDA, Office of the Chief Economist Web site: http//:www.usda.gov/oce/newsroom/congressional_testimony/sentstbiofuels8-26-06_.doc

Collier, C. A., & Glagola, C. R. (1998). *Engineering economic and cost analysis* (Third ed). Menlo Park, California: Addison-Wesley.

Conrad, S. H. (2004, July 25). *The dynamics of agricultural commodities and their responses to disruptions of considerable magnitude*. Proceedings of the 2004 International Conference of the System Dynamics Society. Oxford, England.

Conway, R. (2007, February 23). *Roger Conway: Office of Energy Policy New Uses/USDA*. Presented at the Texas AG Forum Austin, Texas. Retrieved March 23, 2007, from http://agforum.tamu.edu/2007presentations/Conway.pdf

Dale, B. E. (2004, February 23). *Feed protein coproduction with large scale biofuels: Some land resource perspectives & likely economic impacts*. Presented at Role of Biomass in America's Energy Future, Washington, D. C. Retrieved August 26, 2006 from http://engineering.dartmouth.edu/rbaef/meeting/dale_ppt.pdf

Davis, K. S. (2001, September 11). *Corn Milling, Processing and Generation of Co-products.* Presented at the Minnesota Nutrition Conference Technical Symposium. Retrieved from http://www.distillersgrains.org/files/grains/K.Davis--Dry&WetMillProcessing.pdf

Davis, S.C. & Diegel, S.W. (2006). *Transportation Energy Data Book*. ORNL-6974. (Edition 25 of ORNL-5198). Center for Transportation Analysis. Oak Ridge National Laboratory. U.S. Department of Energy. Oak Ridge, TN.

De La Torre Ugarte, D. G., English, B.C., Jensen, K., Hellwinckel, C., Menard, J., and Wilson, B. (2006). *Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion*. Retrieved Jan 7, 2007, from Governors Ethanol Coalition Web site : http://www.ethanol-gec.org/information/Ethanolagimpacts.pdf

Duff, B. (2004, November 16). *Biofuels Project Development: Biodiesel Feasibility Studies*. Presented at the Virginia Biodiesel Conference, Harrisonburg, Virginia. Retrieved March 15, 2006 from http://www.cisat.jmu.edu/biodiesel/presentations/Feasibilty%20Studies%20-%20Duff%201120a%20presentation.ppt

Duffield, J. A. (2006, September 8). *Biodiesel Supply: How Much Can We Produce?* Presented at the Air Quality and Alternative Transportation Fuel Forum, Washington DC.

Edmonds, J., & Reilly, J. M. (1985). *Global energy: Assessing the Future*. New York: Oxford University Press.

Eidman, V. (2006a, 1st Qtr 2006). Renewable Liquid Fuels: Current Situation and Prospects. *Choices,* 21(1). Retrieved March 16, 2006 from http://www.choicesmagazine.org/2006-1/biofuels/2006-1-03.html

Eidman, V. (2006b, June 27). *The Economics of Energy Production in Agriculture*. Paper presented at the "Energy in Agriculture: Managing the Risk" Conference, Kansas City, Missouri. Retrieved January 10, 2007, from Farm Foundation Web site: http://www.farmfoundation.org/projects/documents/Eidmanpaperwithgraphs.pdf

English, B., Jensen, K., & Menard, J. (2002). *Economic Feasibility of Producing Biodiesel in Tennessee*. Retrieved November 14, 2005 from University of Tennessee, Department of Agricultural Economics Web site: http://beag.ag.utkedu/pp/biodiesel.pdf

English, B., De La Torre Ugarte, D. G., Hellwinckel, C., Menard, R. J.,Wilson, B., Roberts, R., and Walsh, M.E. (2006). *25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts*. Retrieved December 1, 2006 from University of Tennessee, Agricultural Policy Analysis Center Web site: http://www.agpolicy.org/ppap/REPORT%2025x25.pdf

Environmental Protection Agency (EPA). (2006*). Renewable Fuel Standard Draft Regulatory Impact Assessment*. Retrieved November 1, 2006, from EPA Fuels and Fuel Additives Website: http://www.epa.gov/oms/renewablefuels/420f06060.htm

Food and Agriculture Organization of the United Nations (FAO) Web site. Accessed January 15, 2007 online at http://faostat.fao.org/

Ford, A. (2002, June 2002). Boom & bust in power plant construction: Lessons from the California electricity crisis. *Journal of Industry, Competition and Trade.* 2(1). Retrieved September 28, 2005, from Washington State University, School of Earth and Environmental Sciences Website: http://www.wsu.edu/~forda/JournalofIndustry.pdf

Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge MA: Productivity Press.

Forrester, J. W. (1971). *World dynamics*. Cambridge, MA: Wright-Allen Press, Inc.

Forrester, J. W. (1975). Collected Papers of Jay W. Forrester. Cambridge MA: Productivity Press.

Forrester, J. W. (1968). *Principles of systems*. Cambridge, MA: Wright-Allen Press, Inc.

Fortenberry, T. (2005). *Biodiesel Feasibility Study: An Evaluation of Biodiesel Feasibility in Wisconsin*. University of Wisconsin-Madison, Department of Agricultural & Applied Economics, Staff Paper No. 481.

Gerard, B. (2006, Jan 2006). Feedstock change is hot and poppin'*, Chemical Processing Magazine*. Jan 2006. Retrieved March 23, 2006 from http://www.chemicalprocessing.com/articles/2006/010.html

Gorley, V. (2006, February 15). Harvest Provides Fuel for Soybean Farmer. *Charlottesville Daily Progress.*

Greene, N. (2004). *Growing energy: How Biofuels Can Help End America's Oil Dependence.* Retrieved July 17, 2006, from Natural Resources Defense Council Web site: http://www.nrdc.org/air/energy/biofuels/biofuels.pdf

GreenShift Corporation (2005, December 22). *GreenShift's Mean Announces 30 Million Gallon Biodiesel Plant in North-Eastern Indiana*. Press Release. Retrieved January 1, 2006 from: http://www.greenshift.com/news.php?id=101

Haas, M.J., Mcaloon, A.J., Yee, W.C., Foglia, T.A. (2006). *A process model to estimate biodiesel production costs*. Bioresource Technology. 97:671-678.

Hamilton, J. (2007, March 28). *NBB and EPA: Where are we going together?* Presented at the EPA Mobile Sources Technical Review Subcommittee Meeting in Arlington, Virginia.

Howell, S., & Weber, A. (2005, March 17). *Biodiesel Plant Investment: Making the Correct Decisions.* Presented at the Iowa Farm Bureau Soy Biodiesel Meeting. Retrieved November 12, 2006, from Iowa Farm Bureau Web site: http://www.iowafarmbureau.com/programs/commodity/energy/Biodiesel%20Plant%20Development%20Considerations.ppt

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science Basis. Summary for Policymakers*. Retrieved February 10, 2007, from the Intergovernmental Panel on Climate Change Web site: http://www.ipcc.ch/SPM2feb07.pdf

International Energy Agency (IEA) (2004), *Biofuels for transport: An international perspective.* Retrieved August 15, 2006, from the International Energy Agency Web site: http://www.iea.org/books

Irwin, L. (2006, Oct 2006). Forecasting the Future. *Ethanol Producer Magazine,* 12 (8). 24.

Jaffe, S. (2005). Biodiesel: A new way of turning plants into fuel. *Technology Review.* Retrieved November 12, 2006 from http://www.technologyreview.com/articles/05/06/wo/wo_060705jaffe.asp?trk=nl

Jones, A., Seville, D., & Meadows, D. H. (2002). Resources sustainability in commodity systems: The sawmill industry in the northern forest. *System Dynamics Review, 18*(2), 171-204.

Koplow, D. (2006). *Government support for ethanol and biodiesel in the United States: Biofuels – at what cost?* Retrieved January 5, 2007 from Earth Track Web site: http://www.earthtrack.net/earthtrack/library/biofuels_subsidies_us.pdf

Kortba, R. (2006, February 2006). Everything under the sun. *Biodiesel Magazine.* 3(2), 28-34.

McClinton, L. (2006, February 2006). Converting bio-diesel co-products into value. *Bio-Prospects,* 3(1). Retrieved August 23,2006 from http://www.agwest.sk.ca/publications/documents/BPFeb06_000.rtf

McMillen, S., Shaw, P., Jolly, N., Goulding, B., Finkle, V., & Broehl, J. (2005). *Biodiesel: Fuel for thought, fuel for Connecticut's future*. Retreived February 11, 2006, from Connecticut Center for Economic Analysis Web site: http://ccea.uconn.edu/studies/Biodiesel%20Report.pdf

McCoy, M. (2006, Feb., 6). Glycerin Surplus: Plants are closing, and new uses for the chemical are being found. *Chemical & Engineering News*, 84 (6). p. 7 , Retrieved from http://pubs.acs.org/isubscribe/journals/cen/84/i06/html/8406notw3.html

Meadows, D. L. (1970). *Dynamics of Commodity Production cycles.* Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. L., Behrens, William W. III, Randers, Donella H., Naill, R. F., Randers, J., & Erich K. O. Zahn. (1974). *Dynamics of growth in a finite world*. Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. H., Randers, J., & Meadows, D. L. (2004). *Limits to growth: The 30-year update.* Vermont: Chelsea Green.

Meeker, D. L (2006). *Essential rendering: all about the animal by-products industry*. Arlington,Virginia: Kirby Lithographic Company, Inc.

National Biodiesel Board (NBB) Web site. Accessed on Feb 7, 2007. http//:www.biodiesel.org

National Corn Growers Association (NCGA) Web site. Accessed on Feb 14, 2007. http//:www.ncga.org

National Renderers Association Web site. Accessed on May 30, 2006. http://www.renderers.org/Statistics/98-05%20prodn-consum.pdf

Neville, D., Wright, D., Rice, P., Sweitzer, S., Jones, A., & Hamilton, H. et al. (2003). *Commodity systems challenges: Moving sustainability into the mainstream of natural resource economies.* Vermont: Sustainability Institute. Retrieved August 21, 2005 from http://www.sustainabilityinstitute.org/pubs/SustainableCommoditySys.2.1.pdf

Nilles, D. (2007, Feb. 2007). NBB stresses quality while aiming for 5 percent market penetration by 2015. *Biodiesel Magazine.* 4(2), 55.

Organisation for Economic Co-operation and Development (OECD). (2005). *Agricultural market impacts of future growth in the production of biofuels*. Working Party on Agricultural Policies and Markets. Paris: OECD. Retrieved from http://www.oecd.org/dataoecd/58/62/36074135.pdf

Orr, J. (2004). *Exploiting clean energy for profit: The Outlook on the Current Biofuels Industry*. Retrieved August 12, 2006, from http://www.newfarm.org/features/0604/biofuels/index.shtml

Pahl, G. (2005). *Biodiesel: growing a new energy economy*. White River Junction, VT: Chelsea Green Publishing.

Pearl, G. (2004, Aug 2004). Rendering 101: Raw material, rendering process, and animal by-products. *Render Magazine.* Retrieved September 15, 2006, from http://www.rendermagazine.com/August2004/Rendering101.pdf

Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J. & Erbach, D.C. (2005) *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge Natl. Lab., Oak Ridge, TN), ORNL Publ. No. TM-2005-66.

Promar International (2005). *Evaluation and Analysis of Vegetable Oil Markets: The Implications of Increased Demand for Industrial Use on Markets and USB Strategy.* Retrieved December 10, 2006, from http://www.unitedsoybean.org/Library/Studies.aspx

Radich, A. (2002). *Biodiesel Production Methods, Costs and Available Capacity*. Retrieved February 23, 2006, from http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/

Reaney, M. J., Furtan, W. H., & Loutas, P. (2006). A Critical Cost Benefit Analysis of Oilseed Biodiesel in Canada. Retrieved March 31,2007, from the BIOCAP Canada Web site://www.biocap.ca/rif/report/Reaney_M.pdf

Renewable Fuels Association (RFA). (2007). U.S. fuel ethanol industry biorefineries and production capacity. Retrieved March 7, 2007, from Renewable Fuels Association Web site: http://www.ethanolrfa.org/industry/locations/

Riley, W. W. (2004). *The Canadian biodiesel industry: An analysis of potential feedstocks.* Paper prepared for the Biodiesel Association of Canada. Retrieved December 15, 2006 from http://www.greenfuels.org/main/biodiesel/pdf/res/102004_Potential_Feedstock_for_Canadian_Biodiesel_Industry.pdf

Roberts, P. (2004). *The end of oil: On the edge of a perilous new world*. New York: Houghton Mifflin.

Roberson, R. (2007, March 22). North Carolina biodiesel plant won't happen. *Southeast Farm Press.* Retrieved April 11, 2007 from http://southeastfarmpress.com/biofuels/032207-biodiesel-carolina/

Rowland, Robert C. (1997). *United States policy on renewable energy use: An overview of the issues related to increasing renewable energy use in the United States.* Lincolnwood, IL: The National Textbook Company.

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York: W.W. Norton & Co.

Sheehan, J., Dunahay, T., Benemann, J., & Roessler, P. (1998). *A look back at the US Department of Energy's aquatic species program: Biodiesel from Algae.* (Report No. NREL/TP-580-24190). Golden, CO: National Renewable Energy Lab.

Shumaker, G. A., McKissick, J., Ferland, C., & Doherty, B. (2001). *A study on the feasibility of biodiesel production in Georgia.*

Soy stats Web site. A reference guide to important soybean facts & figures. Accessed on March 14, 2006. http://www.soystats.com

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world.* McGraw-Hill/Irwin.

Sterman, J. (2002, Winter 2002). All models are wrong: reflections on becoming a systems scientist. *System Dynamics Review*, 18(4), 501–531.

Stroup, R. L. (2004, Jan/Feb 2004). Feedstock Considers for Future US Producers. *Biodiesel Magazine.*1(1).

Tesch, T., Descamps, P.T.& Weiler, R. (2003, September 21).The COSMOPAD modelling framework: Conceptual system dynamics model of planetary agricultural & biomass development. Presented at the Conference Digital Earth2003, BRNO, Czech Republic.

Tickell, J. (2003). *From the fryer to the fuel tank: the complete guide to using vegetable oil as an alternative fuel*. New Orleans, LA: Joshua Tickell Media Productions.

Tickell, J. (2006). *Biodiesel America*. USA: Yorkshire Press.

Tyson, K. S., Bozell, J., Wallace, R., Petersen, E., & Moens, L. (2004). *Biomass oil analysis: Research needs and recommendations*. (Report No. NREL/TP-510-34796). Golden, CO: National Renewable Energy Lab.

US Department of Agriculture, Economic Research Service (USDA-ERS). (2007). *Oil Crops Situation and Outlook Yearbook*. Retrieved January 12, 2007 from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1288
.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2004). *2002 Census of Agriculture: United States Summary and State Data,* Volume 1, Geographic Area Series, Part 51. Retrieved March 23,2006, from http://www.nass.usda.gov/Census_of_Agriculture/index.asp.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2006). *Statistical Highlights of United States Agriculture, 2005/2006.*Retrieved Aug 27, 2006, from http://www.nass.usda.gov/Publications/Statistical_Highlights/2006/STATHI2006.PDF

US Department of Agriculture, Office of the Chief Economist. (USDA-OCE) (2007). *USDA Agricultural Projections to 2016.* World Agricultural Outlook Board, Long-term Projections Report OCE-2007-1 February 2007 Retrieved March 1, 2007, from http://www.ers.usda.gov/publications/oce071/oce20071.pdf

US Department of Energy, Energy Efficiency and Renewable Energy-Alternative Fuels Data Center (USDOE-EERE). (2007). Clean Cities alternative fuel price reports. Accessed on Feb 5, 2007: http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2007). *Annual Energy Outlook 2007 with Projections to 2030*. DOE/EIA-0383. Retrieved February 15, 2007, from http://www.eia.doe.gov/oiaf/aeo/index.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006a). International Energy Annual 2004. Retrieved March 10, 2007 from http://www.eia.doe.gov/iea/

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006b). Energy Information Administration (EIA). Petroleum Overview, 1949-2002. Table 5.1. in Annual Energy Review. Retrieved January 15, 2007 from http://www.eia.doe.gov/emeu/aer/petro.html

US Department of Energy, Office of Biomass Programs (USDOE-OBP) (2006) Biomass Transition Model Workshop Website. Accessed November 15, 2006. http://30x30workshop.biomass.govtools.us/default.aspx?menu=model

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2005). *Building a Successful Biodiesel Business.* Golden, CO: National Renewable Energy Lab.

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004). *Biodiesel Analytical Methods August 2002 - January 2004.* (Report No. SR-510-36240). National Renewable Energy Lab.

Wang, M. (2007). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model Version 1.7. Retrieved March 10, 2007, from the US Department of Energy, Argonne National Laboratory Web site: http://www.transportation.anl.gov/software/GREET/

Weber, J. A. (2007). MARC IV Consulting. Telephone conversation with Steve Bantz March 12, 2007.

Whelan, J., & Msefer, K. (1996). *Economic Supply and Demand.* Retrieved from http://sysdyn.clexchange.org/sdep/Roadmaps/RM6/D-4388.pdf

White, A. S., Yan, Y. C. , Akpunar, E., & Hock, K. K. (2002, July). *Control Strategies for Inventory Management*. Proceedings of the 2002 International Conference of the System Dynamics Society. Palermo, Sicily, July 2002.

Wilson, J. (2007). US Farmers Plan Biggest Corn Planting Since 1944. *Bloomberg.com*. Retrieved March 30, 2007, from http://www.bloomberg.com/apps/news/?pid=20670001&refer=home&sid=ag_W9jQ.1Aoc

Young, N. (2006, January 2006). *Biodiesel & industrial demand for soy oil: study conducted to examine implications for soybean farmers & USB strategy*. Presented at the Qualsoy Board Meeting. Retrieved April 10, 2006, from http://www.unitedsoybean.org/studies_pdf/2005_Promar_Qualsoy.ppt

Zagonel, A. A., Conrad, S. H., & Kaplan, P. G. (2005, July 17). *Modeling the impact of loss in U.S. soybean production resulting from soy rust disease.* Presented at the 23rd International Conference of the System Dynamics Society, Boston, MA. Retrieved February 19, 2006, from the System Dynamics Society Web site: http://www.albany.edu/cpr/sds/conf2005/proceed/proceed.pdf

Zeman, N. (2007, Feb. 2007). Crazy for camelina. *Biodiesel Magazine.* 4(2), 60.

Growing Pains:

Exploring the Future of the US Biodiesel Industry

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A thesis submitted to the Graduate Faculty of

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# Dedication

This research is dedicated to the farmers, scientists, engineers, entrepreneurs, policymakers, and all others working to build a more robust and cleaner renewable energy future. Expanded use of low-carbon fuels such as biofuels pursued in conjunction with aggressive increases in energy efficiency, reduced demand through conservation, and reforms in transportation and land use policies can help to achieve timely reductions in both greenhouse gasses and our dependence on fossil fuels.

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## Preface

In the August of 2004, I became interested in biofuels after attending the Southern Energy and Environment Exposition in Asheville, NC and hearing Lyle Estill and his colleagues from Piedmont Biofuels singing the praises of homegrown fuels. I was hooked. A few months later I discovered the Fuels Diversification Program in the Integrated Science and Technology (ISAT) Department at James Madison University. I decided to enroll in the ISAT masters' degree program because I wanted to learn about biofuels and I recognized that this program would give me a broad, balanced approach when addressing the technical issues society faces with regards to energy, the environment, and sustainability. I had the opportunity to work with the program directors to write a grant proposal to Clean Cities for funding of a small-scale biodiesel processor for the university and performed a detailed process hazards analysis of various small-scale processor designs. Participation in this program afforded me to be opportunity to have discussions with entrepreneurs regarding the development of biofuels plants in the Harrisonburg, Virginia area. After hearing the concerns of these various business leaders, I became extremely interested in the broad drivers, limits, and impacts of the rapidly expanding biofuel industries. This has led to my current thesis research exploring the biodiesel industry using system dynamics (SD) modeling to help understand the impacts of current and future industry growth.

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Abstract

The biodiesel industry -- both in the US and globally -- is experiencing explosive growth. Demand for biodiesel in the US is driven by concerns about energy security, climate change, high oil prices, and economic development and supported by state and federal mandates. The US production capacity has grown by a factor of ten in the past two years, and over forty new plants are currently in or near construction phase. Continued strong growth of biodiesel production capacity depends on producer profitability which will be influenced by several factors such as biomass oil feedstock prices, product and co-product prices, production technologies, and government regulations and incentives. This research aims at evaluating how, when, and to what extent the growth of the biodiesel industry will be influenced by these various factors. A system dynamics (SD) model of the US biodiesel marketplace is developed to explore possible answers to these questions. The construction and use of this model provides a framework for understanding the structure and dynamics of this industry and how feedstock availability will impact growth. Simulating industry behavior over the next decade using the SD model with different scenarios, we can gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. A key finding from this study is that many of the scenario runs indicate that industry may experience a plateau of capacity growth over the next few years due to the impact of increasing feedstock prices on profitability. In addition, the industry will only achieve its own goal to reach five percent of diesel market penetration in the most optimum of feedstock and market conditions.

1. Introduction

1.1. Promise for a new energy future

Biofuels have the potential to yield a range of important societal benefits: reducing emissions of greenhouse gases, increasing energy security, decreasing air and water pollution, conserving resources for future generations, saving money for consumers, and promoting economic development. But, there are increasing concerns about the limits to growth and the unintended economic and environmental consequences of expanding biofuel production. Whereas ethanol and biodiesel made from corn and soybean oil feedstocks have been important in building a strong foundation for the industry; these biofuels feedstocks are currently used for many other purposes such as livestock feed, human food products, and a hundreds of other chemicals and consumer products. Based on land availability and other competing demands, corn and soy based biofuels can ultimately only displace a small percentage of the petroleum-based transportation fuels. The increasing demand from biofuel production will present challenges and opportunities for feedstock markets in the coming years.

Recently, many researchers have attempted to understand the long term growth potential and impacts of the biofuel industries (Perlack et al., 2005; English et al., 2006). For the biodiesel industry, the picture is not at all clear. The Department of Energy Information Administration (USDOE-EIA, 2007) forecasts that biodiesel production will only reach 400 million gallons per year by 2030. This forecast contrasts sharply with the current industry capacity, growth rate, and goals. The current industry capacity in operation is estimated to be over 700 million gallons per year (Biodiesel Magazine,

2007). The National Biodiesel Board recently set industry goals at 5% of the diesel market by 2015 or approximately 2500 million gallons per year of biodiesel (Nilles, 2007). Biodiesel Magazine estimates that if all the capacity in the pipeline becomes a reality, three billion gallons of biodiesel production capacity from all feedstocks may be in place in the US by the end of 2008 (Bryan, 2007). This would require three quarters of all fats and oils produced in the country annually.

With all these lofty numbers and conflicting forecasts, one is left to wonder what the future will hold for biodiesel: boom, bust, or somewhere in between? Have previous analyses adequately focused on the short term growing pains that the industry may incur in the next decade? Using SD modeling tools and techniques, this thesis will explore the nascent biodiesel industry in the US and attempt to evaluate the impact of some of the pressing near-term feedstock supply issues on the growth of this industry.

### 1.2. Costs of our addiction to oil

As President Bush stated in his 2006 State of the Union address, we are addicted to oil. Besides providing 97% of the energy to fuel transportation needs in the US (Davis & Diegel, 2006), petroleum also provides us with everyday products such as plastics, lubricants, man-made fibers, asphalt, and heating oil. As seen in Figure 1, the US consumes one quarter of all the oil consumed every day despite having less than 2% of the world's reserves and slightly less than 5% of the world's population. The US imports 60% of our oil (USDOE-EIA, 2007). The costs of our addiction are staggering: our nation spends approximately a half of a million dollars every minute to pay for imported oil.[1]

[1] Calculations based on $60 per bbl oil price and 2005 EIA oil import data.

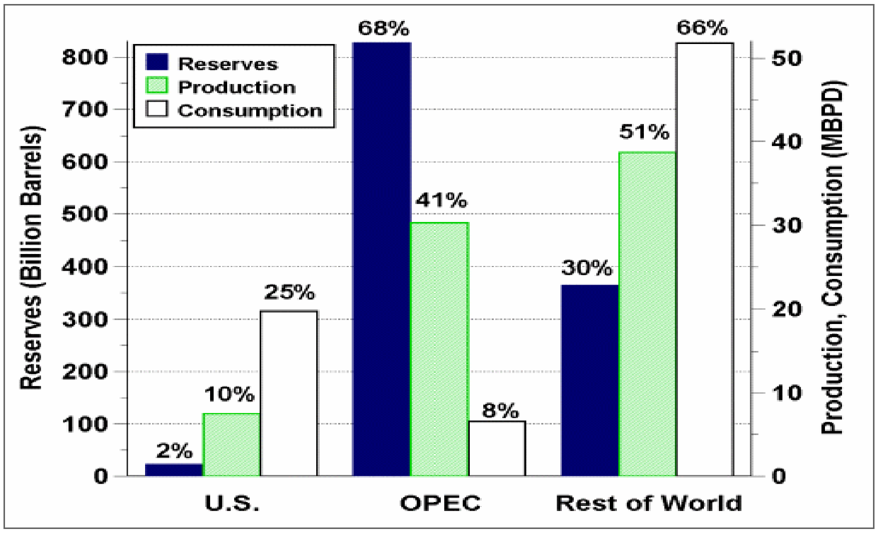


**Figure 1: World oil reserves, production, and consumption 2003**

Source: USDOE Office of Energy Efficiency Renewable Energy [2]

In addition to reducing our dependence on oil, diversifying our energy supply – by including renewable sources of fuel and electricity -- could create tremendous economic opportunities for Americans. And finally, the International Panel on Climate Change, the US National Academy of Sciences, and the scientific academies of ten leading nations have all stated that human activity, especially the burning of petroleum products and other non-renewable fossil fuels, are responsible for the accumulation of heat-trapping gases in the atmosphere, which impacts global climate patterns (IPCC, 2007). Stopping and reversing global climate change may become one of the greatest challenges of our era, and, therefore, we need to measure all energy-related policies by their ability to deliver real and measurable reductions in greenhouse gas emissions. To address the vulnerabilities that result from our oil addiction, we must substantially reduce our demand through efficiency, conservation, and reforms in transportation and land use

[2] Reserves: EIA International Energy Annual 2002, Table 8.1./Production: EIA International Petroleum Monthly, July 2004, Tables 4.1a– 4.1c and 4.3/Consumption: EIA International Petroleum Monthly, July 2004, Table 4.6/ OPEC consumption (2002 data): EIA International Energy Annual 2002, Table 1.2 Data posted at http://www1.eere.energy.gov/vehiclesandfuels/facts/2004/fcvt_fotw336.html.

policies (smart growth), and develop a diverse energy portfolio that emphasizes renewable energy sources such as wind, solar, and biofuels.

1.3. Biofuels- Part of the solution, but no silver bullet

Increasing the use of biofuels -- renewable fuels made from biomass such as ethanol and biodiesel -- can yield a range of important societal benefits, but biofuels alone are not sufficient to remedy the threats that fossil fuels pose to our nation's security, economic health, and environment. Solutions to create a secure and clean energy future must be economically feasible and sustainable, and they must simultaneously address both the supply and the demand sides of the energy equation. Federal and state policy initiatives, consumer demand, high fuel prices and future supply uncertainty, have triggered rapid expansion in the biofuels industries. As seen in Table 1, biofuel production has grown rapidly in response to increasing demand for ethanol and biodiesel, but still only accounts approximately 3% of total US motor vehicle fuel needs. It is estimated that 20% of the 2006/07 US corn crop will be converted to ethanol to supply about 3% gasoline demand (Collins, 2006) and 8% of 2006/07 US soybeans could be converted to biodiesel to supply less than 1% of diesel demand (Conway, 2007).

| | Gasoline (million gals) | Ethanol (million gals) | Pct of gasoline market | Diesel (million gals) | Biodiesel (million gals) | Pct of diesel market |
|---|---|---|---|---|---|---|
| 2000 | 128,662 | 1630 | 0.89% | 37,238 | 0 | 0.00% |
| 2001 | 129,312 | 1770 | 0.96% | 38,155 | 9 | 0.02% |
| 2002 | 132,782 | 2130 | 1.12% | 38,881 | 11 | 0.03% |
| 2003 | 134,089 | 2800 | 1.46% | 40,856 | 18 | 0.04% |
| 2004 | 137,022 | 3400 | 1.74% | 42,773 | 28 | 0.07% |
| 2005 | 136,949 | 3904 | 2.00% | 43,180 | 91 | 0.21% |
| 2006 | | 5450 | | | 225 | |

**Table 1: US motor fuels consumption 2000-2006**

Source: 2000-2005: USDOE-EIA Annual Energy Outlook 2007,
2006: National Biodiesel Board, Renewable Fuels Assoc.

1.4. Limits to growth

In the US, ethanol is predominantly made by fermenting the sugars derived from the starch in the corn kernel, and biodiesel is made by chemically reacting triglycerides (found in plant oils and animals fat feedstocks) with an alcohol and catalyst.[3] Biodiesel feedstocks can come from oilcrops (e.g. soybean, rapeseed, and palm oils), and also from used oils, fats, and greases from rendering facilities and other food processing facilities. The use of corn and soy feedstocks has helped build a strong base for the biofuels industry and has helped to establish a foothold in a transportation fuel marketplace. However, the current feedstocks have many other uses besides fuel production: mainly feed and food for livestock and human consumption, but also products like soy-based ink[4] and plastic from corn.

Ultimately, the limiting factor to growth for today's biofuels will be the availability of feedstocks. For example, if all corn produced in the US in 2005 was converted to ethanol -- with nothing left for food or animal feed -- this would displace less than 15% of the gasoline demand[5]. Biodiesel production from oils and fats may be even more limited. Currently, if we used all the domestically available oil crops, waste fats, and oils to make biodiesel -- with nothing left for margarine, cooking oil, animal feed supplement, or other oil uses -- this would displace less than 10% of the current diesel demand.[6] Moreover, all of the vegetable oil in the world would only make enough biodiesel to supply just over half of the US diesel consumption (Baize, 2006b). Many, like John Sheehan at the National Renewable Energy Laboratory (NREL), agree that corn

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[3] See Appendix B for more details regarding biodiesel chemistry and process.
[4] See Appendix D for a complete listing of edible and industrial soy uses.
[5] Calculations based on data from DOE-EIA (2006) and National Corn Growers Association.
[6] Calculations based on data from Tyson et al. (2004), Soystats, and National Renderers Association.

ethanol and soy biodiesel are not sufficient long-term solutions to breaking our oil addiction (Irwin, 2006).

To capture a greater percentage of the transportation fuel markets and to help realize significant reductions in oil usage and greenhouse gas emissions, we must think outside the kernel and the bean and pursue biofuels that utilize a diverse array of biomass feedstocks. To this end, public and private efforts (and funding) have been has focused on the research, development, demonstration, and deployment of next-generation biofuels. These next-generation biofuels can be produced using a variety of production methods and can be made from corn stalks, wheat straw, woodchips, tree trimmings, switchgrass, municipal wastes, and even algae.

### 1.5. The biodiesel dilemma

Biodiesel has become an attractive alternative for replacement of petroleum-diesel because it is domestically produced, less polluting,[7] and used at any blend percentage with no vehicle modification required. The most common way to produce biodiesel is shown in Figure 2. Reacting biomass oils with a simple alcohol (typically methanol) and a catalyst produces a renewable fuel called Fatty-Acid Methyl Ester (FAME) biodiesel and a co-product, glycerol (or glycerin). Although the renewable diesel market is currently dominated by FAME biodiesel, alternate production pathways are being pursued such as biomass gasification/Fischer-Tropsch diesel and refinery hydrogenation of biomass oils (both are shown in Figure 3).

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[7] Emission reduction of greenhouse gases (GHG), Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Particulate Matter (PM) - based on GREET model from Argonne National Lab (Wang, 2007)

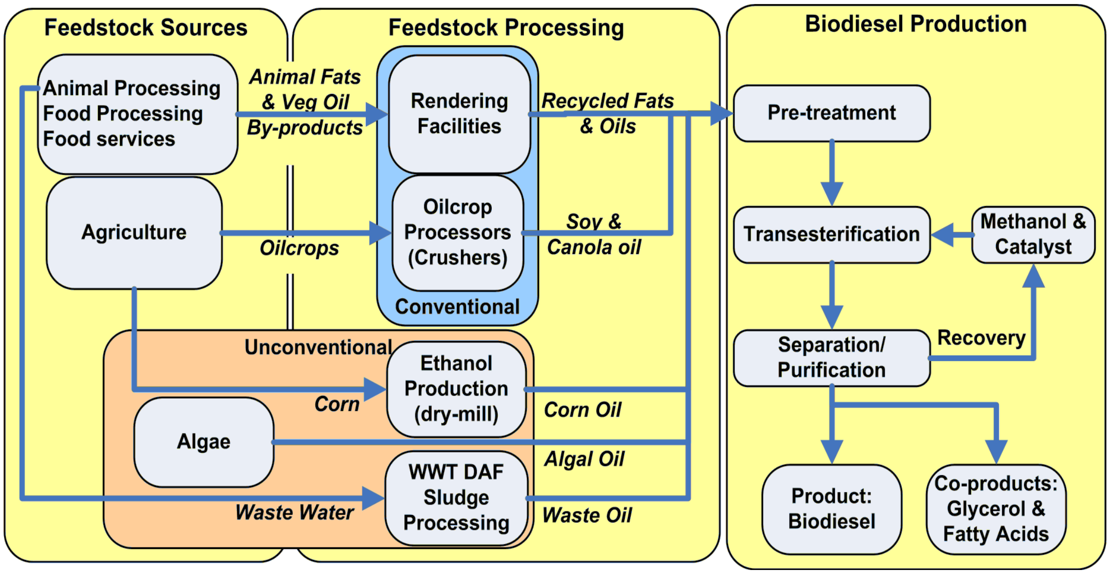


Figure 2: FAME biodiesel feedstocks and production diagram

The biomass gasification process, seen in Figure 3 below, is promising because it enables renewable fuel producers to use a diverse array of feedstocks with an estimated one billion tons of potential feedstock (Perlack et al., 2005). FAME biodiesel and hydrogenation currently have a limited supply of biomass fats and oils as feedstocks.

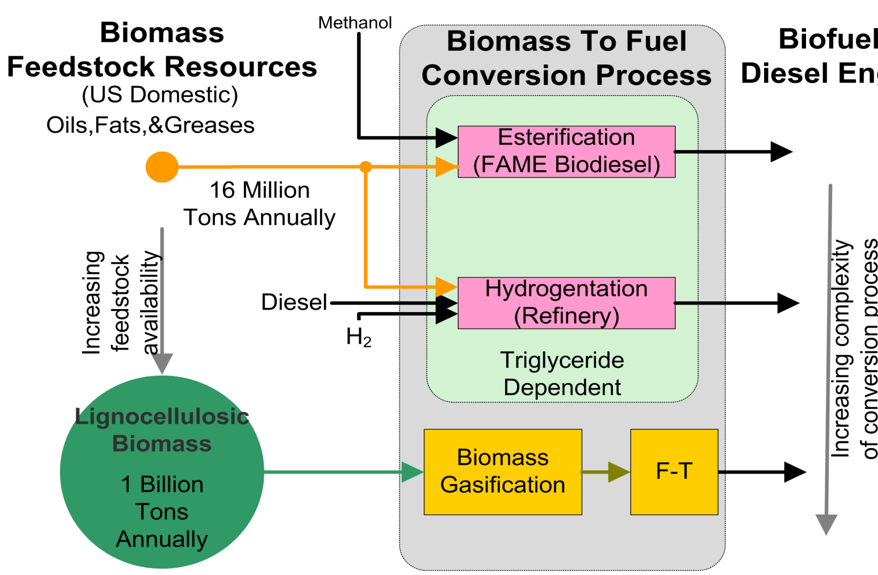


Figure 3: Renewable diesel production pathways

The alternative renewable diesel processes, shown in Figure 3, are currently at various phases of commercialization[8,9] and show great promise. But, due to increased process complexity and capital costs, investors have not yet begun to transition away from FAME biodiesel production to these newer technologies. As the cost of biomass oil feedstocks continues to rise and cut into the profit margins for FAME biodiesel producers, these technologies may soon begin to be more prominent in the biodiesel industry.

The US uses three times more gasoline than diesel (USDOE-EIA, 2006b). Hence, much of the effort to develop renewable transportation fuels has focused on gasoline alternatives such as ethanol. In 2005, the ethanol industry dwarfed biodiesel, producing over 40 times as much fuel. Compared to ethanol which became commercial in 1980's, the US biodiesel industry is in its infancy. Research and development took hold in the early 1990's and commercial production began to appear in the late 1990's. Expanding diesel demand, high oil prices, state and federal environmental mandates, and growing consumer awareness of environmental and energy security issues have fueled the growing demand for biodiesel in the US.

To meet the booming biodiesel demand, US FAME biodiesel production capacity is expanding rapidly. According to Biodiesel Magazine January 2007 online plant listing (see Appendix A), the biodiesel production capacity is approximately 700 million gallons per year and forty eight new biodiesel plants are under construction in the US. Over the next few years, as these new plants become operational, the total capacity will easily

[8] Conoco-Phillips and Neste Oil are working to commercialize a renewable diesel process unit integrated with oil refineries in which they hydrogenate natural oil. This offers advantages to the large fuel producers to better integrate renewable fuels into the fuel pool (versus blending further downstream).

[9] Choren, a European company, and others are gasifying biomass and then processing this gas into a diesel fuel using the Fischer-Tropsch (FT) process.

exceed one billion gallons per year as illustrated in Figure 4. This is an extraordinary growth rate for an industry that had just 30 million gallons of production in 2004 (NBB, 2007).

The actual biodiesel produced annually is currently far below the design capacity of the US plants. In earlier periods, the low capacity utilization (Actual Production/Design Capacity) could be attributed to low demand and/or profitability issues. Currently, low capacity utilization is most likely due to operational (startup) problems associated with rapid growth in a young industry (Koplow, 2006). As shown in Figure 4, the biodiesel industry only achieved up to 42% capacity utilization in the 2001-2006 time-frame.

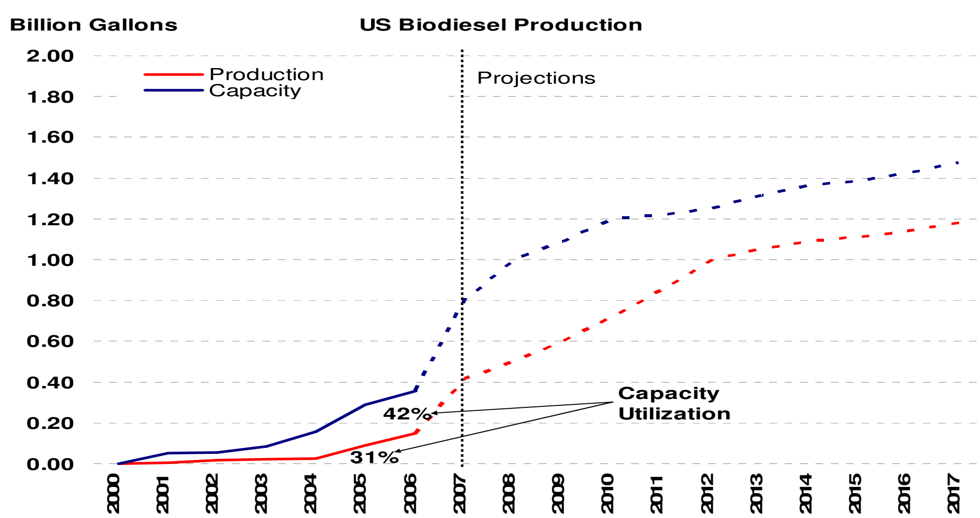



**Figure 4: Biodiesel US production and capacity (historical and projections)**

Sources: Biodiesel Magazine, NBB, Koplow (2006), and production projections used from Ugarte et al. (2006)

As processes improve and the industry builds operational experience, and as the demand and cost pressures on the biofuel producers increase, the productivity (as indicated by capacity utilization) should increase. However, as the industry grows, biomass oil feedstock availability will become a pressing issue. In 2004, US biodiesel

demand consumed less than 1% of the total biomass fats and oils produced in the US (Figure 5). Over the next decade, as new biodiesel plants come online, the biodiesel production crosses one billion gallons per year, the demand could approach one quarter of the total fats and oils the market.

So, the biodiesel dilemma is: production cost are relatively high because the feedstocks compete in high-valued food markets, but the selling price of biodiesel is relatively low because it competes in the fuel market with petroleum diesel which historically has a lower value than animal fats and oil (Duffield, 2006). Uncertainty in the future of biomass oil feedstocks has industry participants worried that new biodiesel production facilities may not have an affordable feedstock supply to make their operations profitable. To be sure, many have recognized this problem and are shifting new plants to multi-feedstock processing capability that enables FAME biodiesel producers to process cheaper, lower quality feedstocks.

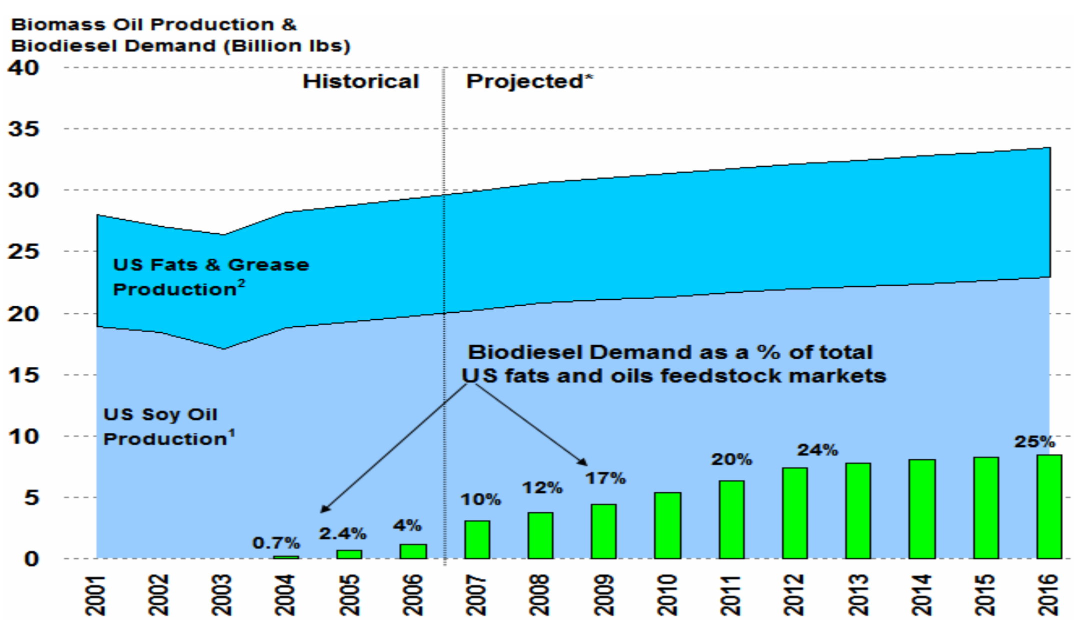



**Figure 5: US biomass oil production (soy oil and fats & greases)**

Sources: Historical data from Soystats (1) and National Renderers Assoc (2)

However, those feedstock supplies are also used in other markets and not expected to grow significantly over the next decade. The potential for a feedstock shortage to impact the growth of the biodiesel market is generally recognized, but it has not seemed to dampen the exuberance for building new FAME production facilities.

### 1.6. Research objectives, organization, and methodology

**Section 1** articulated the problem of feedstock limitations on the expansion of FAME biodiesel industry. The working hypothesis for this thesis is that feedstock limitations will continue to put pressure on producer profitability, and this will adversely impact the industry growth over the next decade. The main objectives for this research are:

- To investigate the market dynamics of the FAME biodiesel industry
- To build a system dynamics research model to help investigate how growth in this market (as represented by the total production capacity of US biodiesel suppliers) will be impacted by feedstock availability over the next decade

System Dynamics (SD) modeling (e.g. see Forrester, 1961; Meadows, 1970; Sterman, 2000) was preferred over other modeling tools because of the inherent heuristic nature of the SD model building process: illustrating the structure, causal relationships, and feedback loops. The research model constructed for this thesis will be referred to as the Biodiesel Industry Growth Simulator (BIGS).

In **Section 2**, I review the research and methods that have been used to analyze the potential for and the impacts of growth in the biofuel and bioenergy industries. Then,

I discuss how my research draws upon these other areas of research, then uses system dynamic modeling to take a unique look at this problem.

In **Section 3,** I define the model boundaries and structure and provide the background for understanding the growth dynamics of the biodiesel industry over the next decade. I discuss the biodiesel supply chain and build up the model sector-by-sector. Then I assemble the model sectors and discuss the important factors and interactions that could impact growth in the next decade. Finally, I conclude this section with a discussion of methods for testing the model structure and assumptions.

In **Section 4,** I outline how the model can be used to answer the research questions by postulating various scenarios and then simulating industry behavior over the next decade using the SD model. This will help to gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. I explore conditions under which the simulated biodiesel market can be expected to experience healthy growth, and the conditions under which this market might experience decline. The results will help identify conditions under which biodiesel production capacity can be expected to grow smoothly, and those conditions under which it could encounter “boom and bust” cycles.

In **Section 5**, I summarize the findings of this study and makes recommendations regard to policy, further research, and technology and market development.

2. Literature Review – Biodiesel Market Dynamics

The basis of this research draws upon four research areas: a) bioenergy assessment modeling; b) regional feasibility studies; c) SD modeling of industrial capacity and production; and d) SD modeling of the bioenergy markets. The rapid expansion of the bioenergy industries has prompted pressing questions such as: How much petroleum can biofuels ultimately displace? How fast can this occur? What will be the impacts of this rapid expansion?

To answer these and other important questions, many researchers from government agencies, academia, non-governmental organizations (NGOs), private consulting firms, and corporations have published assessments and projections for the future potential for biomass to provide transportation fuels, energy, products and power. Many of these assessments such as the often cited joint USDA-DOE Billion Ton Study[10] focus on a "point B" in the distant future -- often decades away – and tend to spend less time examining the dynamics of how we get from point A to point B. To help better understand the near-term transitional dynamics, US DOE Office of Biomass Programs has tasked a team of modelers to build the Biomass Transition Model based on System Dynamics (USDOE-OBP, 2006). This work will be critical for understanding the transition to second generation cellulosic biofuel technologies to displace gasoline, however, this effort does not focus on the specific near-term growth issues that the biodiesel industry is facing.

[10] The USDA-DOE study (Perlack et al., 2005) titled "Biomass as Feedstock for Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion-Ton Annual Supply" assesses the ability of US agricultural and forestry industry to provide sufficient biomass feedstock for transportation fuels, electrical power generation, and bioproducts. Although the report detailed several different land use and biomass production scenarios with a wide variation in results, the optimum scenario which yield 1.3 billion tons of biomass annually is often cited as the ultimate potential to support massive expansion of the bioenergy industries.

2.1. Assessing the potential of bioenergy

In recent years, many studies (e.g. see English et al., 2006; Perlack et al., 2005; IEA, 2004) have been performed at the state, national, and international levels to assess the potential for and implications of expanding biofuel production. Much analysis of the biofuels industry potential in the US tends to focus gasoline displacement (with ethanol) and minimizes discussion of renewable diesel. Two earlier assessments of the biodiesel industry were performed by researchers at the NREL (Tyson et al., 2004) and Promar International (Promar, 2005). The NREL study optimistically concluded[11] that biomass oils can displace up to 10 billion gallons of petroleum by 2030 if incentives or mandates are used to promote fuels and bio-based products from biomass oils. In late 2005, the consulting firm Promar International was commissioned by the United Soybean Board (USB) to analyze the impact of the growth of the industrial use of soybean oil (biodiesel) would have on the soybean oil markets through 2012. They used a global econometric model to assess market impacts and their growth projections are shown with the other projections in Figure 6. More recently a study published by Nexant Consultants in December 2006 concludes that FAME biodiesel will “probably be a transition technology, capable of substituting for only a small fraction of global diesel demand” (Clark, 2006). The report also concludes that integrated thermochemical platforms (as discussed in section 1.5) will soon take the lead in renewable diesel production.

The latest ten-year agricultural outlook from the USDA issued in February 2007 (USDA-OCE, 2007) forecast biodiesel production would only rise to 700 million gallons per year and then plateau at this level due to increased price of feedstocks (Figure 6).

[11] In this estimate, NREL assumed a)canola would be planted on 30 million acres of current wheat acreage (wheat exports), b) 30 million acres of CRP and other pasture land would be used to grow oil crops, and c) 30 million acres of soybean land is converted to higher yielding oil seeds.

The USDA assumed that the current government support (tax credits) for biodiesel would continue, but they also modeled an alternative scenario in which the government support was allowed to expire and the biodiesel industry was shown to collapse almost completely. This USDA forecast also provides insight into the impacts of the rapid increase in corn acreage due to ethanol expansion.

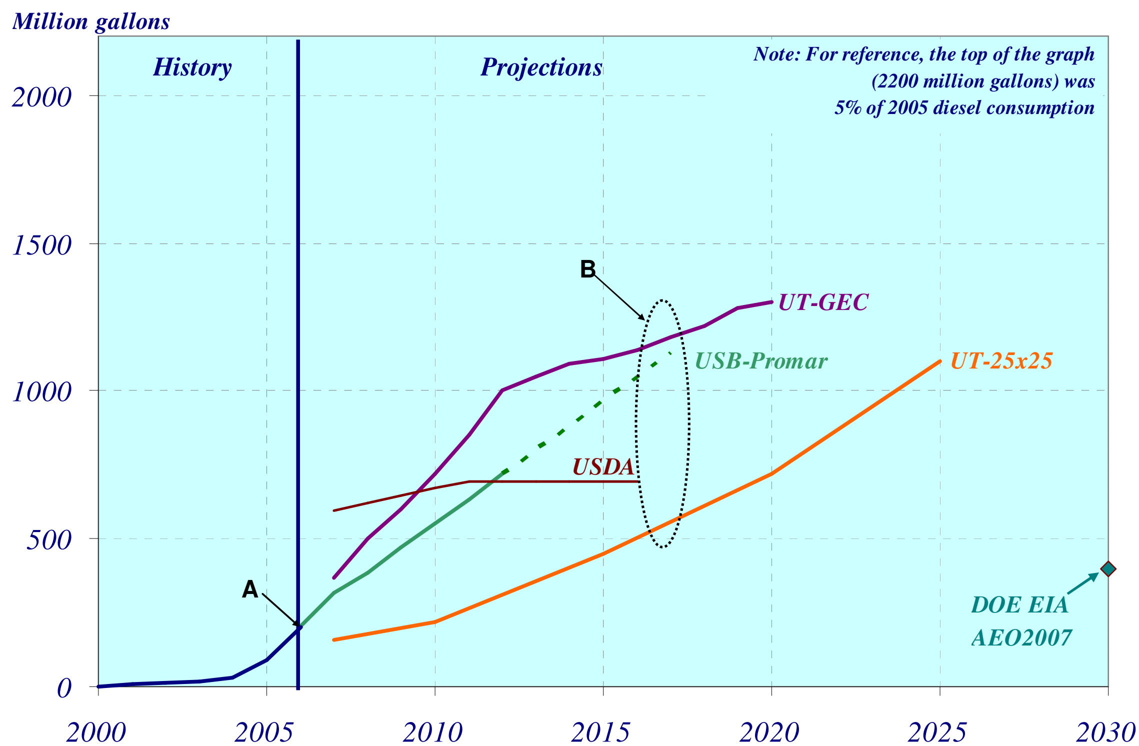



**Figure 6: Projections of biodiesel production compiled from various reports**

Sources: USDA-OCE (2007), Promar(2005), English et al. (2006),
Ugarte et al. (2006), USDOE-EIA (2007)

As mentioned previously, the findings from the various biodiesel growth predictions do not give a clear or consistent picture of the industry future as seen in the trends shown in Figure 6. Included are data from the two reports produced by agricultural economists at the University of Tennessee (UT-GEC and UT-25x25). The UT-GEC projection was generated as a part of study commissioned by the Governor Ethanol Coalition that analyzed the agricultural impacts of a 60 billion gallon per year

Renewable Fuel Standard (RFS). The UT-25x25 projection was generated for a report commissioned by the 25 x ’25 Coalition to study the agricultural impacts of a generating 25% of US energy from renewable resources in the year 2025. Both of the University of Tennessee projections were developed for use with extensive national agriculture and energy models designed in coordination with government labs and agencies (English et al., 2006; Ugarte et al., 2006). Notice the AEO 2007 projection (data point shown on the bottom right for biodiesel production in 2030) contrasts dramatically with all the other projections (USDOE-EIA, 2007).

### 2.2. Biofuel feasibility studies

Feasibility studies are performed when companies are considering plant construction in a region and when state or regional authorities are promoting local economic development (e.g. see Carlson, 2006; Fortenberry, 2005; McMillen et al., 2005; Duff, 2004; Bowman, 2003; English et al., 2002; Shumaker et al., 2001). While these studies often provide a good overview of regional markets and economic impacts and are useful for private and public decision making, they do not adequately address the impacts on larger national markets and overall availability of feedstocks. Feasibility studies are valuable to this effort because they help us to build an understanding of the criteria that investors use to make plant investment and operational decisions. Understanding these micromotives will help us to better model the macrobehavior of the marketplace (Schelling, 1978).

## 2.3. System dynamics modeling of commodity markets

Since Jay Forrester published the landmark book Industrial Dynamics (1961), many researchers have used SD modeling to analyze industrial growth and the interactions in commodity markets. The model in this thesis is built upon basic feedback structure for industrial capacity growth and commodity production cycles proposed by Meadows' hogs model (1970) and Sterman's textbook, Business Dynamics (2000). Others researchers like Sandia National Laboratory's Stephen Conrad have also built upon Meadows' work by describing an initial crop model of corn production cycle and how it interacts with other market sectors (Conrad, 2004). Later, Conrad joined with colleagues to adapt this generic crop model structure for soybean production to help better understand the consequences of soy rust to US agriculture (Zagonel et al., 2005). These modeling efforts reinforce the research methodology used in this thesis and validate certain structural assumptions made in constructing the agricultural feedstock (soy oil) sector of the BIGS model.

## 2.4. System dynamics modeling of bioenergy markets

Key researchers at the national government research institutes have seen the potential of SD modeling tools to analyze the transitional dynamics of emerging bioenergy markets. As mentioned above, a team comprised of systems modelers and bioenergy experts from top government research laboratories are currently developing a SD model – named the Biomass Transition Model -- to better understand drivers and constraints on the large-scale deployment of biofuel production.[12] This extensive SD

[12] The Biomass Transition Model is sponsored by the US Department of Energy Office Biomass Programs (DOE-OBP). The initial model development, led by researchers at NREL, began in July 2005.

modeling effort focuses on the transition of the ethanol market from corn to cellulosic feedstock and should be a valuable resource for analysis of current and future policies. The current version of this model will not be completed until the end of fiscal year 2007, hence no official reports have yet been published formally documenting this work.[13] The model description and minutes from the intermediate model review workshops have been posted online for the general public (USDOE-OBP, 2006).

The development of the BIGS research model has drawn from all four research areas: bioenergy assessment modeling; regional feasibility studies; SD modeling of industrial capacity and production; and SD modeling of the bioenergy markets. This understanding has been synthesized with data and information from other biodiesel industry and feedstock market sources to create a working SD model to investigate the near-term growth in the biodiesel industry. While these simulated behaviors are not a "crystal ball" into the future, this unique SD perspective may provide insights to industry leaders and policy-makers to improve understanding of the biodiesel industry.

[13] Version 1.0 of the model was peer-reviewed at a group session of industry experts in Washington DC in October 2006. The results of this modeling workshop are posted online at http://www.30x30workshop.biomass.govtools.us/documents/061106ScenarioModelWorkshopReport.pdf

3. Modeling the Biodiesel Industry

3.1. Biodiesel market overview

Recall that the purpose of this thesis is to investigate how biodiesel industry growth will be impacted over the next decade through its interaction with the feedstock markets. The purpose of this chapter is to define the boundary and structure of the Biodiesel Industry Growth Simulation (BIGS) SD model and then to explore the dynamic behavior and the causal relationships between the main actors in the market. A high level overview of the biodiesel supply chain (see Figure 7) highlights the important market sectors and interactions.

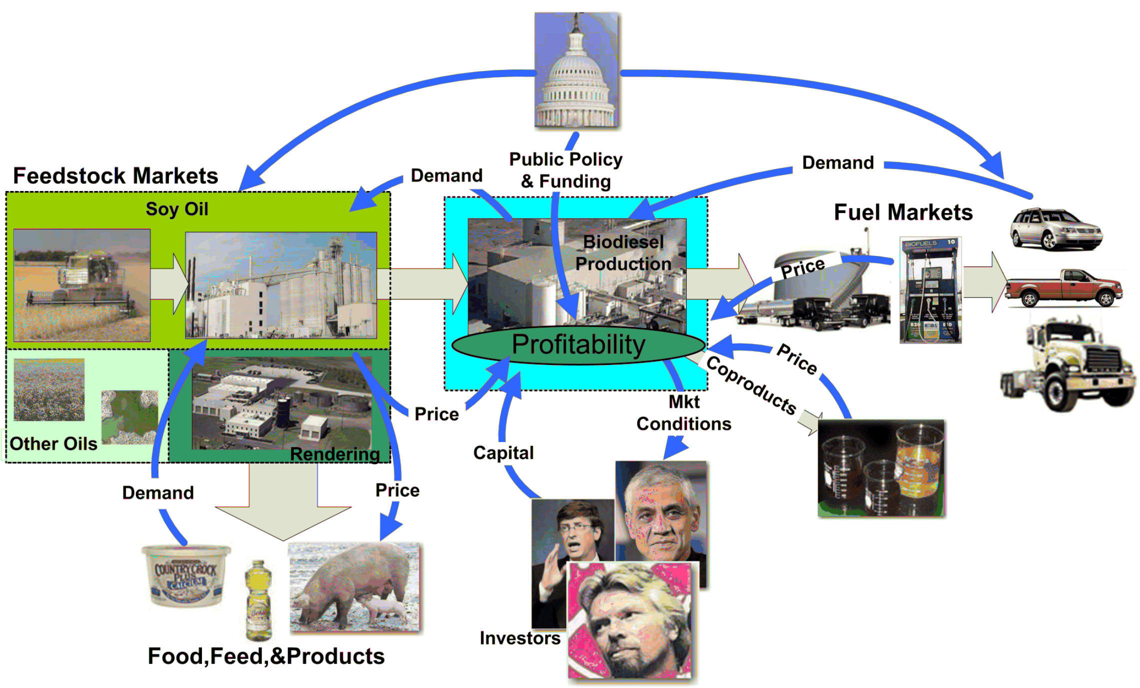



Figure 7: Biodiesel Market Overview

Beginning at the left, the feedstock markets provide oils and fats to the production facilities where it is converted into biodiesel fuel. Biodiesel fuel is then blended with petroleum diesel and sold as a transportation fuel (alternatively it also can be used to

displace heating oil or in industrial boilers). The growth of the biodiesel industry has been driven by state and federal public policies such as renewable fuel mandates and tax credits, high oil prices, and consumer awareness of energy security and environmental issues. The stock and flow diagram presented in Figure 8 shows the ***Exuberance*** reinforcing loop (R1) that has driven the industry growth in recent years and has been dominated by ***Perceived Future Profitability.*** The working hypothesis of this research is that the balancing feedback loops, ***Build*** and ***Produce*** (B1 and B2) will limit industry growth as ***Profitability*** is impacted by rising feedstock prices. In the model, ***Profitability*** is influenced endogenously by feedstock prices and exogenously by crude oil prices (reflected in the diesel price), co-products prices, and government interaction in the market (e.g., tax credits).

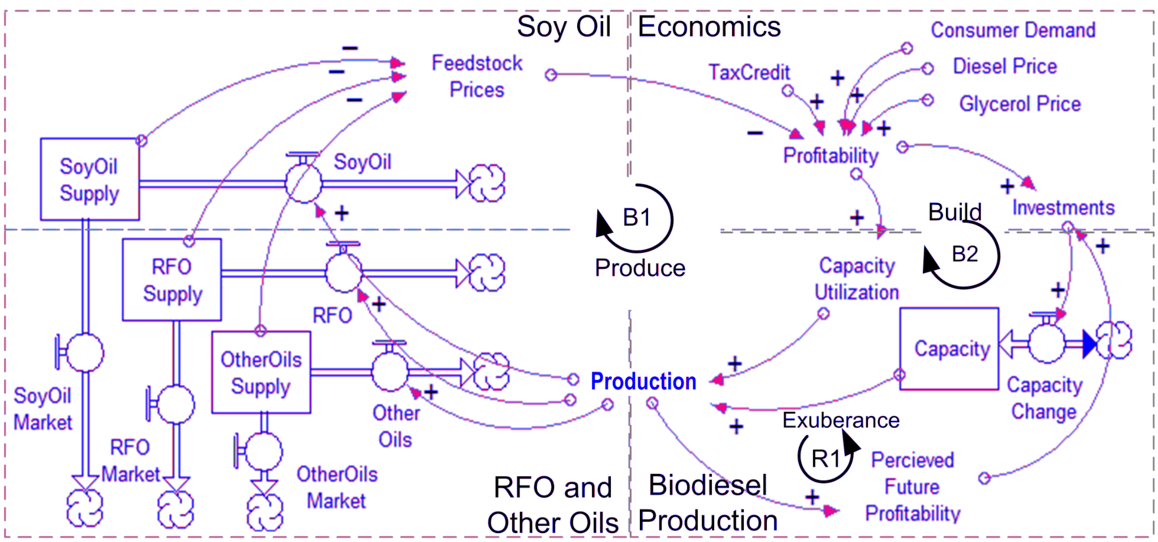



Figure 8: Biodiesel Model Main Feedback Loops

An increase in biodiesel ***Production*** will increase the demand for fats and oils. This will put upward pressure on ***Feedstock Prices*** as biodiesel demands an increasing market share. Increasing feedstock prices, in turn, will negatively impact ***Profitability.***

Decreasing ***Profitability*** will impact the decisions that investors and producers make with regards to capacity utilization and capital investments. The aggregated, high level SD stock-and-flow model diagram (Figure 8) is divided into sectors. In the following sections, these sectors are further examined, focusing on the important variables, causal relationships, and dynamic behavior.

3.2. Biodiesel production sector

Investors have been attracted to the biodiesel industry because they have seen an opportunity to make a profit and to enter a market where there is a high probability that demand will far exceed supply for the foreseeable future. Hence, industry players are investing in capacity that could produce ten times the demand seen in 2005 (Irwin, 2006). To help understand the dynamics of capacity growth, the biodiesel production capacity stock and flow diagram, based on the industrial capacity structure in Sterman (2000), is presented in Figure 9.

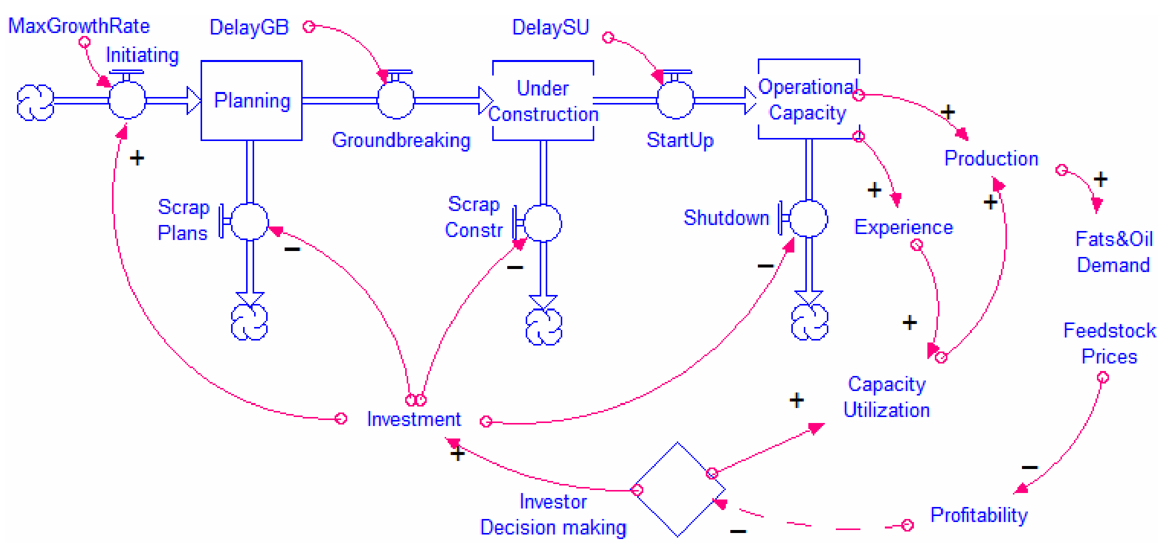



Figure 9: Stock and Flow Diagram – Biodiesel Production Sector

The three main stocks in this sector represent the aggregate industry production capacity at various stages in the "capacity pipeline" -- ***Planning***, ***UnderConstruction***,

and ***OperationalCapacity*** -- in millions of gallons of biodiesel per year. The investor decision-making process is modeled by using the current and anticipated profitability to determine the rate new capacity is added (***Initiating***). In an attempt to model real-world plant limitations such as construction/engineering bottlenecks, the ***Initiating*** rate is limited to a maximum growth rate. Investors also use this same profitability information when making decisions to shut down existing operating capacity or to scrap facilities that are under construction or in the planning phase. In the model, time delays were added to represent real-world market information and management decision-making delays. These delays in the system create an important dynamic during periods of rapid growth, as they allow the possibility that the investment in new biodiesel capacity can overshoot the actual long-term demand. This overcapacity could eventually lead to contraction (or possibly collapse) of the biodiesel production capacity. This is somewhat analogous to the boom and bust cycles in the electric power industry (discussed in Ford, 2002). In addition to the capacity stocks, the model variable ***CapacityUtilization*** (%) is adjusted endogenously by profitability and exogenously by accumulating operating experience. ***Production*** of biodiesel is modeled as the product of ***CapacityUtilization*** and ***OperationalCapacity.***

### 3.3. Biodiesel economics sector

In the real world, the profitability of individual biodiesel plants will be affected by many other factors such as plant size, location, capital installed cost, financing, and other operating costs (fixed and variable). But to simplify the modeling of industry profitability, I use the margin (as defined in Eq.1) as an aggregate indicator of overall industry profitability. For biodiesel production, the margin is:

**Margin = (Biofuel Price + Co-Product Price) – (Feedstock Price + Other variable costs) Eq. 1**

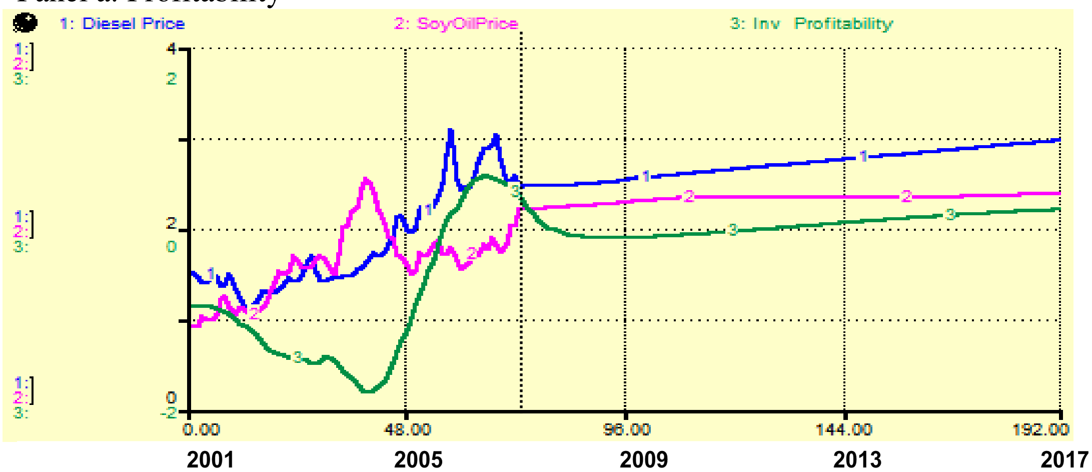
The feedstock makes up 70-80% of costs on average (vanGerpen et al., 2005). The other variable costs are much less significant and the model assumes them to stay relatively constant. The glycerol co-product assumptions are discussed in more detail in section 3.6.4. Simplified, the aggregate indicator of profitability is dominated by the difference between the biofuel price and the oil feedstock price.

Biodiesel is typically priced similar to that of a petroleum diesel blend component in order to be attractive in the blend component market. For that reason, in the model, I assume biodiesel will track diesel prices (plus an offset) for the calculation of the margin. Diesel price will be calculated from the AEO crude oil price projections (USDOE-EIA, 2007). The historical nationwide average price of biodiesel is difficult to track, but according to the sparse data compiled from quarterly price reports from the Alternative Fuel Data Center (USDOE-EERE, 2007) the price of biodiesel has been approximately $0.80 to $1.00 above the price of diesel over the past year and a half.

Since investors use current margin and anticipated future margin in the decision-making process, these two variables are combined in the composite variable ***InvProfitability***. To be profitable, this composite margin must exceed an aim or an acceptable minimum margin (***MarginMin)***. As the deviation from aim increases, the more attractive the market to potential investors and the greater the rate of growth in biodiesel production capacity. The investor decision making details are encapsulated the ***Investor Decision Block*** (Figure 9). The investor propensity to add or to decrease production capacity in is modeled through the use of a Proportional-Integral-Derivative (PID) controller, which acts on the difference between the Margin and the Minimum

Acceptable Margin (White et al., 2002). In addition, if the rate at which this difference is changing is positive, then higher margins are expected in the future, thereby further enhancing the attractiveness of the market. Under such conditions (high margins and higher anticipated margins), the rate at which investors enter the market can be very high indeed.

Panel a: Profitability




Panel b: Capacity stocks and Production

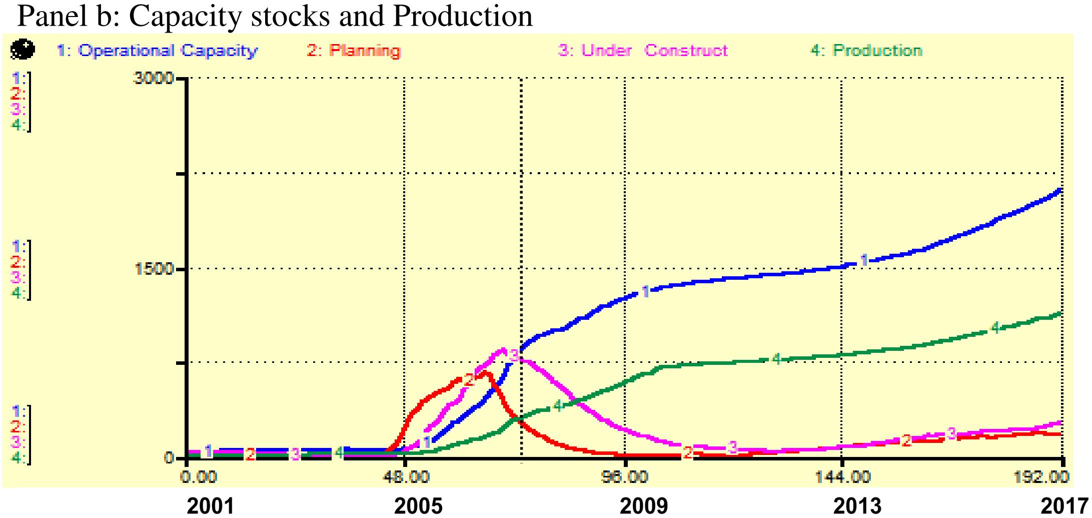



Figure 10: Biodiesel Industry Production and Capacity Dynamics

This mental model is supported by investor behavior in the market since 2004. The BIGS model behavior was calibrated using the industry data aggregate profitability and capacity data from 2001 through December 2006. Figure 10 shows both historic and simulated time trends that illustrate the response of the investor community to change in

biodiesel profitability. Panel (a) presents the historic and forecasted ***Diesel Price*** (1), ***SoyOilPrice*** (2), and the calculated aggregate ***InvProfitability*** (3)**.** Panel (b) presents the simulated impact that changes in ***InvProfitability***, panel (a), have on the industrial capacity stocks ***Planning***(2), ***UnderConstruction***(3), and ***OperationalCapacity***(1). Note that the rapid growth in capacity in the past two years fueled by the long, steep climb in ***InvProfitabiltity,*** panel (a). Also note, as it peaks in 2006 and then falls below zero in 2007/2008 timeframe the market attractiveness to investors diminishes. This is evident in the simulation as investors stop building new plants and/or scrap existing plans (see the simulated ***Planning***(2) and ***UnderConstruction***(3), curves in Figure 10, Panel (b)). As market conditions further deteriorate, new plant startups curtail and eventually existing plants are shuttered or production is scaled back. While it is too early to have confirmatory data to validate the dampened exuberance shown in the simulated trends in panel (b), these results are corroborated in anecdotal evidence in recent trade journal publications (Roberson, 2007).

### 3.4. Oil feedstock sectors

The choice of feedstock impacts operating costs (as discussed in the previous section) and the capital investment decisions that business leaders make when deciding to build a plant. Lower quality feedstocks require more processing equipment and, therefore, more investment. Having the option to process lower quality, cheaper feedstock may give the producer more flexibility, but the additional processing could increase the potential for yield or quality problems. Moreover, the use of lower quality feedstocks could reduce the amount of sale-able glycerol co-product produced (Kortba, 2006) -- decreasing a potential revenue stream for biodiesel producers. Capital

investment and operational decisions regarding feedstock usage are important to the profitability of each individual plant, but the BIGS model of aggregated industry decision-making focuses primarily on the impact that feedstock prices have on the margin. It is our working hypothesis that this balancing feedback presented as loops B1 and B2 in Figure 8 will limit the growth of the biodiesel industry.

Data from two studies (Eidman, 2006; Tyson et al., 2004) (shown in Table 2) indicate between 22 - 25 billion pounds of plant oils and between 9 - 13 billion pounds of animal fats, greases, and recycled cooking oils are produced annually in the US. These feedstocks could yield between 4.2 to 5.8 billion gallons per year of biodiesel which could displace approximately 11 - 15% of the current on-road diesel consumption (USDOE-EIA, 2006b). For reference, Figure 11 shows the prices for various fats and oils in mid-2006.

| | Eidman Estimate[14] 2000-2004 | | NREL Estimate[15] 2001 | |
|---|---|---|---|---|
| | Feedstock (billion lbs) | Biodiesel (million gals) | Feedstock (billion lbs) | Biodiesel (million gals) |
| Soybean Oil | 18.3 | 2378 | 18.9 | 2454 |
| Other Vegetable Oil | 4.5 | 588 | 6.0 | 780 |
| Rendered Fats& Oils | 9.3 | 1212 | 12.7 | 1645 |
| Other Sources | | | 6.9 | 898 |
| Total | 32.2 | 4178 | 44.5 | 5778 |

**Table 2: Estimates of US total domestic fats and oil production**

[14] Eidman (2006b) Table 8 - Pounds of oil are a five year average (2000-2004) from Bureau of the Census and Agricultural Marketing Service, USDA. The pounds of yellow grease and inedible tallow are a two-year averagefor 2002-2003 from US Department of Commerce, US Census Bureau. Current Industrial Report, M311K (03)-13, March 2005.

[15] Tyson et al. (2004) Table 11 -USDA ERS OCS and Outlook, October 2002. Bureau of Census, M311K-Fats and Oils: Production, Consumption and Stocks, 2002, July 2003. USDA ARS, Agricultural Statistics, 2003, Chapter III. Pearl, Gary. Biodiesel Production in the US, Australian Renderers Association 6th Int'l Symposium, July 25-27, 2001. Est from Wiltsee, G., "Urban Waste Grease Resource Assessment," NRELSR-570-26141. USDA ARS, Agricultural Statistics, Chapter XV. Render, Apr 2002, pg. 12.

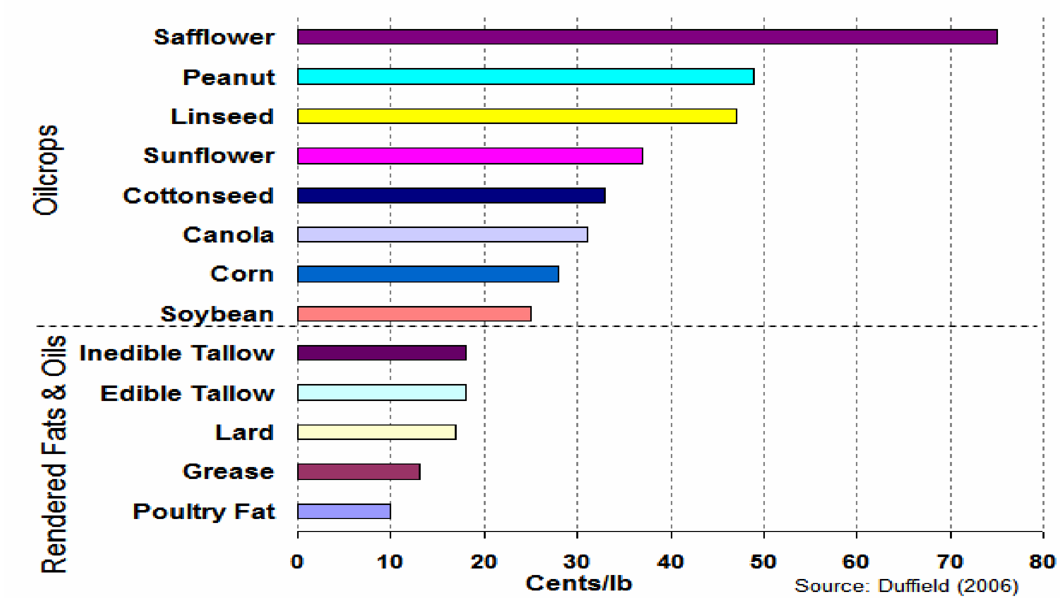



Figure 11: US Biodiesel feedstock prices (2006)

While it is theoretically possible that all the fats and oils in Table 2 could be converted to biodiesel, it is highly improbable because vegetable oils and animal fats are important ingredients for many other products such as baking and frying fats, animal feed, cooking and salad oils, margarine, and other edible products. In 2006, biodiesel demanded less than 5% of the entire US fats and oils market. How will these markets respond as demand from the biodiesel market rapidly increases and begins to demand a much greater percentage of the market for these feedstocks? Currently about 68% of biodiesel producers use soybean oil as a feedstock, but as seen in Table 3, biodiesel producers are shifting from soy oil to canola, other fats and oils, or multi-feedstock processing capabilities (Nilles, 2006). In the model, the percentage of biodiesel plants using soy only is ramped down over time, and this ramp rate is adjusted endogenously by the relationship between the soy and other oil prices.

| Fall 2006 | % of US Biodiesel Plant Capacity | |
|---|---|---|
| Feedstock | Operational Capacity | Under Construction or Expansion |
| Soy | 62.9 % | 51.5 % |
| Canola/Rapeseed | -- | 11.9 % |
| Multi-Feedstock | 20.2 % | 24.8 % |
| Animal Fats | 12.8 % | 10 % |
| Other | 4.1 % | 1.5 % |

**Table 3: US biodiesel capacity by feedstock**

Source: Biodiesel Magazine US & Canada Plant Map (Fall 2006)

### 3.4.1. Soybean oil market sector

Soybean oil has historically been available in large quantities at relatively low prices because it was considered a surplus product of the soybean meal crushing industry (USDOE-EIA, 2007). The stock and flow diagram modeling the planting, harvesting, crushing, and disposition of soybeans and soy oil are presented in Figure 12. Soybeans harvested in the US are exported, sold domestically as whole beans, or crushed to produce soy meal and soy oil. The amount of soybeans harvested each year in the US is dependent on many variables such as acres planted, yield, weather, and disease.

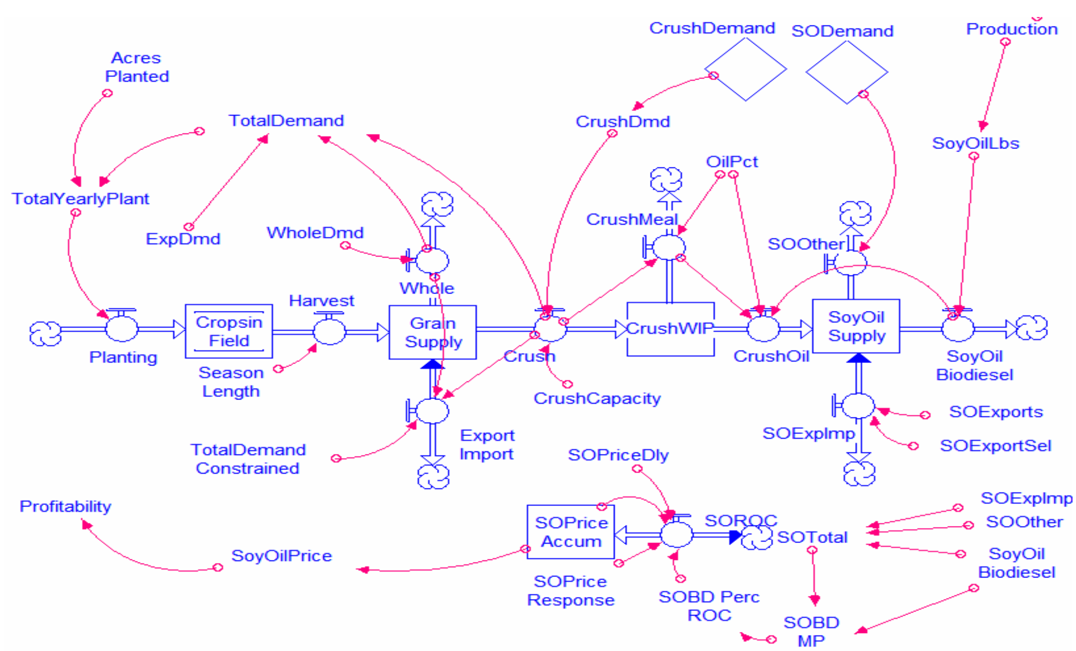



Figure 12: Stock and flow diagram – Soy oil production

Sectoral model testing results in Figure 13 how the behavior of the ***CropsinField*** and ***GrainSupply*** stocks in the soy oil production supply chain. The model structure shown in Figure 12 was verified using USDA data and was helpful in understanding the seasonal dynamics of the soybean and soy oil production supply chain. However, subsequent model testing confirmed that the seasonal harvest dynamics in Figure 13 occur over too short of a time span to impact the longer-term dynamics of interest in this research. Hence, a decision was made to simplify this structure by eliminating the planting and disposition of soy beans and focusing only on the crushing and soy oil disposition.

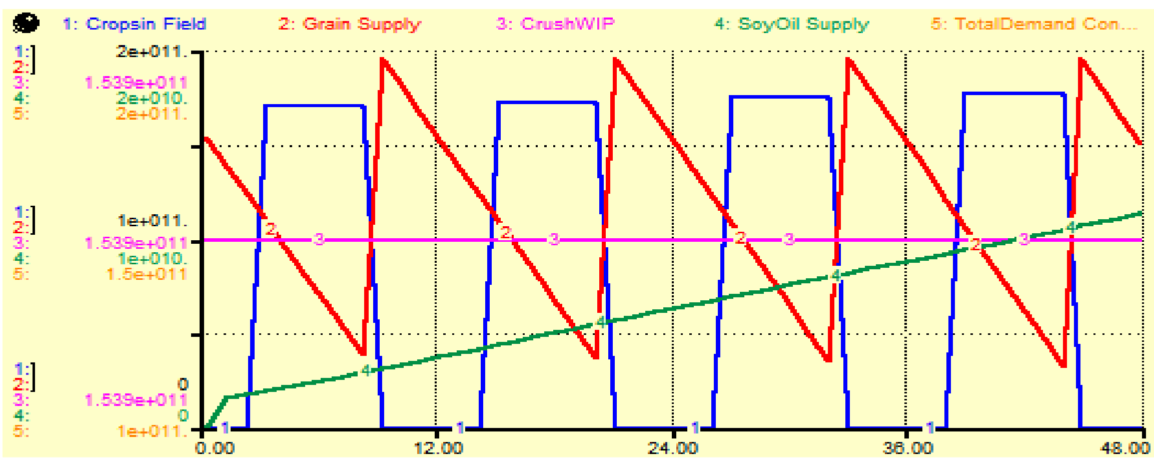


Figure 13: Soy production planting and harvesting dynamics

The simplified Soy Oil Sector stock and flow diagram finally used in BIGS model is presented in Figure 14. The biodiesel demand for soy oil (***SoyOilLbs)*** comes from the Biodiesel Production model sector, and the ***SoyOil Price*** completes the loop by providing feedback to the Biodiesel Production sector through its impact on ***Profitability***. The ***SoyOil Price*** is determined using the price setting stock and flow structure (discussed in Sterman, 2000; Whelan & Msefer, 1996) in which the price is adjusted by the ratio of

actual to perceived inventory coverage. The flow to biodiesel, ***SoyOilBiodiesel,*** is fed from the ***SoyOilSupply*** stock which also feeds the other users of soy oil (***SoyOilOthe***r and ***SoyOilExportImport***). Note that ***SoyOilExportImport*** flow is bi-directional which allows either export or import if desired.

In Figure 14, the ***Crush*** flow and the percentage of oil in the soybeans (***OilPct***) determine the amount of soy oil produced (***CrushOil*)*.** Depending on the future of soy meal and soy oil demand relationship, increasing the oil component of soybeans -- which historically average 18–19 % by weight (Ash et al., 2006) -- could be a alternative solution to provide more biodiesel feedstocks from soy. In all the scenarios explored, ***OilPct*** is kept constant, but further research could explore this option. Other important exogenous variables for determining the amount of soybeans crushed are ***Acres***, ***Yield, Crush Capacity***, and ***SoyExports.***

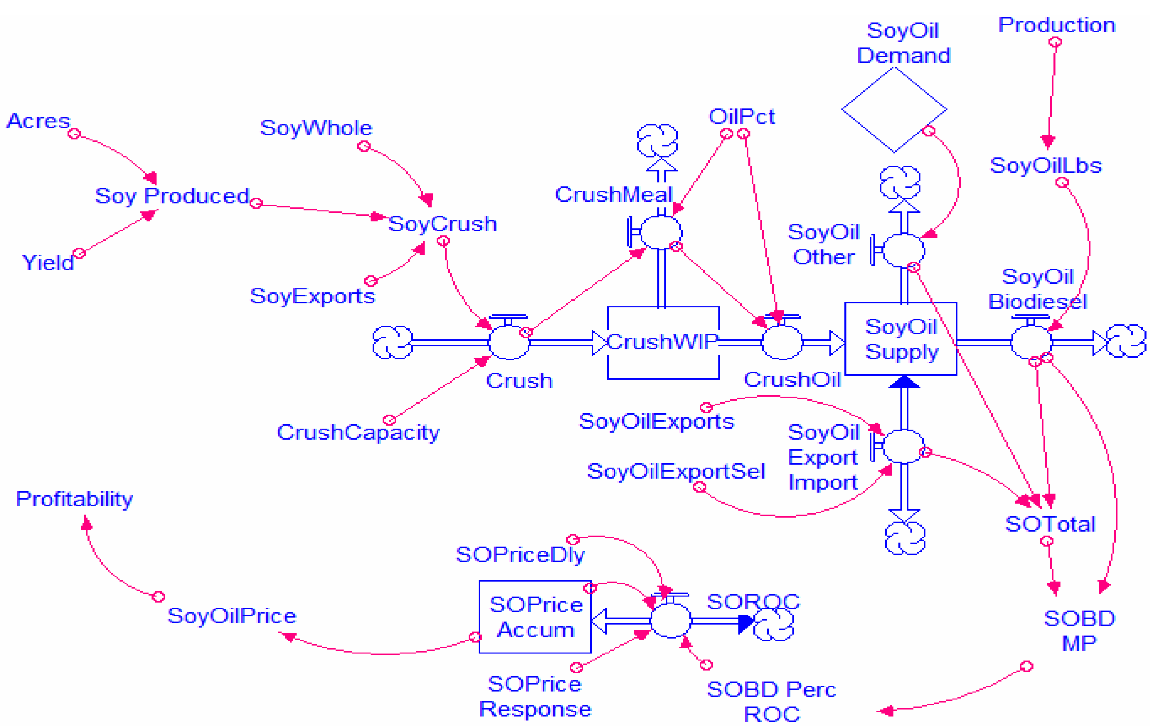



Figure 14: Stock and Flow Diagram – Simplified Soy Oil Sector

The percentage of the acreage for soybean planting will most likely be impacted by competition from other crops – corn in the short term and possibly energy crops such as switchgrass in the longer term -- as demand for ethanol continues to expand rapidly. In the model, the ***Acres*** variable will be an exogenous variable that can be set by the user to constrain the amount of soybean acreage in the US.

The average soybean yield, shown in Figure 15, is increasing at an accelerated rate due to improved cropping practices and technological advances. Increased yields allow farmers to harvest considerably more soybeans without significantly increasing acreage. These yield gains will be important to offset the downward trend in soybean acreage. US soybean growers set a new yield record in 2005 with 43.0 bushels per acre (USDA-OCE, 2007). In the model, it is assumed that yields continue to increase along a 25-year trend line (1980-2005) shown in Figure 15, but the user will be able to set yield trend through a graphical input block. Based on this trend, the average yield is projected to be approximately 46 bushels per acre by 2016.

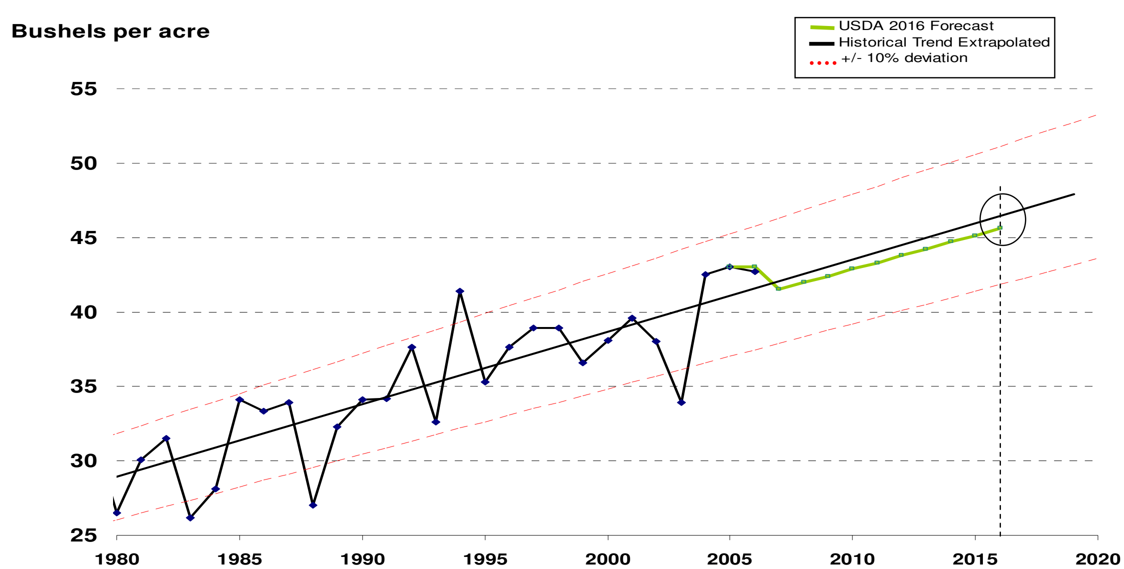



Figure 15: Soybean Yield US Average Historical and Trend
Source: USDA-OCE (2007), Soystats

To illustrate the impact of incremental yield growth, consider that an increase of just one bushel per acre from one year to the next results in an additional 68 million bushels of soybeans. After crushing, the soybean oil from an additional 68 million bushels of soy beans could be used to produce just over 100 million gallons of biodiesel. To better understand the magnitude of the flows in the soy sector, the historical (Soystats) and USDA forecast amounts (USDA-OCE, 2007) are presented in Figure 16.

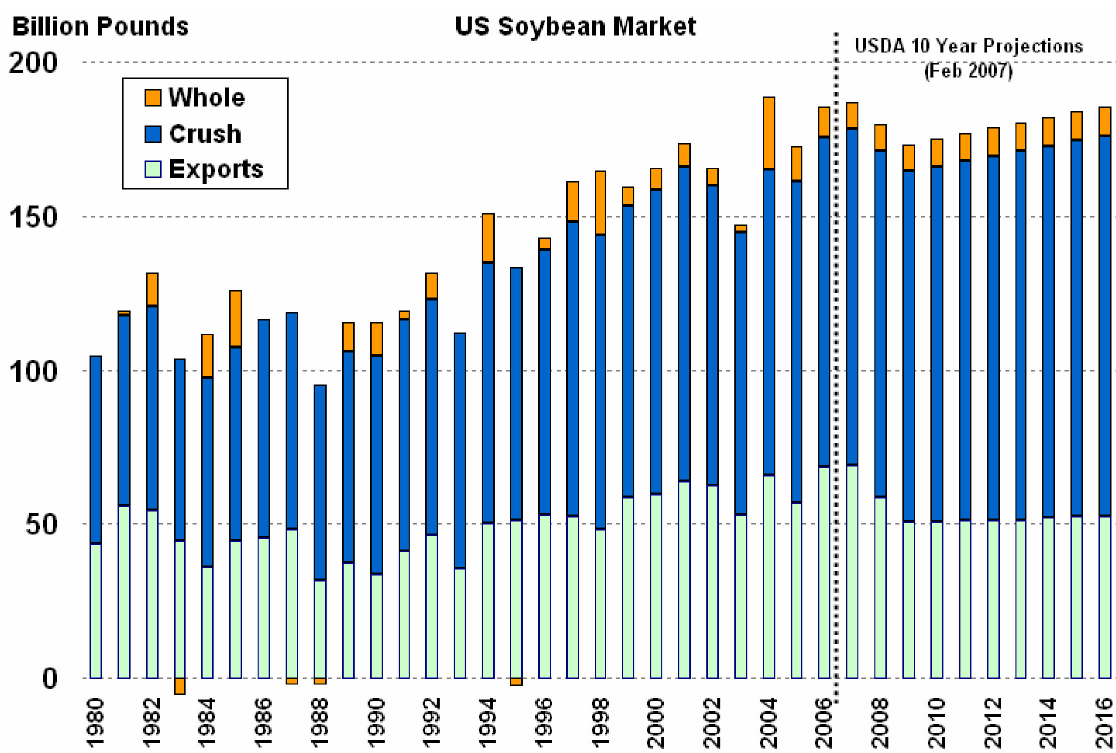



Figure 16: US Soybean Market Historical and Projections
Source: Soystats, USDA Agricultural Projections to 2016

In Figure 14, the ***SoyOilSupply*** stock feeds biodiesel, other (food, feed, and chemicals), and export markets. In the model, the ***SoyOilOther*** flow will be set to increase at historical growth rates and the ***SoyOilExportImport*** flow will be exogenously manipulated in the scenario testing.

### 3.4.2. Rendered fats and other oils market sector

The rendering industry produces fats and oils from byproducts of the food and animal processing industries. Products such as tallow, choice white grease (lard), poultry fat, and yellow grease are cheaper than virgin vegetable oil – selling for about half the price of soybean oil historically (Radich, 2001). Although they offer an economic advantage compared to soy oil, there is a limited supply of these oil feedstocks, and consumption is not limited to use as biodiesel feedstocks. Rendering industry products are important ingredients in animal feed, fatty acids, chemicals, and lubricants (Meeker, 2006), as seen in Figure 17. Domestically, sixty percent of rendered fats and oils go into animal feed and less than two percent is used for industrial uses such as biodiesel.

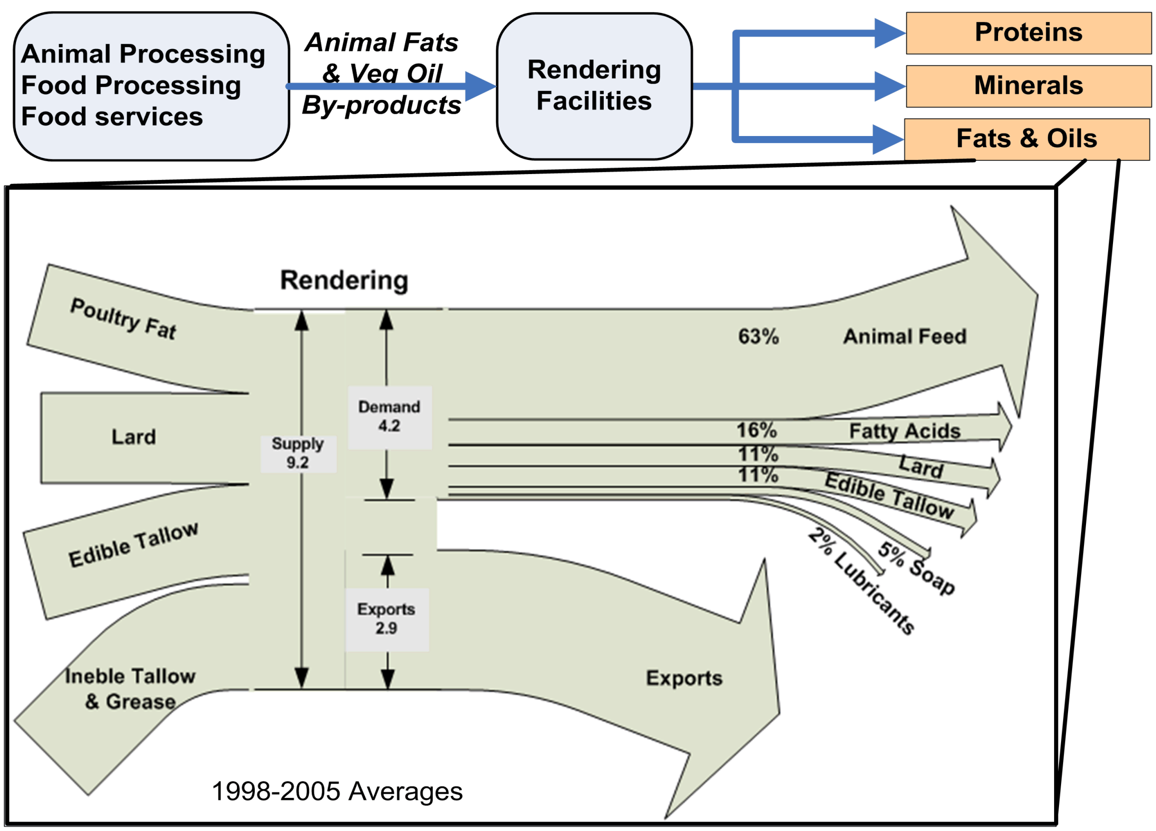



Figure 17: US Fats and Oils Overview
Source: Data compiled from the National Renderers Association

As seen in Figure 18, from 1998-2005, the domestic rendering industry produced nine billion pounds of inedible tallow and greases, edible tallow, lard, and poultry fat on average and has not demonstrated significant industry growth. The assumptions in the model are based on the industry continuing this minimal growth rate through the time period simulated.

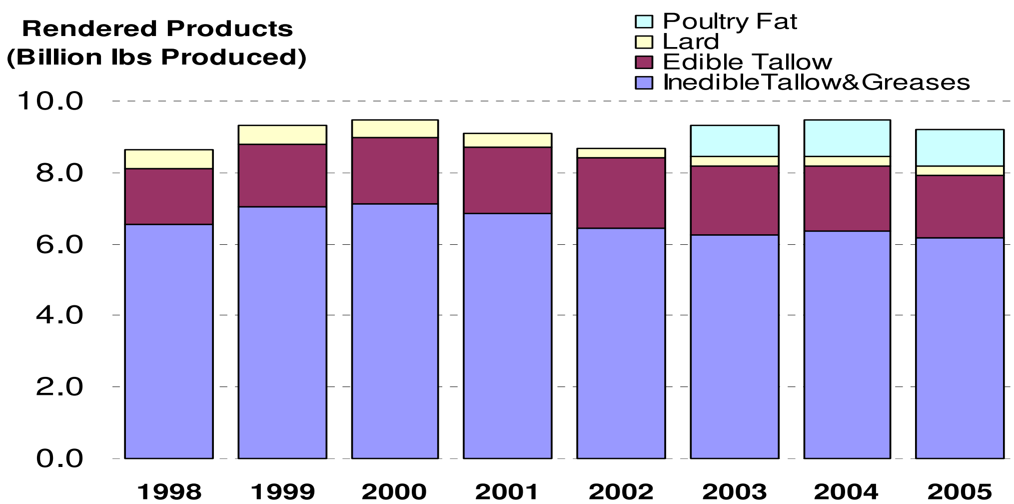



Figure 18: US Rendering Fats and Oils Production
Source: National Renderers Association

The stock and flow diagram modeling the rendered fats and other oils industry sector is presented in Figure 19. The biodiesel demand for rendered fats and other oils (***RFOLbs***) comes from the Biodiesel Production model sector. The ***RFOPrice*** completes the loop by providing feedback to the Biodiesel Production sector through it influence on ***Profitability.*** In the BIGS model, the model users will be able to set the industry growth rate, but in all scenarios I assume the industry growth rate will continue to grow at historical rates. In the BIGS model, the percentage of biodiesel plants using fats and oils (determined by the ***SoyUsage*** variable) is increased over time but is adjusted endogenously by the relationship between the ***SoyOilPrice*** and ***RFOPrice***.

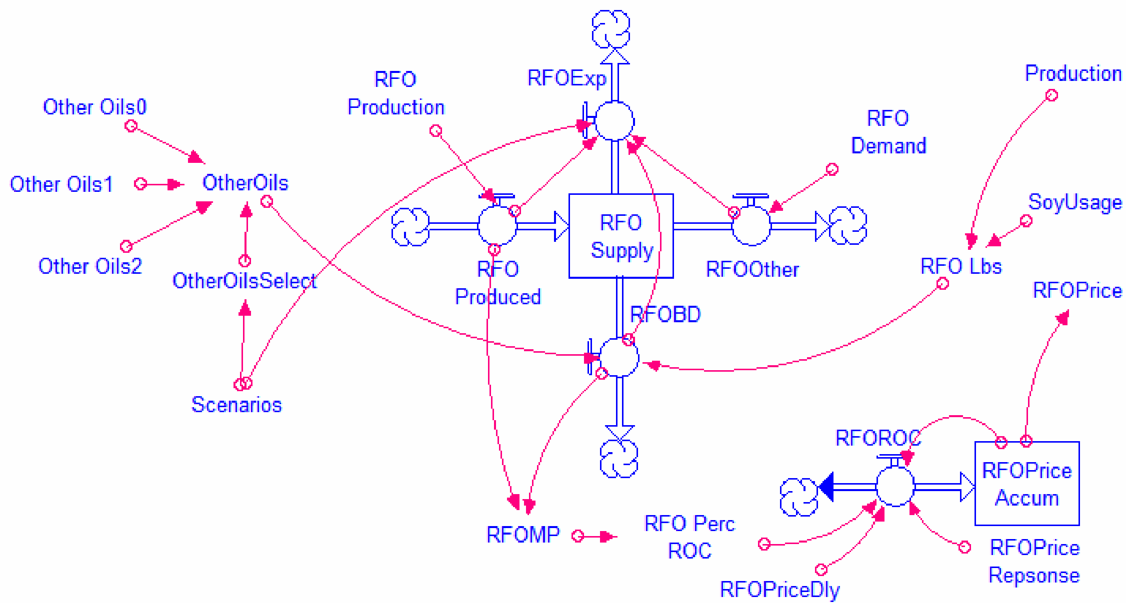



Figure 19: Stock and Flow Diagram – Rendered Fats and Other Oils

### 3.4.3. Other oil feedstocks

In addition to soybean oil and rendered fats and oils, there are other sources of natural oils that could be tapped to increase the supply of potential biodiesel feedstocks. Many in the industry, such as National Biodiesel Board president, Joe Jobe, cite "the availability of other oil sources" as one of the many factors that will support continued growth of this industry in the next decade (Bryan, 2007). In the sections below, I briefly review alternative triglyceride sources that could potentially provide additional FAME biodiesel feedstocks. Since there are many uncertainties around future availability, the total supply of these other alternate oil sources are aggregated in the ***OtherOils*** variable in the model (Figure 19). Alternate ***OtherOil*** scenarios can be selected using the ***OtherOilSelect*** variable, or the supply curves can be changed through the graphical input device to determine the overall impact on the system. As the amount of ***OtherOils***

increases, the price pressure will decrease on both ***SoyOilPrice*** and ***RFOPrice***. This will help to boost overall biodiesel industry profitability.

### 3.4.4. Other domestic oilcrops

Although soy is the dominate oil crop in the world (as seen in Figure 20) six other major oilseeds crops are produced around the world canola/rapeseed, cottonseed, peanut, sunflower seed, palm kernel, and copra (Pahl, 2005). Rapeseed is the favored biodiesel feedstock in Europe and Canola -- a genetic variation of rapeseed -- is gaining popularity in the US. Many US farmers are planting non-traditional oil crops such as Canola and camelina, but Canola currently only makes up one tenth of one percent of the oilseeds market in the US (Nilles, 2007). Ninety percent of this crop is grown in North Dakota. The recent construction of a ADM crushing facility and biodiesel plant in North Dakota is enticing farmers to grow more Canola, but it is estimated that demand at this one plant will not be satisfied entirely by domestic production.

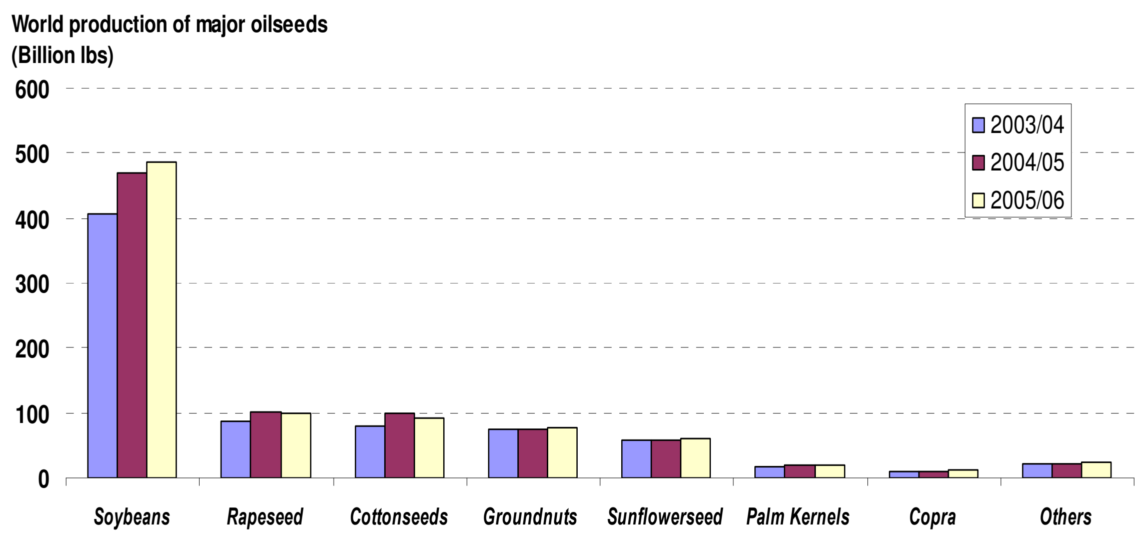



Figure 20: World Production of major oilseeds
Source: Food and Agriculture Organization (FAO) of the United Nations

Another hopeful domestic oil crop candidate is camelina. Farmers in the Midwest and plains states are considering camelina for a winter cover crop in place of winter wheat (Weber, 2007). The potential of these domestic oil crops will also be determined by acreage competition with the other major domestic crops.

#### 3.4.5. Imported oils

Palm Oil -- mainly imported from the Southeast Asian countries of Malaysia and Indonesia -- is rapidly becoming the biodiesel feedstock of choice throughout many regions of the world. Biodiesel production fed mainly by palm oil is beginning to take off throughout Asia – not only in Malaysia and Indonesia, but also India and China. In addition to feeding the Asian biodiesel demand, European and US producers are beginning to consider palm oil. Although it is attractive because of the price, concerns about deforestation and sustainable production methods have combined with cold weather quality issues to dampen some of the North American and European enthusiasm.

#### 3.4.6. Corn oil from ethanol production

At ethanol production facilities, corn oil can be extracted before processing or after fermentation and distillation (Bryan, M., 2006). One company, Greenshift, with a patent on this technology has proposed installing oil extraction equipment in dry mill ethanol production facilities at no charge to client ethanol producers in exchange for first rights of refusal for the oil extracted. Greenshift (2005) estimates that a 50 million gallon per year ethanol plant could extract enough corn oil support a 20 million gallons per year biodiesel plant. Hypothetically, if one quarter of the 60 to 80 ethanol plants being built

today were to install this capability, this could provide enough feedstock for 400 million gallons per year of biodiesel.

#### 3.4.7. Waste fats and oils

About 10.5 billion animals are slaughtered and processed each year in the US (Meeker, 2006) and meat-processing facilities are required to use large volumes of water to rinse the meats as during processing. The waste water from this process contains about 5-20% fat and it is estimated that the concentrated Dissolved Air Flotation ("DAF") sludge from the poultry industry alone could provide 2.5 billion pounds per year of additional feedstock to the biodiesel industry (GreenShift, 2005). These 2.5 billion pounds of fat could be converted to 325 million gallons of biodiesel if it could be processed economically with good yields. Another potential source of feedstock is trap grease, which is collected, treated, and disposed of via land-filling, burning, composting, or anaerobic digesting (typically by waste water treatment facilities). According to researchers at NREL, approximately 13 lbs per person per year of trap grease is created in the US (Tyson et al., 2004). Theoretically, 3.8 billion pounds could be converted to 495 million gallons of biodiesel if it could be collected and processed economically with good yields. A few companies that are pursuing these waste feedstock options, but due to the difficulties involved in producing high quality biodiesel fuel from a low quality, highly variable, feedstock stream, the future for this feedstock option remains uncertain.

#### 3.4.8. Algal oil

From 1978 through 1996, the Aquatic Species Program at NREL investigated algae with oil-content that could be grown specifically for the purpose of biofuels

production (Sheehan, 1998). In recent years, several companies such as GreenFuel Technologies (www.greenfuelonline.com), along with those in government and academia, have been trying to make large-scale bioenergy algae production a reality. Although the potential is promising -- estimates range up to 10,000 gallons of biodiesel per acre – nobody has scaled this technology to support a commercial size biodiesel facility. Due to the uncertainty in the future of this technology, it is not assumed that algal oil will contribute significantly to the amount of triglycerides available for biodiesel production in the next decade.

### 3.5. Diesel fuel market

Although diesel prices have recently been higher than gasoline prices, the demand for diesel fuel is growing at an annual rate of 2.5%, and vehicles in the US will consume approximately 65 billion gallons of diesel by 2030 (USDOE-EIA, 2007). Diesel fuel powers most of the medium and heavy duty on-road vehicles and most of the heavy duty off-road vehicles such as bulldozers and farm tractors. Light-duty diesel vehicles have been popular in Europe for a long time and they are making a comeback in the US. In addition to highway vehicles, diesel is also used in farm tractors, trains, boats, generators, and other heavy duty equipment. In the BIGS model, diesel fuel price is derived from the price of crude oil which is set exogenously. The model user will be able to select alternate crude oil forecasts – Low, High and User determined -- to determine the impacts on the biodiesel industry. The Low and Hi forecasts are based on the 2007 AEO crude oil price projections shown in Figure 21.

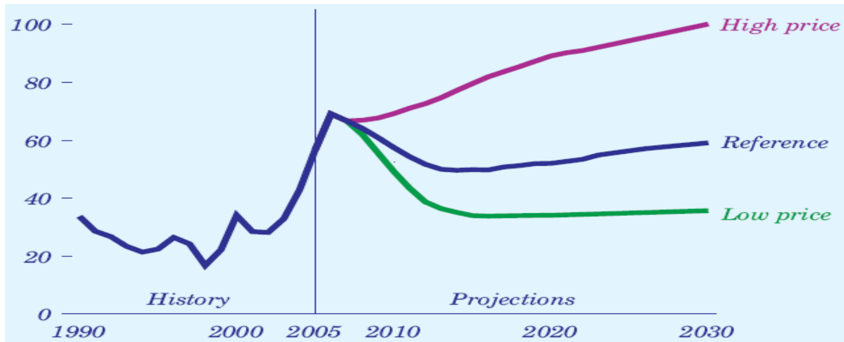



Figure 21: Crude oil prices in three AEO2007 cases
Source: EIA AEO 2007 (2005 $/bbl)

3.6. Putting it all together – Interactions and market dynamics

In the previous sections, the overall model boundaries, structure, and sectoral details including various feedstock, production, and product markets (shown in Figure 22) were described. Now, it is important to discuss the market interactions and other external factors that could impact behavior of the biodiesel market in the next decade.

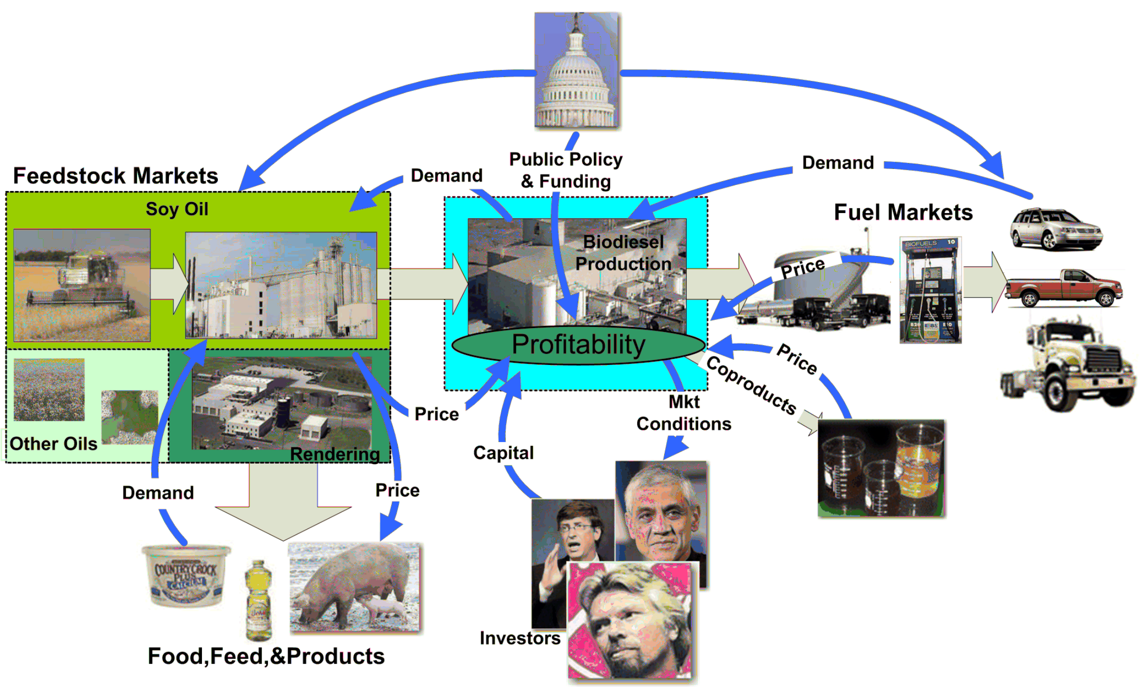



Figure 22: Biodiesel Market Overview

### 3.6.1. Ethanol competition

USDA forecasts that US farmers will plant more corn and less soy over the next decade to meet increasing demand from fuel ethanol (USDA-OCE, 2007). The USDA and University of Tennessee agricultural economists' alternate forecasts (English et al., 2006) are presented in Figure 23. The 2007 spring plantings intentions reported by the USDA on March 30, 2007, indicated corn acres will rise 15% from 2006 plantings to 90.4 million acres and soybean planted acres may drop 11% to 67 million acres (Wilson, 2007). This significant shift of acreage away from soy will most likely affect the price of soy oil and negatively impact the profitability of biodiesel producers.

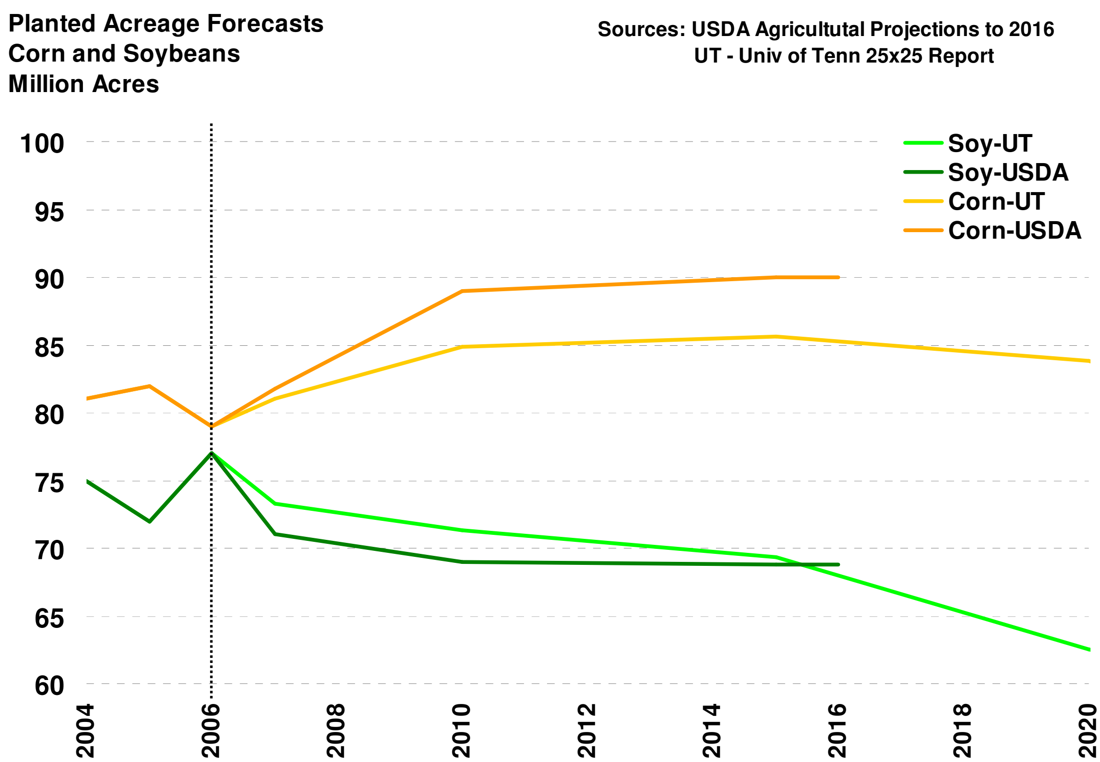



Figure 23: Decreasing US soy acreage
Source: USDA (2007), Univ of Tenn 25x25 report (2006)

Moreover, distillers grains, a co-product from the dry mill ethanol production process can be used as a substitute for soy meal in some animal feeding operations

(Davis, 2001). As ethanol production increases, the expanding supply of DDG will increasingly compete with soy meal and other protein oilseed meals. This is likely to result in lower oilseed meal prices and a possible decline in domestic soy meal consumption. The combined effects of decreased soy acreage and decreased demand for soy meal could have negative impacts on FAME biodiesel production. These impacts could possibly be partially offset by developing new technologies for the production of corn oil from the dry-mill ethanol process to be used for biodiesel production, as discussed earlier in Section 3.4.6. In addition, the acreage loss to corn can be offset by displacing wheat with soybean plantings and by bringing more land into production, but the impacts of these changes could also have unintended consequences.

### 3.6.2. Exports and imports

When introducing the 5 x ‘15 plan, the National Biodiesel Board stated that decreasing biomass oil exports would be a key factor for biodiesel growth (Bryan, 2007). More oil can be made available for domestic biodiesel production by decreasing the exports of both soy beans and soy oil and/or increasing imports. The US exports around one billion pounds of vegetable oil and approximately 2.5 billion pounds of rendered fats and oils annually (Soystats, 2005; Meeker, 2006). These feedstock exports could have some impact if redirected into the domestic market.

Biodiesel producers may begin to import more palm, canola, coconut, and other oils if the economics are favorable, but concerns about deforestation and sustainable production methods have combined with cold weather quality issues and domestic protectionism to dampen some of the enthusiasm in the US.

### 3.6.3. Crushing capacity and oil content

Both the domestic capacity to extract the oil from oilseeds – called crushing capacity – and the percentage of oil in the oilcrops will affect the amount of oil available in the market. The US exports about a third of its soybean crop annually (USDA-ERS, 2007), and crushing these soybeans domestically would produce enough soybean oil to produce 1.5 billion gallons of biodiesel. This would be beneficial for the biodiesel industry, but not for the soy bean crushers' margins as it would also produce a 67% increase in domestic meal. The industry crushing capacity was typically expanded based on the demand from the oilseed meal market. For soy, only 18.5% of seed by weight is oil, the remainder is sold into meal and other markets and has traditionally been the most valuable part of the bean. The demand for soy oil -- driven up by biodiesel production -- may pressure the industry to change their business models and add new crushing capacity.

### 3.6.4. Glycerol glut

Glycerol (also called glycerin) is a co-product of biodiesel production and can be sold in a crude or refined form. Refined glycerol is a commodity used in the production of hundreds of other products. Chemical industry analysts forecast the glycerol price to continue its current downward slide, and a serious overcapacity problem (Figure 24) is likely to develop as the biodiesel industry continues at its current growth rate (McCoy, 2001). If the overcapacity problem continues, biodiesel producers may soon be faced the problem of disposing of glycerol instead of selling it (Hamilton, 2007).

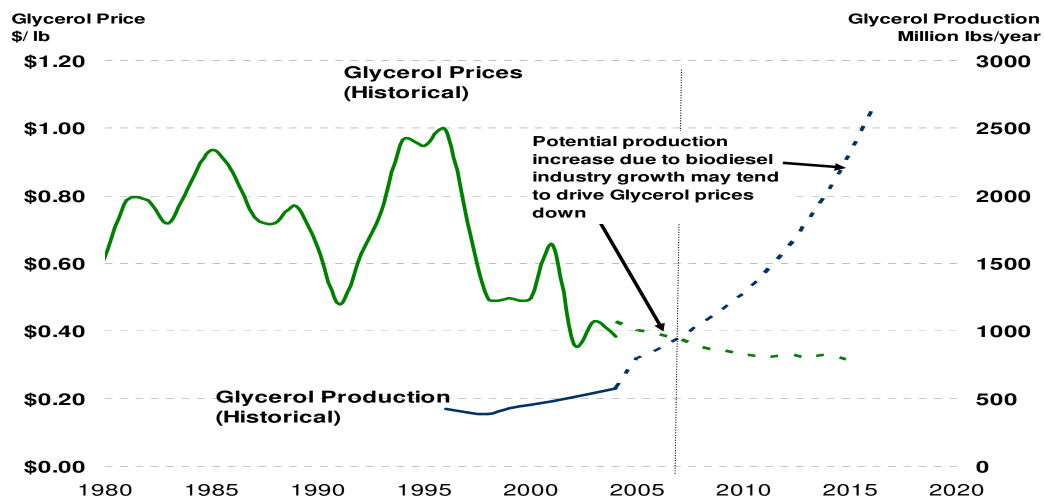



Figure 24: Glycerol Production and Prices – Historical and Projected
Source: Historical data - Bondioli (2003) and Tyson (2004)

The Department of Energy has recognized this issue and has created initiatives -- such as the "top 12" bio-based chemicals that may help new glycerol markets develop which help offset this price decrease (Gerard, 2006). Glycerol sales account for a small percentage of the revenues in the biodiesel industry. Therefore, their impact on the aggregate industry profitability is small compared to the other factors we are exploring. Although this will not be the primary focus in the simulation runs, the model does incorporate an exogenous glycerol price variable that will allow the user to explore this variable.

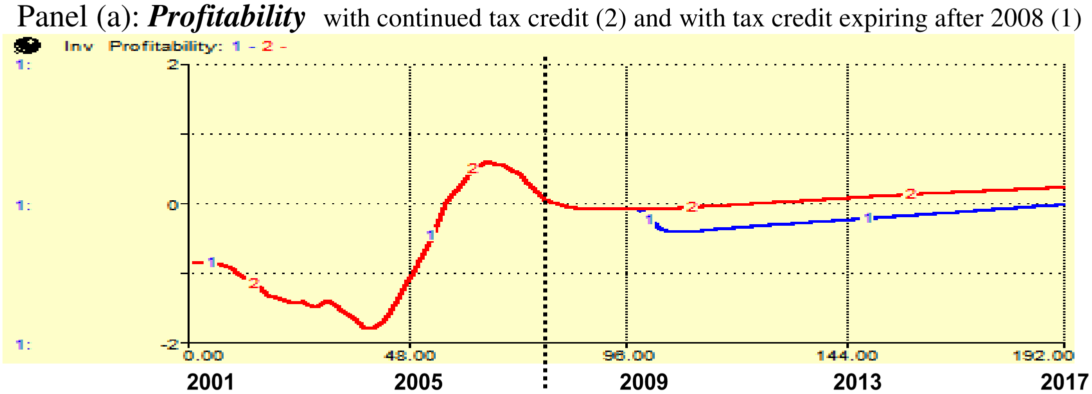
### 3.6.5. Government intervention in the markets

Effective, targeted public investments and policies at the federal and state level -- in the form of research funding, market-creating purchases and mandates, and producer price supports -- have helped to build a strong base for the biodiesel industry. The most well known of these market interactions is the biodiesel tax credit, which was enacted into law as part of the American JOBS Creation Act of 2004 and extended to end of 2008

by the Energy Policy Act of 2005 (Koplow, 2006). Fuel blenders received $1.00 credit for every gallon of soy biodiesel and half that amount for biodiesel produced using other oil sources. Market-based advocates are debating the efficacy and cost of biofuel subsidies, but these government subsidies have helped the industry develop and flourish and are still necessary for profitability. Although the future is not guaranteed, it is likely that the biodiesel tax credits will be extended.

The tax credit has been included in the model as an exogenous variable that can be manipulated to simulate the effects it has on the profitability of producers. The USDA (2007) in its most recent forecast to 2016 also assumed the current biofuel subsidies would remain in place but did run an alternate scenario in which the subsidies were not extended. In that scenario, the biodiesel industry almost entirely collapsed.

Panel (a): ***Profitability*** with continued tax credit (2) and with tax credit expiring after 2008 (1)




Panel (b): ***Operational Capacity*** with cont'd tax credit (2) and with tax credit expiring after 2008 (1)

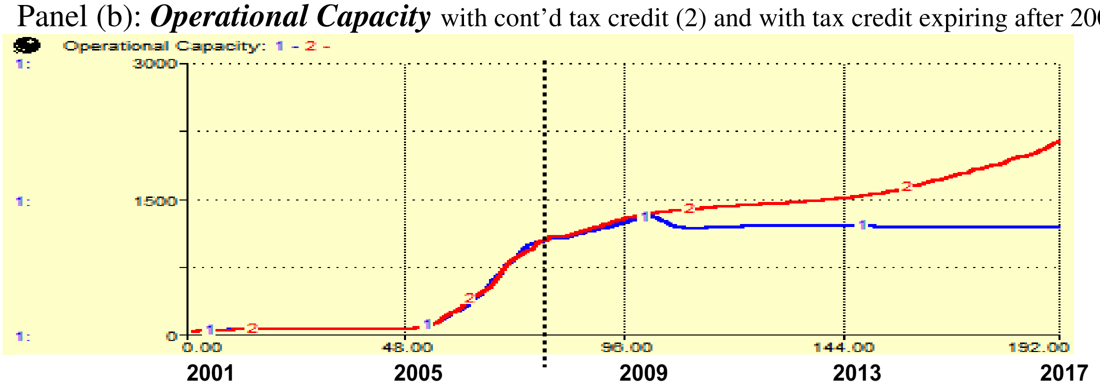


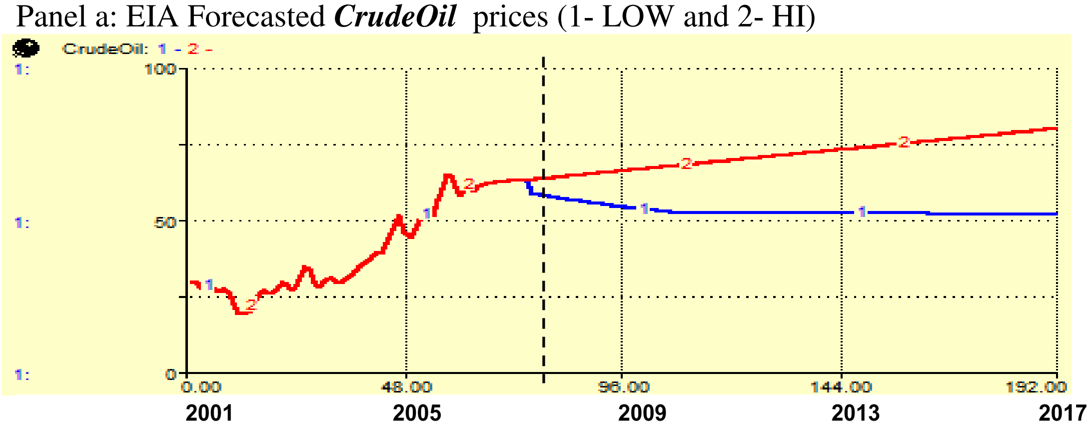

Figure 25: Impact of not extending the tax credit after 2008

The trends presented in Figure 25 are typical of many of the simulated scenarios in which the biodiesel tax credit was not extended after 2008. The ***Profitability*** (Panel (a), Trend line "1") drops off leading either to stagnation or to deflation in the industry ***Capacity*** (Panel (b), Trend line "1").

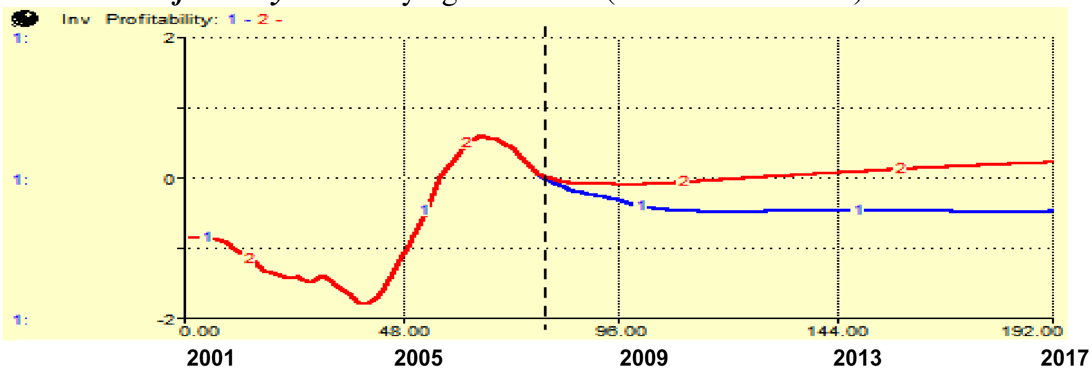
3.6.6. World oil prices

As discussed in Section 3.5, diesel prices which are dependent on crude oil prices have a direct impact on the biodiesel profitability. Elevated diesel prices over the past two years have sparked the current boom in the biofuels industry. Before the scenarios are developed and assumptions are made regarding crude oil prices, the system sensitivity to crude oil needs to be explored. The ***Profitability*** and ***Capacity*** trends in Panel (b) and (c) of Figure 26 are typical of most of the scenarios tested using the low ***CrudeOil*** price forecast. The ***Profitability*** would drop off and this would ultimately lead to the industry ***Capacity*** (and ***Production***) deflating.

Panel a: EIA Forecasted ***CrudeOil*** prices (1- LOW and 2- HI)



Panel b: ***Profitability*** with varying ***CrudeOil*** (1- LOW and 2- HI)




Panel c: ***Operational Capacity*** under the Baseline Scenario is shown here impacted by ***Profitability*** with different ***CrudeOil*** prices

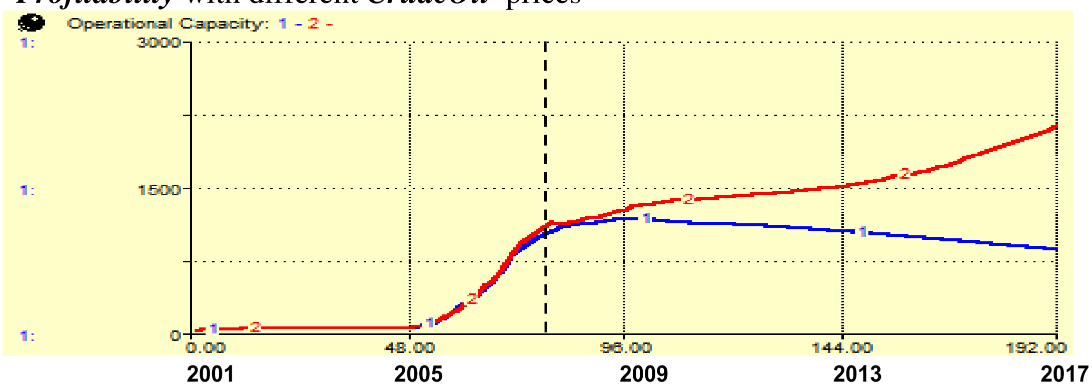



Figure 26: Impact of varying Crude Oil prices

### 3.6.7. Global biofuels growth

Although this thesis focuses on the US biodiesel industry, it is important to put it in context of the global biofuel industry growth. Although the EU biodiesel industry is larger and more mature than most regions, it is still exhibit strong growth behavior. These other global markets are excluded from this analysis, biodiesel industry expansion in Brazil, Argentina, China, India, Malaysia and Indonesia has driven global vegetable oil and fats inventories -- as indicated by the stocks-to-use ratio -- to thirty year lows (Baize, 2006a) and will continue to keep upward pressure on global vegetable oil prices for the near future.

## 3.7. Putting it all together – Testing and using the model

Above I defined the model scope and boundaries and examined the structure of the biodiesel industry and the interaction between sectors. Now I use the model to help answer the original research questions. Keeping in mind that models are simplifications of the real world and that "all models are wrong" (Sterman, 2001), one must demonstrate that this model is at least "right enough" to be useful for its stated purpose. For the young biodiesel industry, little historical data are available. Therefore, one must rely heavily on an understanding of the underlying industry structure and decision-making process and on sectoral testing using analogies provided by similar industries. Model assessment is often done with prescribed sets of tests, but in many cases, model testing becomes an iterative process of building, testing, using, sharing, explaining, and then updating based on the feedback one receives.

### 3.7.1. Face validity and structural assessment testing

In the process of building the BIGS model, I had numerous discussions with biofuel industry analysts that validated many parametric and structural assumptions made. These interactions with industry experts helped to qualitatively test the fit between the structure of the model and the essential characteristics of the real system. This is referred to as face validity testing (Sterman, 2000). Structural assessment testing, to verify whether the model is consistent with the real system relevant to the purpose (Sterman, 2000), was accomplished through discussion and interactions with key modelers from NREL. This interaction with system modelers responsible for the development of the Biomass Transition Model validated the methodology and much of the structure of the model. Finally, I was able to test dimensional consistency and other

hypothesis and key assumptions through extensive sectoral testing and sensitivity analysis.

### 3.7.2. Behavior reproduction tests

As an important part of the model building and testing process, I calibrated the biodiesel capacity and production sector using the historical prices of soybean oil and diesel to calculate the profitability as discussed in sections 3.2 and 3.3 and in Figure 10. This helped to validate the model by comparing the simulation results to historically observed conditions. Also, sensitivity analyses were used to determine which variables in the model have a major influence on the behavior when they are changed. In this way the modeler can identify which variables must be most carefully researched to confirm their numeric values. Moreover, sensitivity analysis is invaluable for analyzing various scenarios.

The price response of the soy oil sector was calibrated against the price projection in the USDA ten year forecast. In the latest ten year projections, in the USDA ten year projection (USDA-OCE, 2007), they modeled the impacts of the soy oil prices with and without the biodiesel tax credits. Using these projections, I was able to further calibrate the model by adjusting the parameters that impact the rates at which investors decide to build (or not to build) biodiesel plants and also the rate at which biodiesel producers ramp back production rates due to decreasing profitability. The recent investor behavior in the biodiesel market could be compared to behavior in a speculative bubble market. It is often hard to model this type of investor behavior, so calibrating the model against other projections (such as those from the USDA) is very helpful in building confidence in the model.

4. Dynamic Analysis of the Biodiesel Industry

In this section, the BIGS SD model described in Section 3 is used to investigate the impact of different market conditions on the biodiesel industry through 2016 and to gain insight into the original research questions. In Section 4.1, the STELLA™ user interface will be briefly reviewed enabling model users to interact with model and to run the various simulation scenarios. Section 4.2 establishes assumptions underlying a set of "core" scenarios including such features as availability of feedstock and other variables affecting profitability. Section 4.3 then presents results for the scenarios including production, capacity, and feedstock prices and market percentages.

4.1. User interface

The STELLA™ SD modeling program consists of four views (or layers) – *Equation, Model, Map,* and *Interface.* To interact with the Biodiesel Industry Growth Simulation, users will start at the main page on the Interface layer provided in Figure 27.

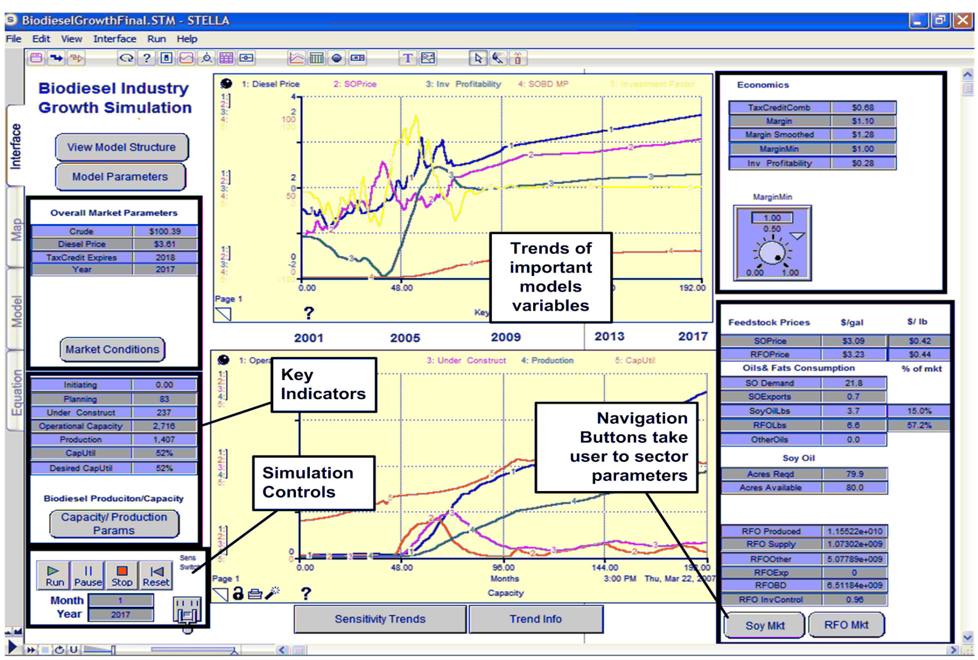
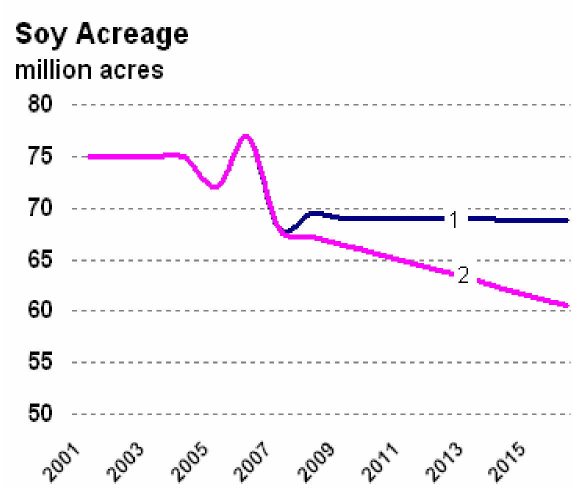


Figure 27: STELLA$^{TM}$ Biodiesel Industry Growth Simulation User Interface

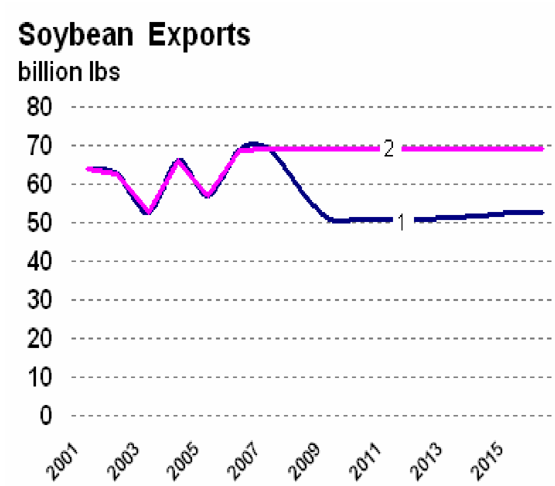
From this "flight simulator" display, the user can run scenarios, and view the model inputs and outputs or navigate to other displays and layers to view the model structure, set model parameters, and perform sensitivity analysis.

4.2. Scenario discussion

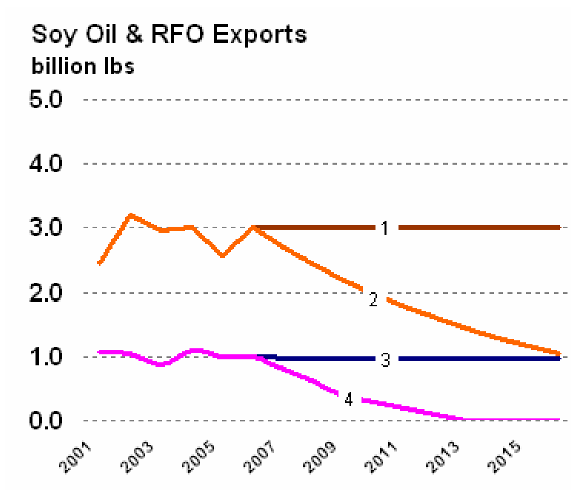
By simulating different scenarios, we can gain a better understanding of how realistic the current growth predictions are and how sensitive the industry is to changing various parametric and structural changes. Hence, I defined market conditions that would affect producer profitability by varying constraints on the availability of fats and oil feedstocks. The main exogenous variables manipulated in the scenarios impact the supply of oils and fats in the market. The first two variables impact soybeans available for crushing: soy acres planted (***Acres***) and soybean exports (***SoyExports***). The historic and future scenario trends for these two variables are shown in Figure 28. Panel (a) shows the USDA (USDA-OCE, 2007) ten year forecast (trend (1)) and University of Tenn 25x25 (English et al., 2006) soy acreage (trend (2)). Both forecasts show decreasing soy acreage but trend (2) drops significantly due to competition from energy crops such as switchgrass. Soybean exports are shown in panel (b) the USDA 2016 Forecast (trend (1)) and in trend (2) exports are held constant at current levels. The other exogenous variables that affect the amount of fats and oils supply are the exports (or imports) of soy and RFO oils (in panel (c)) and the availability of other oils in the market place (panel (d)). In panel (d) trend (2), it is assumes that other oils come into the market as imports, new oil crops, corn oil (ethanol), or through waste stream utilization with an 33% annual growth rate and will increase the supply up to 5 billion pounds per year in 2016. Panel (d) trend (2) assumes only a 5% annual growth rate in other oils.



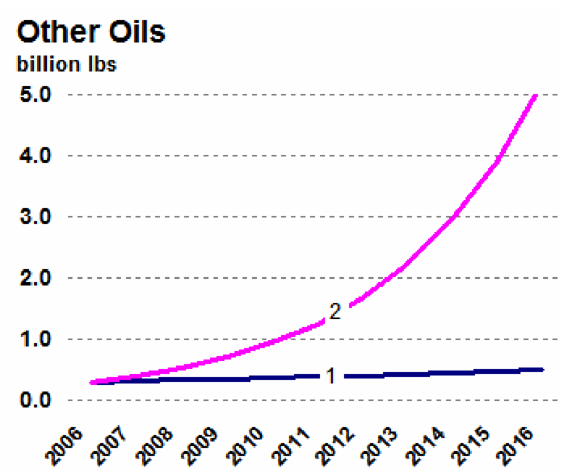

Panel a
(1 - USDA baseline, 2 – UT-25x25)




Panel b
(1 - USDA baseline, 2 – 2006 level)




Panel c
(1&3 – 2006 levels, 2&3 - Decreasing)




Panel d
(1 – 5% growth rate , 2 – 33% growth rate)

Figure 28: Variables affecting Biodiesel Oil Feedstock Supplies

The inputs for the key exogenous variables for three scenarios analyzed are summarized in Table 4. Based on discussions above, for all the scenarios, it is assumed that crude oil prices will continue to trend high and the federal biodiesel tax credit is extended through 2016.

| Scenario | Exogenous Variables Adjusted in each Scenario (see panels in Fig 27) | | | |
|---|---|---|---|---|
| | Soy Acres Planted (Panel a) | Soybean Exports (Panel b) | Fats and Oil Exports (Panel c) | Other Oils (Panel d) |
| Baseline | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Held at 2006 levels | Increasing at 5% per year |
| Five by Fifteen | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Decreasing per trends in Fig.27 | Increasing at 33% per year |
| Constrained Oil | Decreasing (11% reduction by 2016) | Held at 2006 levels | Held at 2006 levels | Increasing at 5% per year |

**Table 4: Scenario Overview Table**

4.2.1. Baseline scenario

The reference or business-as-usual scenario is based on the assumption that existing trends in the biodiesel market will continue on their current trajectories with no major shifts in the feedstock markets. This essentially represents the assumptions currently held by many investors interested the business of producing biodiesel. By examining this scenario, we can gain insight whether the growth of biodiesel industry can be sustained even if these assumptions are correct. The soy acreage is set per USDA 2016 forecast (USDA-OCE, 2007) and soy exports are fixed at 2005 levels. The exports of soy oil and RFO are also set at historical levels. The demand for soy oil and RFO are assumed to grow at historical growth rates. Other oils exhibit a small 5% annual growth.

4.2.2. Five by fifteen Scenario

This scenario evaluate the assumptions underlying the National Biodiesel Board 5 by ‘15 goal (i.e. achieve 5% market share for diesel market by 2015). Most importantly, the

NBB projections postulate a sufficient growth in “other oil” feedstocks to support the 5% market share goal. Assuming the decline in soy oil production as projected by USDA, the model analysis suggests that a roughly 33% annual growth rate in “other oils” is required to achieve this goal (see Figure 28, Panel (d), Trend (2)). Hence, this scenario employs such an increase. The results are useful in evaluating how realistic the NBB 5 x ‘15 goal actually is. Exports of soy oil and RFO oils will also be decreased as shown in the trends in Figure 28. Although the NBB assumes additional soy acreage may come from CRP and pasture lands, this scenario assumes soy acreage will more closely follow the USDA 2016 baseline. The other oils in this scenario may come from corn, canola and palm oil as they enter the market through new technologies, increased domestic production and increased oil feedstock imports to meet the increasing demand from biodiesel. Also other waste streams fat sources will be tapped.

#### 4.2.3. Limited biomass oil scenario

In this scenario, it is assumed that soy acreage will significantly decrease due to increased corn and switchgrass planting for ethanol production and other bioenergy uses. This scenario (shown in Figure 28 Panel a) uses the acreage assumptions developed by the agricultural economists at the University of Tennessee as a way to meet 25% of the nation’s transportation and electricity needs with renewable energy (English et al., 2006). Also in this scenario, it is assumed that exports are maintained at 2006 levels and no significant increases in other oils occur.

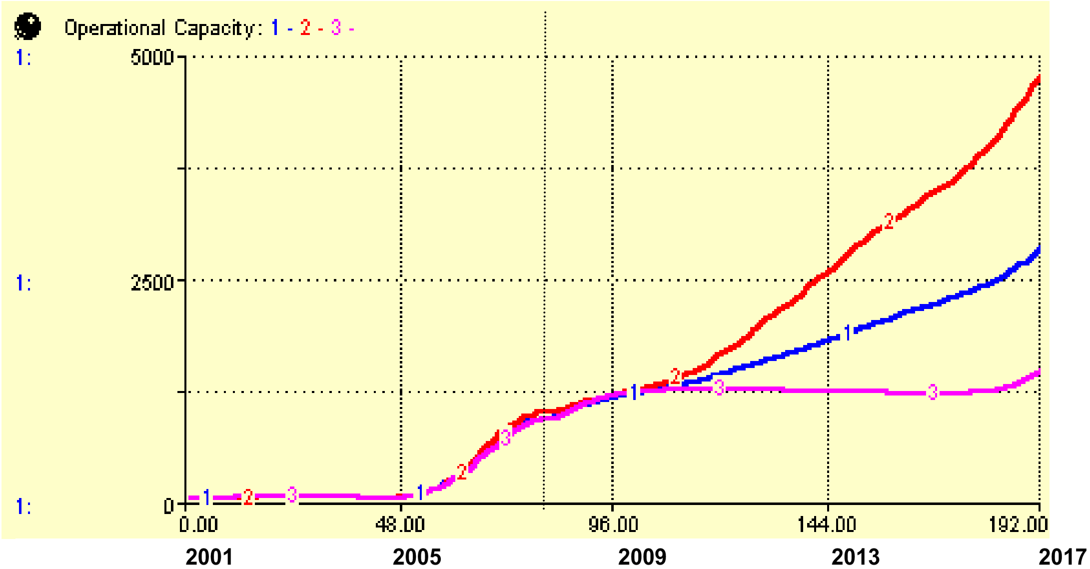
4.3. Scenario results

The projections presented in this section are dependent on assumptions about the availability of FAME biodiesel feedstocks discussed in the section above. The core assumptions are intended to set a reasonable context for assessment of the various growth behaviors in the US biodiesel industry as indicated by biodiesel industry capacity and production and soy oil and rendered fats and oils prices and market share. Capacity and production projections for the three core scenario are depicted in panels (a) and (b) in Figure 29. These projections suggest that biodiesel production, could possibly hit the industry goals of 5% market share (panel (b) trend (2)) by 2015 but, only under ideal conditions. In the Limited Biomass Scenario, the production plateaus at approximately 700 million gals per year (Figure 29, panel (b) trend (3)) which is consistent with the USDA model results (USDA-OCE, 2007). The Baseline scenario in Figure 29 trend (1) shows production capacity is slightly over 2.5 billion gallons per year wh production at approximately 1.5 billion gallons per year. This production level is consistent with the UT-GEC report (Ugarte et al., 2006), discussed in section 2, and possibly the Promar study, if extrapolated to 2016.

In all cases, there will be a slowing of growth in the next three years as production comes on line and rising feedstock prices cut into producer profitability (seen in Figure 30). Soy and rendered fats & oils prices and their impact on the investor profitability for the three core scenario are depicted in panels (a) and (b) in Figure 30. As expected, the acreage constraints in the Limited Biomass Oil scenario have a major impact on soy prices as seen in (Figure 30, panel (a) trend (3)).

**Index:** Baseline ----1---- 5x15 Scenario ----2----- Limited Biomass Oil -----3----

Panel a: ***OperationalCapacity*** *(million gallons per year)*




Panel b: ***Production*** *(million gallons per year)*

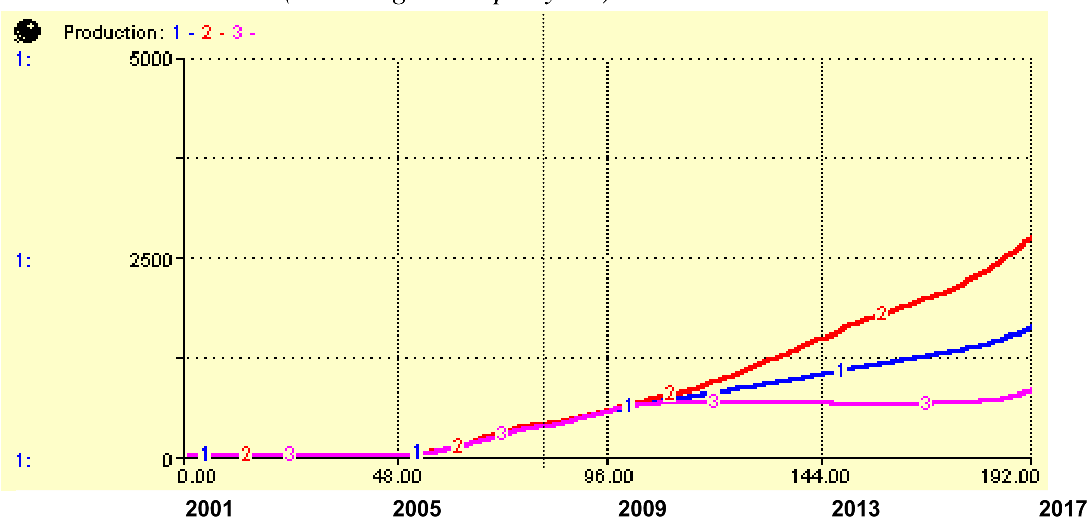
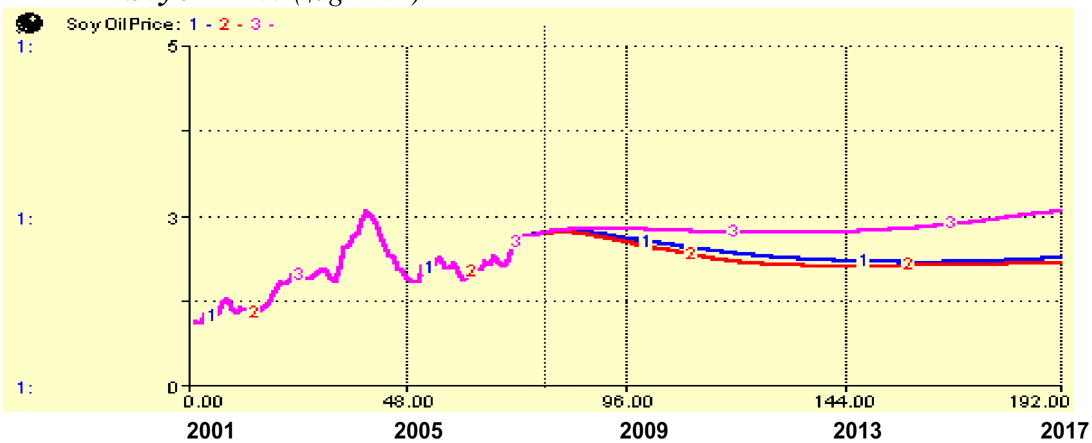


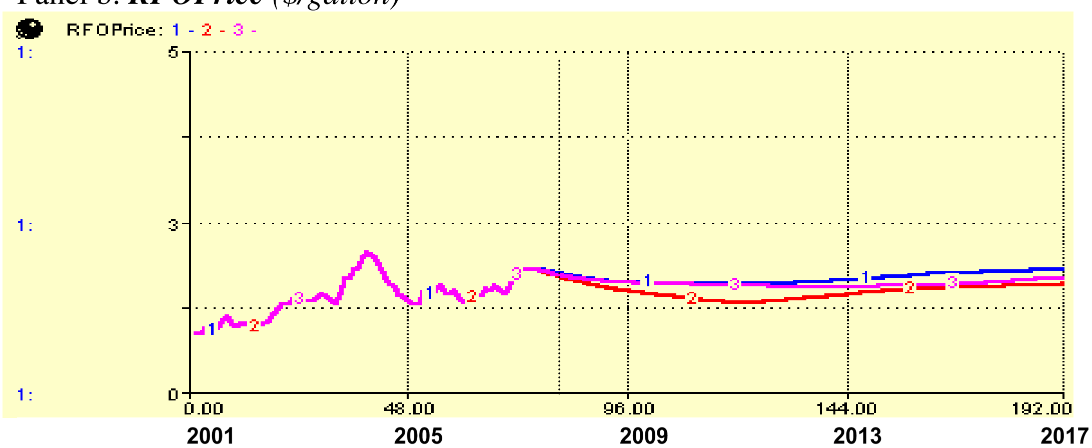

Figure 29: Biodiesel Capacity and Production under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: ***SoyOilPrice*** *($/gallon)*




Panel b: ***RFOPrice*** *($/gallon)*




Panel c: ***Inv Profitability****($/gallon)*

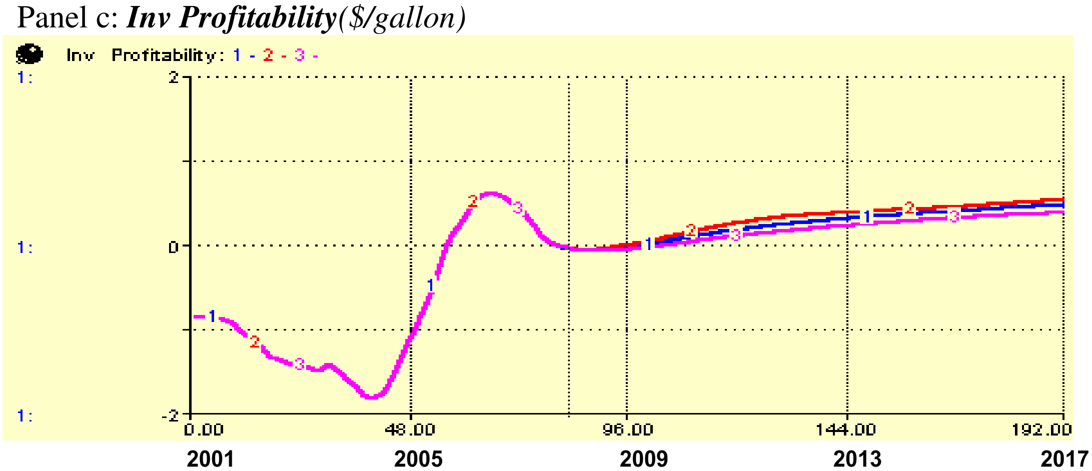
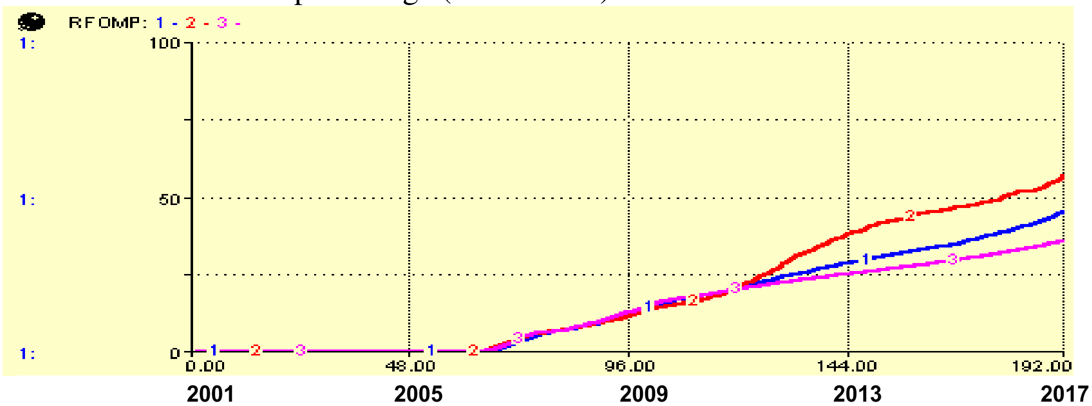



Figure 30: Feedstock prices and profitability under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: RFO market percentage (to biodiesel)




Panel b: Soy Oil market percentage (to biodiesel)

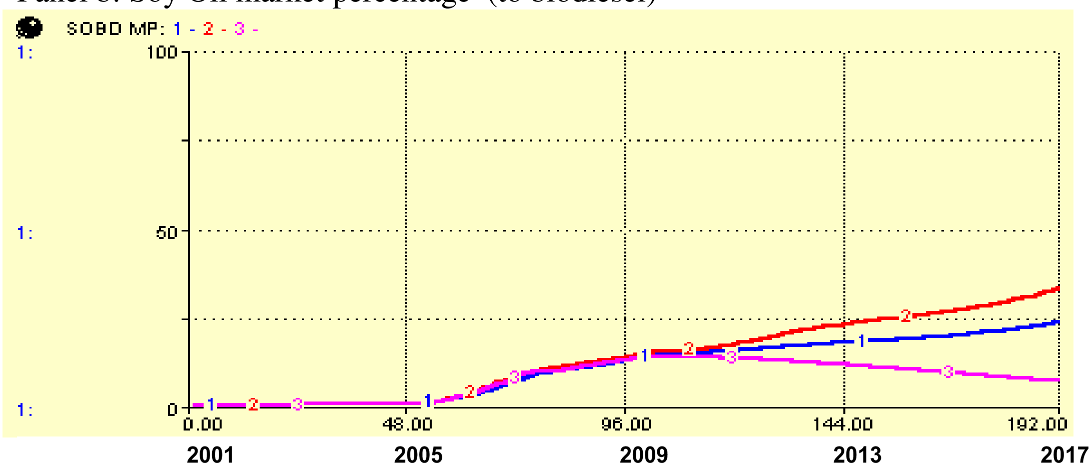



Figure 31: Feedstock Market Percentage under alternative scenario assumptions

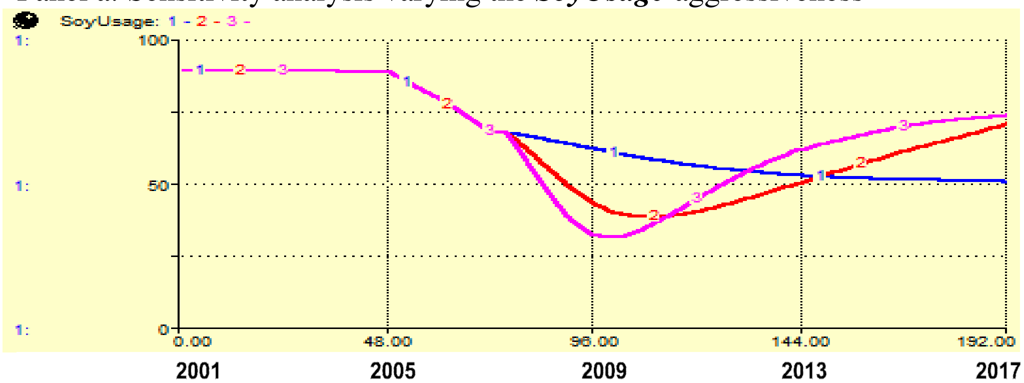
The share of the feedstock markets that biodiesel demand is claiming is show in Figure 31 (soy oil-panel (b), rendered fats and oils-panel (a)). When soy oil supply is impacted by soy acreage constraints in the Limited Biomass Scenario, the amount of soy used for biodiesel feedstock drops off significantly (panel (b), trend (3)) due to high prices. In the other two scenarios, the soy biodiesel market percentage gradually increases to 25-35% of the market. In panel (a), biodiesel takes from 35-60 % of the RFO market share. In reality, this may not be practical, given the elasticities of the other markets.

As these scenarios are evaluated, other factors come into play and other assumptions are also plausible. For example, the industry has been gradually diversifying its feedstock sources and by shifting away from dependence on soy to multi-feedstock facilities. To explore the effect that this shift has on the industry growth, a sensitivity analysis was performed under the baseline scenario and varying the aggressiveness of the ***SoyUsage*** variable. The trends in Fig 31 panel (a) show the varying rate of aggressiveness at which producers are shift from using soy to other feedstocks. The results of the sensitivity analysis shown in Figure 32, reveal that if the industry aggressively moves away from soy in the next three to four years (trend lines (2) and (3) in Panel (a), Figure 32), then a rapid increase in rendered fats and oils market share (***RFOMP***) trend lines (2) and (3) in Panel (b) will occur. The will cause the RFO price to increase and the SoyUsage will be adjusted endogenously as seen when trend lines (2) and (3) in panel (a) reverse direction and begin to increase the soy usage. The simulation indicates that these lower soy oil prices could trigger another boom in construction and more capacity growth towards the end of the simulation run as seen in panel (c) trend lines (2) and (3).

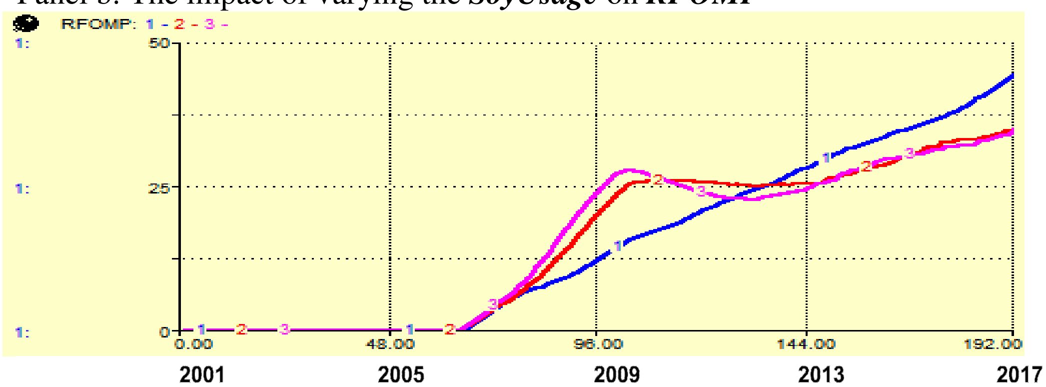
By developing scenarios that affected producer profitability by varying constraints on the availability of fats and oil feedstocks and then using BIGS model to simulate the industry grow, we have gained a better understanding of how realistic the current growth predictions. The sensitivity analyses above provide examples of how the BIGS model can be used to explore the dynamics interactions between different factors that affect growth in the biodiesel industry and help better understand how sensitive the industry is to changing various parametric and structural changes.

**Index:** **SoyUsageChg(3%/yr) (1), Soy UsageChg (13%/yr) (2), Soy Usage Chg(20%/yr)(3)**

Panel a: Sensitivity analysis varying the ***SoyUsage*** aggressiveness




Panel b: The impact of varying the ***SoyUsage*** on ***RFOMP***




Panel c: The resultant effect on industry ***OperationalCapacity***

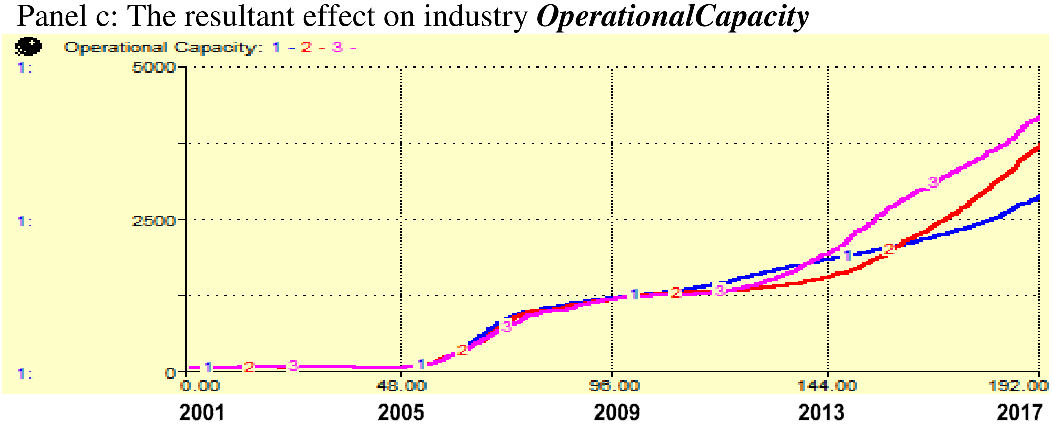



Figure 32: Baseline Scenario- varying the Soy Usage Parameter

## 5. Recommendations and Conclusions

The objective of this study is to investigate the market dynamics of the FAME biodiesel industry through the use of a SD research model. Conceptualization of the model structure, key parametric assumptions and relationships between them was informed by literature review and discussions with key personnel in the biodiesel industry. Simplifications and assumptions to model structure and parameters are integrated by means of these discussions. Simulation of various scenarios helped to help explore the bottlenecks in feedstock availability and sensitivity of industry growth to various parameters over the next decade. The future of FAME biodiesel is, indeed, not clear and could take many different routes depending on market conditions, government actions, and as we thoroughly investigated, on the availability of affordable oil feedstocks.

A key finding from this study is that many of the scenarios run indicate that industry may experience a plateau of capacity growth in the next few years because of decreased profitability. In fact, only in the most optimum of feedstock and market conditions -- high oil prices, extension of tax credits, reduced exports and 33% annual growth rate of new sources of fats and oils – will the market reach five percent of diesel market penetration. Realistically, growth of the FAME biodiesel industry beyond that in the ten year period studied is not likely. As hypothesized, the dampening of the industry growth is influenced heavily due by increases of feedstock prices. The price increases are brought about by the rapid increase in the feedstock market share of biodiesel and influenced also by agricultural pressures from corn ethanol. Analysis of the various scenarios also finds that decreasing soy usage by increasing multi-feedstock capability

may temporarily delay the pending feedstock squeeze but unless significant amount of other oils become available in the short term the industry will be severely limited.

## 5.1. Recommendations

### 5.1.1. Explore other renewable diesel alternatives

Although the scope of this thesis does not include exploring the transition of the renewable diesel industry to non-FAME alternatives, it is important that this task be addressed urgently. To raise the low feedstock ceiling that will soon limit FAME biodiesel to somewhere less than one tenth of the diesel market, the biodiesel industry must embrace change and quickly expand to production technologies that are not solely dependent on fats and oils. These technologies -- such as biomass gasification/Fischer-Tropsch diesel -- can open the door to a broader and more diverse array of feedstock choices. Although diesel is a smaller piece of the transportation fuel pie, the growth of the diesel market combined with the potential for other non-renewable alternatives to displace petroleum diesel demand appropriate attention to this matter. The EIA projects that by 2030, fuels derived from coal (Coal-To-Liquids or CTL) will account for 93% of non-petroleum diesel alternatives (USDOE-EIA, 2007a) -- making up 7 percent of the total distillate pool. Liquid coal is produced from domestic feedstocks but only the fuels produced from renewable resources give us real energy security by significantly reducing our greenhouse gas emissions.

SD modeling efforts could be used to help policy makers and industry leaders envision a renewable diesel future with multiple production pathways. As discussed previously, several government agencies and labs are collaborating to develop a SD-based Biomass Transition Model (USDOE-OBP, 2006) to help simulate the evolution of

the ethanol industry to lignocellulosic feedstock sources. The learnings from this model will help to inform policy makers and industry players in their decision making process. It is important that similar modeling efforts include the future of renewable diesel pathways.

### 5.1.2. Maintain government interaction in the markets

As demonstrated in the model testing, if the current biodiesel tax credit is not extended the production of biodiesel may drop off quite rapidly because producers will have difficulty being profitable. These businesses will not continue production for long if they are losing money. The results of the simulation in this thesis concurred with the USDA industry collapse simulated in the most recent ten year outlook (USDA, 2007a). Therefore, until alternative renewable diesel pathways become established and renewable feedstock supplies markets are stable, effective, targeted public investments in the form of research, market-creating purchases and mandates, and tax credits should be provided for emerging biodiesel technologies and industries. However, these government policies should promote and support the production and uses of biodiesel that meet appropriate performance standards -- such as lifecycle greenhouse gas emissions -- not just specific feedstock types.

### 5.1.3. Promote sustainable development of new oilcrops

There are possible benefits to producing a diverse array of oil crops that can be used for biodiesel production. For example, planting camelina as a winter cover crop will reduce soil erosion and give the farmers a crop that has a higher value in the market. The need for further research into these matters is recognized by the government and industry.

Researchers at the Danforth Center in St. Louis (Hamilton, 2007) are trying to understand what is needed to achieve a 5% market share for biodiesel.

Increasingly, oil palm could begin to play a major role in US biodiesel industry development. In addition to palm oil, new oilseed crops such as the perennial Jatropha can provide income for rural farming communities in India while providing another valuable source of biomass oil that can be turn in to fuel. Many in the US and Europe are concerned that oilcrops from the tropics, may not be grown in a sustainable manner. To avoid replacing unsustainable fossil fuels with unsustainable biofuels, the international community must act quickly to establish global sustainability standards for biofuels.

#### 5.1.4. Understand the dynamics of the domestic oilseed industry

The domestic crushing industry – which extracts oil from oilseeds – is undergoing a rapid transition driven by international competition in China and Argentina. It is also by the changes of the end use of its products (soy meal and soy oil) domestically which are influenced by the rapid growth of the biodiesel and ethanol industries. Many of the old business models for soybean crushing are being "flipped on their head" by a rapidly changing market environment where soybean meal is losing value and soy oil is gaining. One recent industry trend is to locate crushing facilities at or near biodiesel production facilities to reduce costs for the biodiesel producers. This issue is ripe for analysis using SD modeling methods similar as performed in this thesis.

#### 5.1.5. Develop other non-conventional sources of oil

There are many exciting possibilities for sources of new biomass oil to raise the FAME biodiesel feedstock ceiling such as corn oil, oil from algae, and other under-

utilized waste oils. Research, development, and deployment should be supported at appropriate levels.

## 5.2. Conclusion

Understanding current and future growth in the biodiesel industry requires taking a holistic view of the industry and analyzing key factors that influence profitability. Exploring various scenarios using SD modeling and simulation can be extremely helpful in developing a deeper understanding of the rapidly changing biofuels industry. This thesis described the formulation of a SD model to simulate the behavior of the FAME biodiesel industry and as hypothesized the industry will most likely hit a feedstock ceiling in the next decade and remain only a small fraction (less than 10%) of the non-petroleum diesel replacement market.

# Appendix A: US Biodiesel Plant Listing

**Table 5: US biodiesel plant listing - Jan 2007**

(Source: Biodiesel Magazine online plant listing, last updated 3-Jan-2007)

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Independence Renewable Energy Corp. | Claiborne | AL | soy oil | 40 | Under Construction | |
| Alabama Biodiesel Corp. | Moundville | AL | soy oil | 10 | Operational | N/A |
| Alabama Bioenergy | Bridgeport | AL | soy oil | 10 | Operational | Nov-06 |
| Arkansas Soy Energy Group LLC | Dewitt | AR | soy oil | 3 | Under Construction | |
| FutureFuel Chemical Co. | Batesville | AR | soy oil | 24 | Operational | N/A |
| Patriot BioFuels | Stuttgart | AR | soy oil/animal fats | 3 | Operational | N/A |
| Bay Biodiesel LLC | San Jose | CA | virgin oils/yellow grease | 5 | Under Construction | |
| Energy Alternative Solutions Inc. | Gonzales | CA | tallow | 1 | Under Construction | |
| Simple Fuels LLC | Vinton | CA | yellow grease | 2 | Under Construction | |
| Bio-Energy Systems LLC | Vallejo | CA | virgin oils/yellow grease | 2 | Operational | N/A |
| Biodiesel Industries-Port Hueneme | Ventura | CA | multi-feedstock | 3 | Operational | N/A |
| Imperial Western Products | Coachella | CA | yellow grease | 7 | Operational | N/A |
| LC Biofuels | Richmond | CA | canola oil | 1 | Operational | N/A |
| American Biofuels Corp. o | Bakersfield | CA | soy oil/tallow/waste vegetable oil | 5 | Not Producing | N/A |
| American Agri-Diesel | Burlington | CO | soy oil | 6 | Operational | N/A |
| BioEnergy of Colorado | Denver | CO | soy oil | 10 | Operational | N/A |
| BioFuels of Colorado | Denver | CO | soy oil | 5 | Operational | N/A |
| Rocky Mountain Biodiesel Industries | Berthoud | CO | multi-feedstock | 3 | Operational | N/A |
| Bio-Pur Inc. | Bethlehem | CT | soy oil | 0.4 | Operational | N/A |
| Mid-Atlantic Biodiesel | Clayton | DE | multi-feedstock | 5 | Operational | N/A |
| Purada Processing LLC | Lakeland | FL | multi-feedstock | 18 | Operational | N/A |
| Renewable Energy Systems Inc. | Pinellas Park | FL | recycled vegetable oil | 0.5 | Operational | N/A |
| Middle Georgia Biofuels | East Dublin | GA | soy oil/poultry fat | 2.5 | Operational | Sep-06 |
| US Biofuels Inc. | Rome | GA | multi-feedstock | 10 | Operational | N/A |
| Pacific Biodiesel Inc. | Honolulu | HI | yellow grease | 1 | Operational | N/A |
| Pacific Biodiesel Inc. | Kahului | HI | yellow grease | 0.2 | Operational | N/A |
| Central Iowa Energy LLC | Newton | IA | multi-feedstock | 30 | Under Construction | |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| East Fork Biodiesel LLC | Algona | IA | soy oil/animal fats | 60 | Under Construction | |
| Freedom Fuels LLC | Mason City | IA | soy oil/animal fats | 30 | Under Construction | |
| Iowa Renewable Energy | Washington | IA | soy oil | 30 | Under Construction | |
| Riksch Biofuels | Crawfordsville | IA | multi-feedstock | 9 | Under Construction | |
| Sioux Biochemical Inc. | Sioux Center | IA | corn oil/animal fats | 1.5 | Under Construction | |
| Western Dubuque Biodiesel | Farley | IA | soy oil | 30 | Under Construction | |
| Ag Processing Inc. | Sergeant Bluff | IA | soy oil | 30 | Operational | N/A |
| Cargill Inc. | Iowa Falls | IA | soy oil | 37 | Operational | N/A |
| Clinton County Bio Energy | Clinton | IA | soy oil | 10 | Operational | N/A |
| Mid-States Biodiesel LLC | Nevada | IA | multi-feedstock | 0.5 | Operational | N/A |
| Renewable Energy Group | Ralston | IA | soy oil | 12 | Operational | N/A |
| Soy Solutions | Milford | IA | soy oil | 2 | Operational | N/A |
| Tri-City Energy | Keokuk | IA | multi-feedstock | 5 | Operational | N/A |
| Western Iowa Energy | Wall Lake | IA | soy oil-animal fats | 30 | Operational | N/A |
| Blue Sky Biodiesel LLC | New Plymouth | ID | multi-feedstock | 12 | Operational | N/A |
| Biofuels Company of America LLC | Danville | IL | soy oil | 45 | Under Construction | |
| American Biorefining Inc. | Saybrook | IL | soy oil | 10 | Operational | N/A |
| Columbus Foods Co. | Chicago | IL | soy oil | 3 | Operational | N/A |
| Incobrasa Industries Ltd. | Gilman | IL | soy oil | 30 | Operational | Dec-06 |
| Stepan Co. | Joliet | IL | multi-feedstock | 21 | Operational | N/A |
| e-Biofuels LLC | Middletown | IN | soy oil | 25 | Under Construction | |
| Louis Dreyfus Agricultural Industri | Claypool | IN | soy oil | 80 | Under Construction | |
| Evergreen Renewables LLC | Hammond | IN | soy oil | 5 | Operational | N/A |
| Integrity Biofuels | Morristown | IN | soy oil | 5 | Operational | N/A |
| Owensboro Grain Biodiesel | Owensboro | KY | soy oil | 50 | Under Construction | |
| Griffin Industries | Butler | KY | soy oil/tallow/yellow grease | 2 | Operational | Dec-98 |
| Allegro Biodiesel Corp. | Pollock | LA | soy oil | 15 | Operational | N/A |
| Maryland Biodiesel | Berlin | MD | soy oil | 0.5 | Operational | N/A |
| Bean's Commercial Grease | Vassalboro | ME | waste vegetable oil | 0.25 | Operational | N/A |
| Ag Solutions Inc. | Gladstone | MI | soy oil | 5 | Operational | N/A |
| Michigan Biodiesel | Bangor | MI | soy oil | 10 | Operational | N/A |
| FUMPA Biofuels | Redwood Falls | MN | soy oil/animal fats | 3 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Minnesota Soybean Processors | Brewster | MN | soy oil | 30 | Operational | N/A |
| SoyMor | Glenville | MN | soy oil | 30 | Operational | Aug-05 |
| Ag Processing Inc. | St. Joseph | MO | soy oil | 28 | Under Construction | |
| Great River Soy Co-op | Lilbourn | MO | multi-feedstock | 5 | Under Construction | |
| Natural Biodiesel Inc. | Braggadocio | MO | multi-feedstock | 5 | Under Construction | |
| Prairie Pride Inc. | Nevada | MO | soy oil | 30 | Under Construction | |
| Mid-America Biofuels LLC | Mexico | MO | soy oil | 30 | Operational | N/A |
| Missouri Better Bean LLC | Bunceton | MO | soy oil/animal fats | 4 | Operational | N/A |
| Missouri Bio-Products Inc. | Bethel | MO | soy oil | 2 | Operational | N/A |
| Scott Petroleum Corp. | Greenville | MS | multi-feedstock | 20 | Under Construction | |
| CFC Transportation Inc. | Columbus | MS | soy oil | 1 | Operational | N/A |
| Channel Chemical Corp. | Gulfport | MS | soy oil | 5 | Operational | N/A |
| Earth Biofuels | Meridian | MS | multi-feedstock | 2 | Operational | N/A |
| Evans Environmental Energies | Wilson | NC | multi-feedstock | 3 | Under Construction | |
| Filter Specialty Inc. | Autryville | NC | soy oil/yellow grease | 1 | Under Construction | |
| Blue Ridge Biofuels | Asheville | NC | multi-feedstock | 1 | Operational | N/A |
| Foothills Bio-Energies LLC | Lenoir | NC | soy oil | 5 | Operational | N/A |
| Piedmont Biofuels | Pittsboro | NC | yellow grease/animal fats | 1 | Operational | Sep-06 |
| All-American Biodiesel | York | ND | soy oil/canola oil | 5 | Under Construction | |
| Archer Daniels Midland | Velva | ND | canola oil | 85 | Under Construction | |
| Magic City Biodiesel LLC | Minot | ND | canola oil | 30 | Under Construction | |
| Beatrice Biodiesel LLC | Beatrice | NE | soy oil | 50 | Under Construction | |
| Northeast Nebraska Biodiesel | Scribner | NE | soy oil | 5 | Under Construction | |
| Horizon Biofuels Inc. | Arlington | NE | animal fats | 0.4 | Operational | Sep-06 |
| Fuel:Bio One | Elizabeth | NJ | undeclared | 50 | Under Construction | |
| Environmental Alternatives | Newark | NJ | soy oil | 13 | Operational | N/A |
| Biodiesel of Las Vegas | Las Vegas | NV | multi-feedstock | 30 | Under Construction | |
| Infinifuel Biodiesel | Wabuska | NV | multi-feedstock | 5 | Under Construction | |
| Bently Biofuels | Minden | NV | multi-feedstock | 1 | Operational | N/A |
| Biodiesel of Las Vegas Inc. | Las Vegas | NV | soy oil | 3 | Operational | N/A |
| GS Fulton Biodiesel | Fulton | NY | soy oil | 5 | Under Construction | |
| North American Biofuels Company | Bohemia | NY | trap grease | 1 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Alternative Liquid Fuel Industries | McArthur | OH | multi-feedstock | 6 | Under Construction | |
| Jatrodiesel Inc. | Dayton | OH | multi-feedstock | 5 | Under Construction | |
| American Ag Fuels LLC | Defiance | OH | soy oil | 3 | Operational | N/A |
| Peter Cremer | Cincinnati | OH | soy oil | 30 | Operational | N/A |
| Earth Biofuels | Durant | OK | multi-feedstock | 10 | Operational | N/A |
| Green Country Biodiesel Inc. | Chelsea | OK | soy oil | 2 | Operational | N/A |
| OK Biodiesel | Gans | OK | soy oil | 10 | Operational | N/A |
| Sequential-Pacific Biodiesel LLC | Salem | OR | yellow grease | 1 | Operational | N/A |
| Lake Erie Biofuels | Erie | PA | multi-feedstock | 45 | Under Construction | |
| Agra Biofuels Inc. | Middletown | PA | soy oil | 3 | Operational | N/A |
| Biodiesel of Pennsylvania Inc. | White Deer | PA | multi-feedstock | 3.6 | Operational | Jan-07 |
| Keystone Biofuels | Shiremansto wn | PA | soy oil | 2 | Operational | Jan-06 |
| United Biofuels Inc. | York | PA | soy oil | 1 | Operational | N/A |
| United Oil Co. | Pittsburg | PA | multi-feedstock | 2 | Operational | Dec-04 |
| Southeast BioDiesel LLC | North Charleston | SC | multi-feedstock | 6 | Under Construction | |
| Carolina Biofuels LLC | Taylors | SC | soy oil | 5 | Operational | N/A |
| Midwest Biodiesel Producers | Alexandria | SD | soy oil | 7 | Operational | N/A |
| Freedom Biofuels Inc. | Madison | TN | multi-feedstock | 12 | Under Construction | |
| Agri Energy Inc. | Lewisburg | TN | soy oil | 5 | Operational | N/A |
| Memphis Biofuels LLC | Memphis | TN | multi-feedstock | 36 | Operational | N/A |
| Milagro Biofuels | Memphis | TN | soy oil | 5 | Operational | N/A |
| NuOil Inc. | Counce | TN | soy oil | 1 | Operational | Nov-05 |
| Big Daddy's Biodiesel | Hereford | TX | multi-feedstock | 30 | Under Construction | |
| BioSelect Galveston Bay | Galveston Island | TX | multi-feedstock | 20 | Under Construction | |
| Global Alternative Fuels LLC | El Paso | TX | multi-feedstock | 5 | Under Construction | |
| Green Earth Fuels LLC | Houston | TX | multi-feedstock | 43 | Under Construction | |
| Biodiesel Industries of Greater Dal | Denton | TX | multi-feedstock | 3 | Operational | N/A |
| Brownfield Biodiesel LLC | Ralls | TX | multi-feedstock | 2 | Operational | Jul-06 |
| Central Texas Biofuels | Giddings | TX | vegetable oils | 1 | Operational | N/A |
| GeoGreen Fuels | Gonzales | TX | soy oil | 3 | Operational | N/A |
| Huish Detergents | Pasadena | TX | tallow/palm oil | 4 | Operational | N/A |
| Johann Haltermann Ltd. | Houston | TX | soy oil | 20 | Operational | N/A |
| Momentum Biofuels Inc. | Pasadena | TX | soy oil | 20 | Operational | N/A |
| Organic Fuels LLC | Houston | TX | multi-feedstock | 30 | Operational | Apr-06 |
| Pacific Biodiesel Texas | Carl's Corner | TX | multi-feedstock | 2 | Operational | Aug-06 |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Safe Fuels Inc. | Conroe | TX | soy oil | 10 | Operational | N/A |
| Smithfield Bioenergy LLC | Cleburne | TX | animal fats | 12 | Operational | Jan-06 |
| SMS Envirofuels Inc. | Poteet | TX | soy oil | 5 | Operational | Jun-06 |
| South Texas Blending | Laredo | TX | beef tallow | 5 | Operational | N/A |
| Sun Cotton Biofuels | Roaring Springs | TX | cottonseed oil | 2 | Operational | N/A |
| Better BioDiesel | Spanish Fork | UT | multi-feedstock | 3 | Operational | Sep-06 |
| Reco Biodiesel LLC | Richmond | VA | soy oil | 10 | Under Construction | |
| Chesapeake Custom Chemical | Ridgeway | VA | soy oil | 5 | Operational | N/A |
| Virginia Biodiesel Refinery | New Kent | VA | soy oil | 2 | Operational | N/A |
| Biocardel Vermont LLC | Swanton | VT | soy oil | 4 | Under Construction | |
| Imperium Grays Harbor | Grays Harbor | WA | multi-feedstock | 100 | Under Construction | |
| Seattle Biodiesel | Seattle | WA | virgin vegetable oils | 5 | Operational | N/A |
| Best Biodiesel Cashton LLC | Cashton | WI | multi-feedstock | 8 | Under Construction | |
| Sanimax Energy Biodiesel | De Forest | WI | multi-feedstock | 20 | Under Construction | |
| Walsh Biofuels LLC | Mauston | WI | multi-feedstock | 5 | Under Construction | |
| Renewable Alternatives | Howard | WI | soy oil | 0.365 | Operational | N/A |
| A C & S Inc. | Nitro | WV | soy oil | 3 | Under Construction | |

Appendix B: Biodiesel Chemistry and Process Diagram

*Transesterification* is the process of reacting a triglyceride molecule with an excess of alcohol in the presence of a catalyst (KOH, NaOH, $NaOCH_3$, etc.) to produce glycerol and fatty esters. The chemical reaction with methanol is shown schematically below.

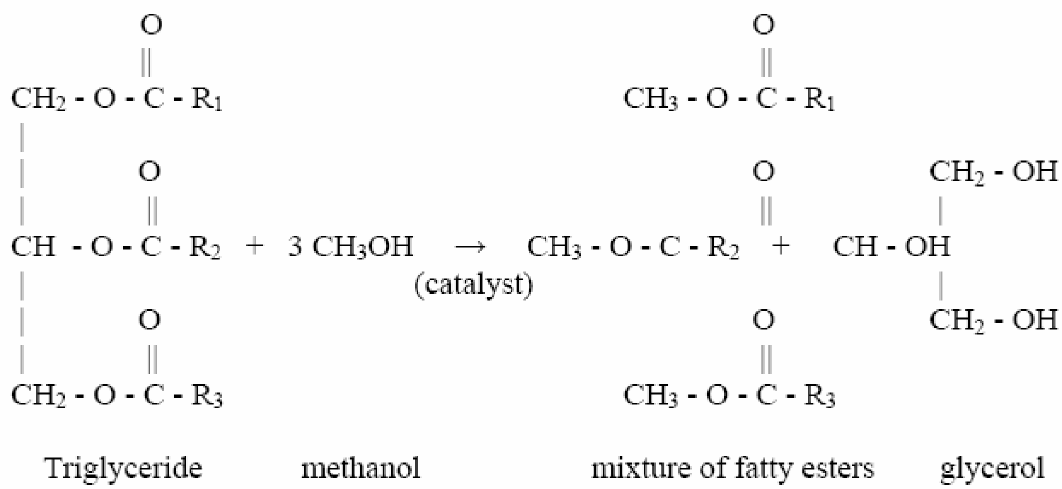



Figure 33: FAME biodiesel chemistry
Source: van Gerpen et al. (2004)

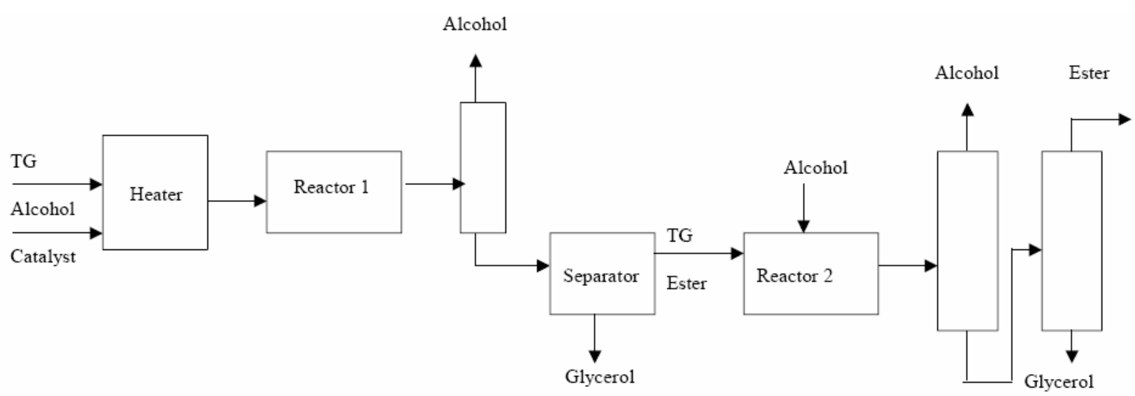
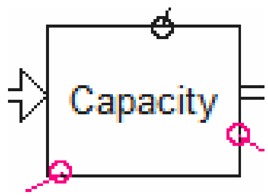
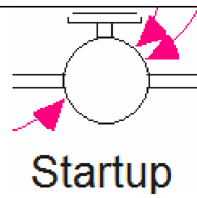
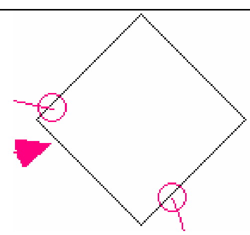
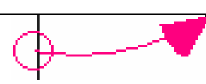



Figure 34: Process flow diagram - Plug flow reactor (typical)
Source: van Gerpen et al. (2004)

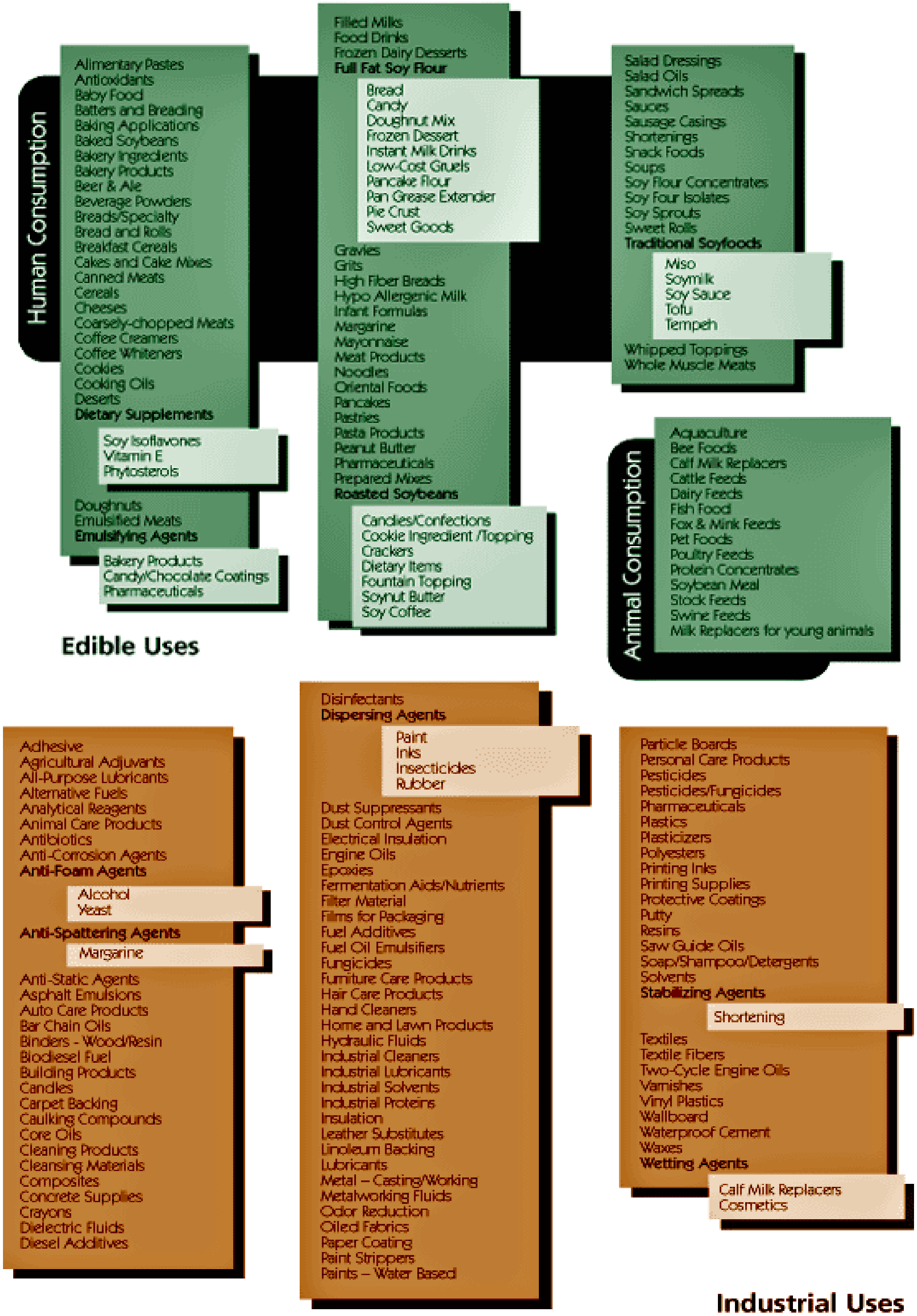
Appendix C: STELLA™ Stock and Flow Symbology

**Table 6: STELLA™ stock and flow overview**

| Name | Symbol | Use |
|---|---|---|
| **Stocks** |   | Accumulates the “stuff” you are modeling such as money, materials, capacity, energy, etc. (flows in – flows out). Stocks can also be linked to other model components using connectors. |
| **Flows** |   | Defines the rate at which the “stuff” moves in and out of the Stocks |
| **Converters** |   | Variables and constants that are all the other model variables that are not Stocks or Flows. STELLA™ provides a large library of built-in calculations and graphical user input. |
| **Decision Blocks** |  | Used to encapsulate important decision making processes in the model. |
| **Connectors** |  | Links model components |

# Appendix D: Soybean Uses

Figure 35: Soybean Usage
Source: American Soybean Association



References


American Soybean Association (ASA) Web site. Accessed on Feb 14, 2007. http://www.asa.org

Ash, M., Livezey, J., & Dohlman, E. (2006, April). *Soybean Backgrounder*. Outlook Report No. (OCS-200601). Retrieved August 23, 2006, from US Department of Agriculture, Economic Research Service Web site: http://www.ers.usda.gov/publications/OCS/apr06/OCS200601/

Baize, J. (2006a, February 17).*The Outlook and Impact of Biodiesel on the Oilseeds Sector*. Presented at USDA Outlook Conference in Arlington, VA. Retrieved January 25, 2007 from http://www.usda.gov/oce/forum/2006_speeches.htm

Baize, J. (2006b, October 18). *The global biodiesel industry: A road to riches or an impending train wreck?* Presented at the 2006 American Fats & Oils Association Annual Meeting in New York. Retrieved March 18, 2007 from http://www.afoaonline.org/annualmeeting/slides/AFOA_keynote_presentation_10-18-06.ppt

Biodiesel Magazine. (2007). *Online US biodiesel plant list.* Retrieved Feb 14, 2007 from Biodiesel Magazine Web site. http://www.biodieselmagazine.com/plant-list.jsp

Blondeau, J., Pon, G., Bresciani, S., & Reaney, M. (2006). *Bio-Oils Market Study-Executive Summary*. Retrieved February 18, 2006 from http://res2.agr.ca/saskatoon/result/biooils-biohuile_e.htm#glycer

Bondioli, P. (2003, May 15). *From oilseeds to industrial products: present and next future of oleochemistry*. Presented at International South Europe Symposium Non-Food Crops: From Agriculture to Industry, Bologna, Italy. Retrieved February 20, 2006 from http://www.ienica.net/italyseminar/oils/bondiolipresentation.pdf

Bonnardeaux, J. (2006). *Glycerin Overview*. Retrieved March 25, 2007, from Government of Western Australia Department of Agriculture and Food Web site: http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/SUST/BIOFUEL/GLYCERINOVERVIEW.pdf

Bowman, M. S. (1999). *Applied Economics Analysis*. Upper Saddle River, NJ: Prentice Hall.

Bowman, K. (2003). *Economic Impact of Soy Diesel in Kentucky.* Retrieved February 12, 2006 from http://www.biog-3000.com/PDFs/NEW%20files/biodieselstudy.pdf

Broehl, J. (2006, February 17). The US biodiesel industry matures. *RenewableEnergyAccess.com*. Retrieved February 20, 2006 from http://www.renewableenergyaccess.com/rea/news/story?id=43614

Bryan, M. (2006, Feb 2006). Corn oil extraction can help sustain biodiesel industry growth. *Biodiesel Magazine,* 3 (2).70.

Bryan, T. (2007, Mar 2007). Will 2 billion gallons be a floor or a ceiling? *Biodiesel Magazine,* 4 (3). 8.

Caparella, T. (2005, October 2005). Minnesota mandate takes effect, and IRS clarifies tax incentive issues. *Render Magazine.* Retrieved March 20, 2006 from http://www.rendermagazine.com/October2005/BiodieselBulletin.html

Carlson, R. (2006). *Prospects for Expansion of the Soy-based Biodiesel Industry in Minnesota*. Agricultural Utilization Research Institute. Marshall, Minnesota. Retrieved February 14, 2007 from http://www.auri.org/research/diesel/pdfs/Executive%20Summary%20Bio-Diesel%20Study%20December%2006.pdf

Clark, G. (2006, December 31). Biodiesel is transitional technology says Nextant. *Biofuel Review*. Retrieved from http://www.biofuelreview.com/content/view/705/

Collins, K. (2006, August 26). *Economic Issues Related to Biofuels*. Written testimony to U.S. Senate Committee on Appropriations Subcommittee on Agriculture, Rural Development, and Related Agencies. Retrieved October 26, 2006, from the USDA, Office of the Chief Economist Web site: http//:www.usda.gov/oce/newsroom/congressional_testimony/sentstbiofuels8-26-06_.doc

Collier, C. A., & Glagola, C. R. (1998). *Engineering economic and cost analysis* (Third ed). Menlo Park, California: Addison-Wesley.

Conrad, S. H. (2004, July 25). *The dynamics of agricultural commodities and their responses to disruptions of considerable magnitude*. Proceedings of the 2004 International Conference of the System Dynamics Society. Oxford, England.

Conway, R. (2007, February 23). *Roger Conway: Office of Energy Policy New Uses/USDA*. Presented at the Texas AG Forum Austin, Texas. Retrieved March 23, 2007, from http://agforum.tamu.edu/2007presentations/Conway.pdf

Dale, B. E. (2004, February 23). *Feed protein coproduction with large scale biofuels: Some land resource perspectives & likely economic impacts*. Presented at Role of Biomass in America's Energy Future, Washington, D. C. Retrieved August 26, 2006 from http://engineering.dartmouth.edu/rbaef/meeting/dale_ppt.pdf

Davis, K. S. (2001, September 11). *Corn Milling, Processing and Generation of Co-products.* Presented at the Minnesota Nutrition Conference Technical Symposium. Retrieved from http://www.distillersgrains.org/files/grains/K.Davis--Dry&WetMillProcessing.pdf

Davis, S.C. & Diegel, S.W. (2006). *Transportation Energy Data Book*. ORNL-6974. (Edition 25 of ORNL-5198). Center for Transportation Analysis. Oak Ridge National Laboratory. U.S. Department of Energy. Oak Ridge, TN.

De La Torre Ugarte, D. G., English, B.C., Jensen, K., Hellwinckel, C., Menard, J., and Wilson, B. (2006). *Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion*. Retrieved Jan 7, 2007, from Governors Ethanol Coalition Web site : http://www.ethanol-gec.org/information/Ethanolagimpacts.pdf

Duff, B. (2004, November 16). *Biofuels Project Development: Biodiesel Feasibility Studies*. Presented at the Virginia Biodiesel Conference, Harrisonburg, Virginia. Retrieved March 15, 2006 from http://www.cisat.jmu.edu/biodiesel/presentations/Feasibilty%20Studies%20-%20Duff%201120a%20presentation.ppt

Duffield, J. A. (2006, September 8). *Biodiesel Supply: How Much Can We Produce?* Presented at the Air Quality and Alternative Transportation Fuel Forum, Washington DC.

Edmonds, J., & Reilly, J. M. (1985). *Global energy: Assessing the Future*. New York: Oxford University Press.

Eidman, V. (2006a, 1st Qtr 2006). Renewable Liquid Fuels: Current Situation and Prospects. *Choices,* 21(1). Retrieved March 16, 2006 from http://www.choicesmagazine.org/2006-1/biofuels/2006-1-03.html

Eidman, V. (2006b, June 27). *The Economics of Energy Production in Agriculture*. Paper presented at the "Energy in Agriculture: Managing the Risk" Conference, Kansas City, Missouri. Retrieved January 10, 2007, from Farm Foundation Web site: http://www.farmfoundation.org/projects/documents/Eidmanpaperwithgraphs.pdf

English, B., Jensen, K., & Menard, J. (2002). *Economic Feasibility of Producing Biodiesel in Tennessee*. Retrieved November 14, 2005 from University of Tennessee, Department of Agricultural Economics Web site: http://beag.ag.utkedu/pp/biodiesel.pdf

English, B., De La Torre Ugarte, D. G., Hellwinckel, C., Menard, R. J.,Wilson, B., Roberts, R., and Walsh, M.E. (2006). *25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts*. Retrieved December 1, 2006 from University of Tennessee, Agricultural Policy Analysis Center Web site: http://www.agpolicy.org/ppap/REPORT%2025x25.pdf

Environmental Protection Agency (EPA). (2006*). Renewable Fuel Standard Draft Regulatory Impact Assessment*. Retrieved November 1, 2006, from EPA Fuels and Fuel Additives Website: http://www.epa.gov/oms/renewablefuels/420f06060.htm

Food and Agriculture Organization of the United Nations (FAO) Web site. Accessed January 15, 2007 online at http://faostat.fao.org/

Ford, A. (2002, June 2002). Boom & bust in power plant construction: Lessons from the California electricity crisis. *Journal of Industry, Competition and Trade.* 2(1). Retrieved September 28, 2005, from Washington State University, School of Earth and Environmental Sciences Website: http://www.wsu.edu/~forda/JournalofIndustry.pdf

Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge MA: Productivity Press.

Forrester, J. W. (1971). *World dynamics*. Cambridge, MA: Wright-Allen Press, Inc.

Forrester, J. W. (1975). Collected Papers of Jay W. Forrester. Cambridge MA: Productivity Press.

Forrester, J. W. (1968). *Principles of systems*. Cambridge, MA: Wright-Allen Press, Inc.

Fortenberry, T. (2005). *Biodiesel Feasibility Study: An Evaluation of Biodiesel Feasibility in Wisconsin*. University of Wisconsin-Madison, Department of Agricultural & Applied Economics, Staff Paper No. 481.

Gerard, B. (2006, Jan 2006). Feedstock change is hot and poppin'*, Chemical Processing Magazine*. Jan 2006. Retrieved March 23, 2006 from http://www.chemicalprocessing.com/articles/2006/010.html

Gorley, V. (2006, February 15). Harvest Provides Fuel for Soybean Farmer. *Charlottesville Daily Progress.*

Greene, N. (2004). *Growing energy: How Biofuels Can Help End America's Oil Dependence.* Retrieved July 17, 2006, from Natural Resources Defense Council Web site: http://www.nrdc.org/air/energy/biofuels/biofuels.pdf

GreenShift Corporation (2005, December 22). *GreenShift's Mean Announces 30 Million Gallon Biodiesel Plant in North-Eastern Indiana*. Press Release. Retrieved January 1, 2006 from: http://www.greenshift.com/news.php?id=101

Haas, M.J., Mcaloon, A.J., Yee, W.C., Foglia, T.A. (2006). *A process model to estimate biodiesel production costs*. Bioresource Technology. 97:671-678.

Hamilton, J. (2007, March 28). *NBB and EPA: Where are we going together?* Presented at the EPA Mobile Sources Technical Review Subcommittee Meeting in Arlington, Virginia.

Howell, S., & Weber, A. (2005, March 17). *Biodiesel Plant Investment: Making the Correct Decisions.* Presented at the Iowa Farm Bureau Soy Biodiesel Meeting. Retrieved November 12, 2006, from Iowa Farm Bureau Web site: http://www.iowafarmbureau.com/programs/commodity/energy/Biodiesel%20Plant%20Development%20Considerations.ppt

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science Basis. Summary for Policymakers*. Retrieved February 10, 2007, from the Intergovernmental Panel on Climate Change Web site: http://www.ipcc.ch/SPM2feb07.pdf

International Energy Agency (IEA) (2004), *Biofuels for transport: An international perspective.* Retrieved August 15, 2006, from the International Energy Agency Web site: http://www.iea.org/books

Irwin, L. (2006, Oct 2006). Forecasting the Future. *Ethanol Producer Magazine,* 12 (8). 24.

Jaffe, S. (2005). Biodiesel: A new way of turning plants into fuel. *Technology Review.* Retrieved November 12, 2006 from http://www.technologyreview.com/articles/05/06/wo/wo_060705jaffe.asp?trk=nl

Jones, A., Seville, D., & Meadows, D. H. (2002). Resources sustainability in commodity systems: The sawmill industry in the northern forest. *System Dynamics Review, 18*(2), 171-204.

Koplow, D. (2006). *Government support for ethanol and biodiesel in the United States: Biofuels – at what cost?* Retrieved January 5, 2007 from Earth Track Web site: http://www.earthtrack.net/earthtrack/library/biofuels_subsidies_us.pdf

Kortba, R. (2006, February 2006). Everything under the sun. *Biodiesel Magazine.* 3(2), 28-34.

McClinton, L. (2006, February 2006). Converting bio-diesel co-products into value. *Bio-Prospects,* 3(1). Retrieved August 23,2006 from http://www.agwest.sk.ca/publications/documents/BPFeb06_000.rtf

McMillen, S., Shaw, P., Jolly, N., Goulding, B., Finkle, V., & Broehl, J. (2005). *Biodiesel: Fuel for thought, fuel for Connecticut's future*. Retreived February 11, 2006, from Connecticut Center for Economic Analysis Web site: http://ccea.uconn.edu/studies/Biodiesel%20Report.pdf

McCoy, M. (2006, Feb., 6). Glycerin Surplus: Plants are closing, and new uses for the chemical are being found. *Chemical & Engineering News*, 84 (6). p. 7 , Retrieved from http://pubs.acs.org/isubscribe/journals/cen/84/i06/html/8406notw3.html

Meadows, D. L. (1970). *Dynamics of Commodity Production cycles.* Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. L., Behrens, William W. III, Randers, Donella H., Naill, R. F., Randers, J., & Erich K. O. Zahn. (1974). *Dynamics of growth in a finite world*. Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. H., Randers, J., & Meadows, D. L. (2004). *Limits to growth: The 30-year update.* Vermont: Chelsea Green.

Meeker, D. L (2006). *Essential rendering: all about the animal by-products industry*. Arlington,Virginia: Kirby Lithographic Company, Inc.

National Biodiesel Board (NBB) Web site. Accessed on Feb 7, 2007. http//:www.biodiesel.org

National Corn Growers Association (NCGA) Web site. Accessed on Feb 14, 2007. http//:www.ncga.org

National Renderers Association Web site. Accessed on May 30, 2006. http://www.renderers.org/Statistics/98-05%20prodn-consum.pdf

Neville, D., Wright, D., Rice, P., Sweitzer, S., Jones, A., & Hamilton, H. et al. (2003). *Commodity systems challenges: Moving sustainability into the mainstream of natural resource economies.* Vermont: Sustainability Institute. Retrieved August 21, 2005 from http://www.sustainabilityinstitute.org/pubs/SustainableCommoditySys.2.1.pdf

Nilles, D. (2007, Feb. 2007). NBB stresses quality while aiming for 5 percent market penetration by 2015. *Biodiesel Magazine.* 4(2), 55.

Organisation for Economic Co-operation and Development (OECD). (2005). *Agricultural market impacts of future growth in the production of biofuels*. Working Party on Agricultural Policies and Markets. Paris: OECD. Retrieved from http://www.oecd.org/dataoecd/58/62/36074135.pdf

Orr, J. (2004). *Exploiting clean energy for profit: The Outlook on the Current Biofuels Industry*. Retrieved August 12, 2006, from http://www.newfarm.org/features/0604/biofuels/index.shtml

Pahl, G. (2005). *Biodiesel: growing a new energy economy*. White River Junction, VT: Chelsea Green Publishing.

Pearl, G. (2004, Aug 2004). Rendering 101: Raw material, rendering process, and animal by-products. *Render Magazine.* Retrieved September 15, 2006, from http://www.rendermagazine.com/August2004/Rendering101.pdf

Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J. & Erbach, D.C. (2005) *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge Natl. Lab., Oak Ridge, TN), ORNL Publ. No. TM-2005-66.

Promar International (2005). *Evaluation and Analysis of Vegetable Oil Markets: The Implications of Increased Demand for Industrial Use on Markets and USB Strategy.* Retrieved December 10, 2006, from http://www.unitedsoybean.org/Library/Studies.aspx

Radich, A. (2002). *Biodiesel Production Methods, Costs and Available Capacity*. Retrieved February 23, 2006, from http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/

Reaney, M. J., Furtan, W. H., & Loutas, P. (2006). A Critical Cost Benefit Analysis of Oilseed Biodiesel in Canada. Retrieved March 31,2007, from the BIOCAP Canada Web site://www.biocap.ca/rif/report/Reaney_M.pdf

Renewable Fuels Association (RFA). (2007). U.S. fuel ethanol industry biorefineries and production capacity. Retrieved March 7, 2007, from Renewable Fuels Association Web site: http://www.ethanolrfa.org/industry/locations/

Riley, W. W. (2004). *The Canadian biodiesel industry: An analysis of potential feedstocks.* Paper prepared for the Biodiesel Association of Canada. Retrieved December 15, 2006 from http://www.greenfuels.org/main/biodiesel/pdf/res/102004_Potential_Feedstock_for_Canadian_Biodiesel_Industry.pdf

Roberts, P. (2004). *The end of oil: On the edge of a perilous new world*. New York: Houghton Mifflin.

Roberson, R. (2007, March 22). North Carolina biodiesel plant won't happen. *Southeast Farm Press.* Retrieved April 11, 2007 from http://southeastfarmpress.com/biofuels/032207-biodiesel-carolina/

Rowland, Robert C. (1997). *United States policy on renewable energy use: An overview of the issues related to increasing renewable energy use in the United States.* Lincolnwood, IL: The National Textbook Company.

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York: W.W. Norton & Co.

Sheehan, J., Dunahay, T., Benemann, J., & Roessler, P. (1998). *A look back at the US Department of Energy's aquatic species program: Biodiesel from Algae.* (Report No. NREL/TP-580-24190). Golden, CO: National Renewable Energy Lab.

Shumaker, G. A., McKissick, J., Ferland, C., & Doherty, B. (2001). *A study on the feasibility of biodiesel production in Georgia.*

Soy stats Web site. A reference guide to important soybean facts & figures. Accessed on March 14, 2006. http://www.soystats.com

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world.* McGraw-Hill/Irwin.

Sterman, J. (2002, Winter 2002). All models are wrong: reflections on becoming a systems scientist. *System Dynamics Review*, 18(4), 501–531.

Stroup, R. L. (2004, Jan/Feb 2004). Feedstock Considers for Future US Producers. *Biodiesel Magazine.*1(1).

Tesch, T., Descamps, P.T.& Weiler, R. (2003, September 21).The COSMOPAD modelling framework: Conceptual system dynamics model of planetary agricultural & biomass development. Presented at the Conference Digital Earth2003, BRNO, Czech Republic.

Tickell, J. (2003). *From the fryer to the fuel tank: the complete guide to using vegetable oil as an alternative fuel*. New Orleans, LA: Joshua Tickell Media Productions.

Tickell, J. (2006). *Biodiesel America*. USA: Yorkshire Press.

Tyson, K. S., Bozell, J., Wallace, R., Petersen, E., & Moens, L. (2004). *Biomass oil analysis: Research needs and recommendations*. (Report No. NREL/TP-510-34796). Golden, CO: National Renewable Energy Lab.

US Department of Agriculture, Economic Research Service (USDA-ERS). (2007). *Oil Crops Situation and Outlook Yearbook*. Retrieved January 12, 2007 from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1288
.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2004). *2002 Census of Agriculture: United States Summary and State Data,* Volume 1, Geographic Area Series, Part 51. Retrieved March 23,2006, from http://www.nass.usda.gov/Census_of_Agriculture/index.asp.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2006). *Statistical Highlights of United States Agriculture, 2005/2006.*Retrieved Aug 27, 2006, from http://www.nass.usda.gov/Publications/Statistical_Highlights/2006/STATHI2006.PDF

US Department of Agriculture, Office of the Chief Economist. (USDA-OCE) (2007). *USDA Agricultural Projections to 2016.* World Agricultural Outlook Board, Long-term Projections Report OCE-2007-1 February 2007 Retrieved March 1, 2007, from http://www.ers.usda.gov/publications/oce071/oce20071.pdf

US Department of Energy, Energy Efficiency and Renewable Energy-Alternative Fuels Data Center (USDOE-EERE). (2007). Clean Cities alternative fuel price reports. Accessed on Feb 5, 2007: http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2007). *Annual Energy Outlook 2007 with Projections to 2030*. DOE/EIA-0383. Retrieved February 15, 2007, from http://www.eia.doe.gov/oiaf/aeo/index.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006a). International Energy Annual 2004. Retrieved March 10, 2007 from http://www.eia.doe.gov/iea/

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006b). Energy Information Administration (EIA). Petroleum Overview, 1949-2002. Table 5.1. in Annual Energy Review. Retrieved January 15, 2007 from http://www.eia.doe.gov/emeu/aer/petro.html

US Department of Energy, Office of Biomass Programs (USDOE-OBP) (2006) Biomass Transition Model Workshop Website. Accessed November 15, 2006. http://30x30workshop.biomass.govtools.us/default.aspx?menu=model

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2005). *Building a Successful Biodiesel Business.* Golden, CO: National Renewable Energy Lab.

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004). *Biodiesel Analytical Methods August 2002 - January 2004.* (Report No. SR-510-36240). National Renewable Energy Lab.

Wang, M. (2007). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model Version 1.7. Retrieved March 10, 2007, from the US Department of Energy, Argonne National Laboratory Web site: http://www.transportation.anl.gov/software/GREET/

Weber, J. A. (2007). MARC IV Consulting. Telephone conversation with Steve Bantz March 12, 2007.

Whelan, J., & Msefer, K. (1996). *Economic Supply and Demand.* Retrieved from http://sysdyn.clexchange.org/sdep/Roadmaps/RM6/D-4388.pdf

White, A. S., Yan, Y. C. , Akpunar, E., & Hock, K. K. (2002, July). *Control Strategies for Inventory Management*. Proceedings of the 2002 International Conference of the System Dynamics Society. Palermo, Sicily, July 2002.

Wilson, J. (2007). US Farmers Plan Biggest Corn Planting Since 1944. *Bloomberg.com*. Retrieved March 30, 2007, from http://www.bloomberg.com/apps/news/?pid=20670001&refer=home&sid=ag_W9jQ.1Aoc

Young, N. (2006, January 2006). *Biodiesel & industrial demand for soy oil: study conducted to examine implications for soybean farmers & USB strategy*. Presented at the Qualsoy Board Meeting. Retrieved April 10, 2006, from http://www.unitedsoybean.org/studies_pdf/2005_Promar_Qualsoy.ppt

Zagonel, A. A., Conrad, S. H., & Kaplan, P. G. (2005, July 17). *Modeling the impact of loss in U.S. soybean production resulting from soy rust disease.* Presented at the 23rd International Conference of the System Dynamics Society, Boston, MA. Retrieved February 19, 2006, from the System Dynamics Society Web site: http://www.albany.edu/cpr/sds/conf2005/proceed/proceed.pdf

Zeman, N. (2007, Feb. 2007). Crazy for camelina. *Biodiesel Magazine.* 4(2), 60.

# Growing Pains:

# Exploring the Future of the US Biodiesel Industry

Steven George Bantz

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Science

Department of Integrated Science and Technology

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Dedication

This research is dedicated to the farmers, scientists, engineers, entrepreneurs, policymakers, and all others working to build a more robust and cleaner renewable energy future. Expanded use of low-carbon fuels such as biofuels pursued in conjunction with aggressive increases in energy efficiency, reduced demand through conservation, and reforms in transportation and land use policies can help to achieve timely reductions in both greenhouse gasses and our dependence on fossil fuels.

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## Preface

In the August of 2004, I became interested in biofuels after attending the Southern Energy and Environment Exposition in Asheville, NC and hearing Lyle Estill and his colleagues from Piedmont Biofuels singing the praises of homegrown fuels. I was hooked. A few months later I discovered the Fuels Diversification Program in the Integrated Science and Technology (ISAT) Department at James Madison University. I decided to enroll in the ISAT masters' degree program because I wanted to learn about biofuels and I recognized that this program would give me a broad, balanced approach when addressing the technical issues society faces with regards to energy, the environment, and sustainability. I had the opportunity to work with the program directors to write a grant proposal to Clean Cities for funding of a small-scale biodiesel processor for the university and performed a detailed process hazards analysis of various small-scale processor designs. Participation in this program afforded me to be opportunity to have discussions with entrepreneurs regarding the development of biofuels plants in the Harrisonburg, Virginia area. After hearing the concerns of these various business leaders, I became extremely interested in the broad drivers, limits, and impacts of the rapidly expanding biofuel industries. This has led to my current thesis research exploring the biodiesel industry using system dynamics (SD) modeling to help understand the impacts of current and future industry growth.

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Abstract

The biodiesel industry -- both in the US and globally -- is experiencing explosive growth. Demand for biodiesel in the US is driven by concerns about energy security, climate change, high oil prices, and economic development and supported by state and federal mandates. The US production capacity has grown by a factor of ten in the past two years, and over forty new plants are currently in or near construction phase. Continued strong growth of biodiesel production capacity depends on producer profitability which will be influenced by several factors such as biomass oil feedstock prices, product and co-product prices, production technologies, and government regulations and incentives. This research aims at evaluating how, when, and to what extent the growth of the biodiesel industry will be influenced by these various factors. A system dynamics (SD) model of the US biodiesel marketplace is developed to explore possible answers to these questions. The construction and use of this model provides a framework for understanding the structure and dynamics of this industry and how feedstock availability will impact growth. Simulating industry behavior over the next decade using the SD model with different scenarios, we can gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. A key finding from this study is that many of the scenario runs indicate that industry may experience a plateau of capacity growth over the next few years due to the impact of increasing feedstock prices on profitability. In addition, the industry will only achieve its own goal to reach five percent of diesel market penetration in the most optimum of feedstock and market conditions.

1. Introduction

1.1. Promise for a new energy future

Biofuels have the potential to yield a range of important societal benefits: reducing emissions of greenhouse gases, increasing energy security, decreasing air and water pollution, conserving resources for future generations, saving money for consumers, and promoting economic development. But, there are increasing concerns about the limits to growth and the unintended economic and environmental consequences of expanding biofuel production. Whereas ethanol and biodiesel made from corn and soybean oil feedstocks have been important in building a strong foundation for the industry; these biofuels feedstocks are currently used for many other purposes such as livestock feed, human food products, and a hundreds of other chemicals and consumer products. Based on land availability and other competing demands, corn and soy based biofuels can ultimately only displace a small percentage of the petroleum-based transportation fuels. The increasing demand from biofuel production will present challenges and opportunities for feedstock markets in the coming years.

Recently, many researchers have attempted to understand the long term growth potential and impacts of the biofuel industries (Perlack et al., 2005; English et al., 2006). For the biodiesel industry, the picture is not at all clear. The Department of Energy Information Administration (USDOE-EIA, 2007) forecasts that biodiesel production will only reach 400 million gallons per year by 2030. This forecast contrasts sharply with the current industry capacity, growth rate, and goals. The current industry capacity in operation is estimated to be over 700 million gallons per year (Biodiesel Magazine,

2007). The National Biodiesel Board recently set industry goals at 5% of the diesel market by 2015 or approximately 2500 million gallons per year of biodiesel (Nilles, 2007). Biodiesel Magazine estimates that if all the capacity in the pipeline becomes a reality, three billion gallons of biodiesel production capacity from all feedstocks may be in place in the US by the end of 2008 (Bryan, 2007). This would require three quarters of all fats and oils produced in the country annually.

With all these lofty numbers and conflicting forecasts, one is left to wonder what the future will hold for biodiesel: boom, bust, or somewhere in between? Have previous analyses adequately focused on the short term growing pains that the industry may incur in the next decade? Using SD modeling tools and techniques, this thesis will explore the nascent biodiesel industry in the US and attempt to evaluate the impact of some of the pressing near-term feedstock supply issues on the growth of this industry.

## 1.2. Costs of our addiction to oil

As President Bush stated in his 2006 State of the Union address, we are addicted to oil. Besides providing 97% of the energy to fuel transportation needs in the US (Davis & Diegel, 2006), petroleum also provides us with everyday products such as plastics, lubricants, man-made fibers, asphalt, and heating oil. As seen in Figure 1, the US consumes one quarter of all the oil consumed every day despite having less than 2% of the world's reserves and slightly less than 5% of the world's population. The US imports 60% of our oil (USDOE-EIA, 2007). The costs of our addiction are staggering: our nation spends approximately a half of a million dollars every minute to pay for imported oil.[1]

[1] Calculations based on $60 per bbl oil price and 2005 EIA oil import data.

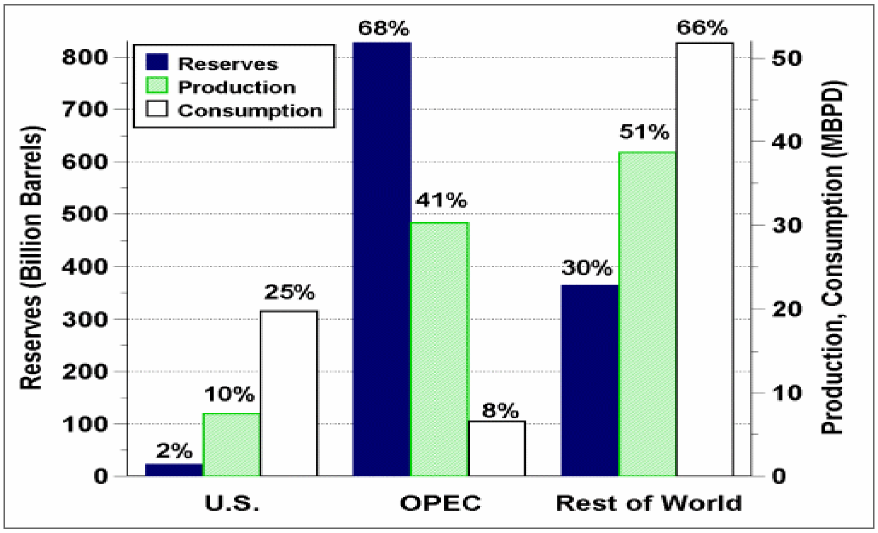


**Figure 1: World oil reserves, production, and consumption 2003**

Source: USDOE Office of Energy Efficiency Renewable Energy [2]

In addition to reducing our dependence on oil, diversifying our energy supply – by including renewable sources of fuel and electricity -- could create tremendous economic opportunities for Americans. And finally, the International Panel on Climate Change, the US National Academy of Sciences, and the scientific academies of ten leading nations have all stated that human activity, especially the burning of petroleum products and other non-renewable fossil fuels, are responsible for the accumulation of heat-trapping gases in the atmosphere, which impacts global climate patterns (IPCC, 2007). Stopping and reversing global climate change may become one of the greatest challenges of our era, and, therefore, we need to measure all energy-related policies by their ability to deliver real and measurable reductions in greenhouse gas emissions. To address the vulnerabilities that result from our oil addiction, we must substantially reduce our demand through efficiency, conservation, and reforms in transportation and land use

[2] Reserves: EIA International Energy Annual 2002, Table 8.1./Production: EIA International Petroleum Monthly, July 2004, Tables 4.1a– 4.1c and 4.3/Consumption: EIA International Petroleum Monthly, July 2004, Table 4.6/ OPEC consumption (2002 data): EIA International Energy Annual 2002, Table 1.2 Data posted at http://www1.eere.energy.gov/vehiclesandfuels/facts/2004/fcvt_fotw336.html.

policies (smart growth), and develop a diverse energy portfolio that emphasizes renewable energy sources such as wind, solar, and biofuels.

1.3. Biofuels- Part of the solution, but no silver bullet

Increasing the use of biofuels -- renewable fuels made from biomass such as ethanol and biodiesel -- can yield a range of important societal benefits, but biofuels alone are not sufficient to remedy the threats that fossil fuels pose to our nation's security, economic health, and environment. Solutions to create a secure and clean energy future must be economically feasible and sustainable, and they must simultaneously address both the supply and the demand sides of the energy equation. Federal and state policy initiatives, consumer demand, high fuel prices and future supply uncertainty, have triggered rapid expansion in the biofuels industries. As seen in Table 1, biofuel production has grown rapidly in response to increasing demand for ethanol and biodiesel, but still only accounts approximately 3% of total US motor vehicle fuel needs. It is estimated that 20% of the 2006/07 US corn crop will be converted to ethanol to supply about 3% gasoline demand (Collins, 2006) and 8% of 2006/07 US soybeans could be converted to biodiesel to supply less than 1% of diesel demand (Conway, 2007).

| | Gasoline (million gals) | Ethanol (million gals) | Pct of gasoline market | Diesel (million gals) | Biodiesel (million gals) | Pct of diesel market |
|---|---|---|---|---|---|---|
| 2000 | 128,662 | 1630 | 0.89% | 37,238 | 0 | 0.00% |
| 2001 | 129,312 | 1770 | 0.96% | 38,155 | 9 | 0.02% |
| 2002 | 132,782 | 2130 | 1.12% | 38,881 | 11 | 0.03% |
| 2003 | 134,089 | 2800 | 1.46% | 40,856 | 18 | 0.04% |
| 2004 | 137,022 | 3400 | 1.74% | 42,773 | 28 | 0.07% |
| 2005 | 136,949 | 3904 | 2.00% | 43,180 | 91 | 0.21% |
| 2006 | | 5450 | | | 225 | |

**Table 1: US motor fuels consumption 2000-2006**

Source: 2000-2005: USDOE-EIA Annual Energy Outlook 2007,
2006: National Biodiesel Board, Renewable Fuels Assoc.

1.4. Limits to growth

In the US, ethanol is predominantly made by fermenting the sugars derived from the starch in the corn kernel, and biodiesel is made by chemically reacting triglycerides (found in plant oils and animals fat feedstocks) with an alcohol and catalyst.[3] Biodiesel feedstocks can come from oilcrops (e.g. soybean, rapeseed, and palm oils), and also from used oils, fats, and greases from rendering facilities and other food processing facilities. The use of corn and soy feedstocks has helped build a strong base for the biofuels industry and has helped to establish a foothold in a transportation fuel marketplace. However, the current feedstocks have many other uses besides fuel production: mainly feed and food for livestock and human consumption, but also products like soy-based ink[4] and plastic from corn.

Ultimately, the limiting factor to growth for today's biofuels will be the availability of feedstocks. For example, if all corn produced in the US in 2005 was converted to ethanol -- with nothing left for food or animal feed -- this would displace less than 15% of the gasoline demand[5]. Biodiesel production from oils and fats may be even more limited. Currently, if we used all the domestically available oil crops, waste fats, and oils to make biodiesel -- with nothing left for margarine, cooking oil, animal feed supplement, or other oil uses -- this would displace less than 10% of the current diesel demand.[6] Moreover, all of the vegetable oil in the world would only make enough biodiesel to supply just over half of the US diesel consumption (Baize, 2006b). Many, like John Sheehan at the National Renewable Energy Laboratory (NREL), agree that corn

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[3] See Appendix B for more details regarding biodiesel chemistry and process.
[4] See Appendix D for a complete listing of edible and industrial soy uses.
[5] Calculations based on data from DOE-EIA (2006) and National Corn Growers Association.
[6] Calculations based on data from Tyson et al. (2004), Soystats, and National Renderers Association.

ethanol and soy biodiesel are not sufficient long-term solutions to breaking our oil addiction (Irwin, 2006).

To capture a greater percentage of the transportation fuel markets and to help realize significant reductions in oil usage and greenhouse gas emissions, we must think outside the kernel and the bean and pursue biofuels that utilize a diverse array of biomass feedstocks. To this end, public and private efforts (and funding) have been has focused on the research, development, demonstration, and deployment of next-generation biofuels. These next-generation biofuels can be produced using a variety of production methods and can be made from corn stalks, wheat straw, woodchips, tree trimmings, switchgrass, municipal wastes, and even algae.

### 1.5. The biodiesel dilemma

Biodiesel has become an attractive alternative for replacement of petroleum-diesel because it is domestically produced, less polluting,[7] and used at any blend percentage with no vehicle modification required. The most common way to produce biodiesel is shown in Figure 2. Reacting biomass oils with a simple alcohol (typically methanol) and a catalyst produces a renewable fuel called Fatty-Acid Methyl Ester (FAME) biodiesel and a co-product, glycerol (or glycerin). Although the renewable diesel market is currently dominated by FAME biodiesel, alternate production pathways are being pursued such as biomass gasification/Fischer-Tropsch diesel and refinery hydrogenation of biomass oils (both are shown in Figure 3).

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[7] Emission reduction of greenhouse gases (GHG), Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Particulate Matter (PM) - based on GREET model from Argonne National Lab (Wang, 2007)

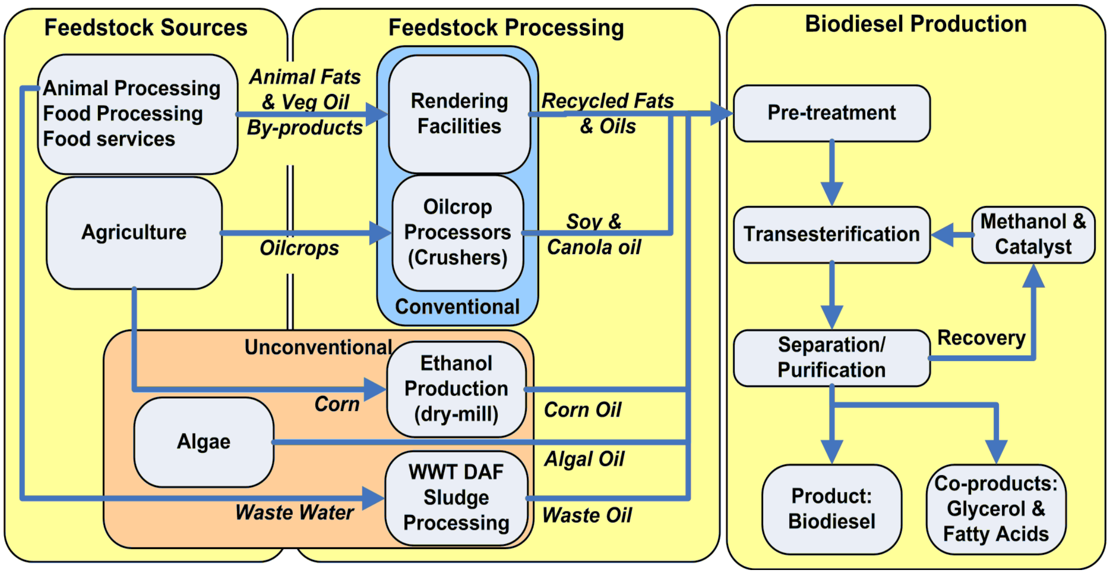


Figure 2: FAME biodiesel feedstocks and production diagram

The biomass gasification process, seen in Figure 3 below, is promising because it enables renewable fuel producers to use a diverse array of feedstocks with an estimated one billion tons of potential feedstock (Perlack et al., 2005). FAME biodiesel and hydrogenation currently have a limited supply of biomass fats and oils as feedstocks.

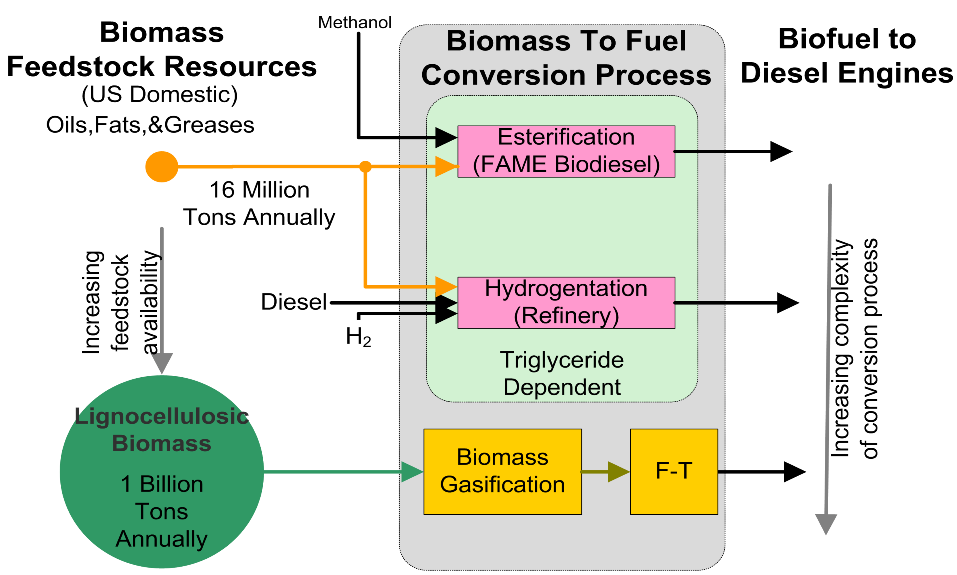


Figure 3: Renewable diesel production pathways

The alternative renewable diesel processes, shown in Figure 3, are currently at various phases of commercialization[8,9] and show great promise. But, due to increased process complexity and capital costs, investors have not yet begun to transition away from FAME biodiesel production to these newer technologies. As the cost of biomass oil feedstocks continues to rise and cut into the profit margins for FAME biodiesel producers, these technologies may soon begin to be more prominent in the biodiesel industry.

The US uses three times more gasoline than diesel (USDOE-EIA, 2006b). Hence, much of the effort to develop renewable transportation fuels has focused on gasoline alternatives such as ethanol. In 2005, the ethanol industry dwarfed biodiesel, producing over 40 times as much fuel. Compared to ethanol which became commercial in 1980's, the US biodiesel industry is in its infancy. Research and development took hold in the early 1990's and commercial production began to appear in the late 1990's. Expanding diesel demand, high oil prices, state and federal environmental mandates, and growing consumer awareness of environmental and energy security issues have fueled the growing demand for biodiesel in the US.

To meet the booming biodiesel demand, US FAME biodiesel production capacity is expanding rapidly. According to Biodiesel Magazine January 2007 online plant listing (see Appendix A), the biodiesel production capacity is approximately 700 million gallons per year and forty eight new biodiesel plants are under construction in the US. Over the next few years, as these new plants become operational, the total capacity will easily

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[8] Conoco-Phillips and Neste Oil are working to commercialize a renewable diesel process unit integrated with oil refineries in which they hydrogenate natural oil. This offers advantages to the large fuel producers to better integrate renewable fuels into the fuel pool (versus blending further downstream).

[9] Choren, a European company, and others are gasifying biomass and then processing this gas into a diesel fuel using the Fischer-Tropsch (FT) process.

exceed one billion gallons per year as illustrated in Figure 4. This is an extraordinary growth rate for an industry that had just 30 million gallons of production in 2004 (NBB, 2007).

The actual biodiesel produced annually is currently far below the design capacity of the US plants. In earlier periods, the low capacity utilization (Actual Production/Design Capacity) could be attributed to low demand and/or profitability issues. Currently, low capacity utilization is most likely due to operational (startup) problems associated with rapid growth in a young industry (Koplow, 2006). As shown in Figure 4, the biodiesel industry only achieved up to 42% capacity utilization in the 2001-2006 time-frame.

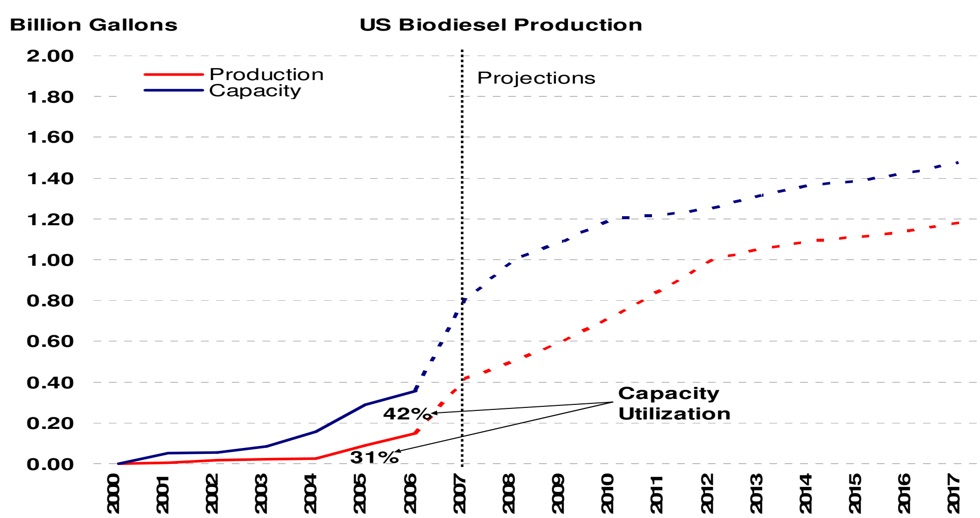


**Figure 4: Biodiesel US production and capacity (historical and projections)**

Sources: Biodiesel Magazine, NBB, Koplow (2006), and production projections used from Ugarte et al. (2006)

As processes improve and the industry builds operational experience, and as the demand and cost pressures on the biofuel producers increase, the productivity (as indicated by capacity utilization) should increase. However, as the industry grows, biomass oil feedstock availability will become a pressing issue. In 2004, US biodiesel

demand consumed less than 1% of the total biomass fats and oils produced in the US (Figure 5). Over the next decade, as new biodiesel plants come online, the biodiesel production crosses one billion gallons per year, the demand could approach one quarter of the total fats and oils the market.

So, the biodiesel dilemma is: production cost are relatively high because the feedstocks compete in high-valued food markets, but the selling price of biodiesel is relatively low because it competes in the fuel market with petroleum diesel which historically has a lower value than animal fats and oil (Duffield, 2006). Uncertainty in the future of biomass oil feedstocks has industry participants worried that new biodiesel production facilities may not have an affordable feedstock supply to make their operations profitable. To be sure, many have recognized this problem and are shifting new plants to multi-feedstock processing capability that enables FAME biodiesel producers to process cheaper, lower quality feedstocks.

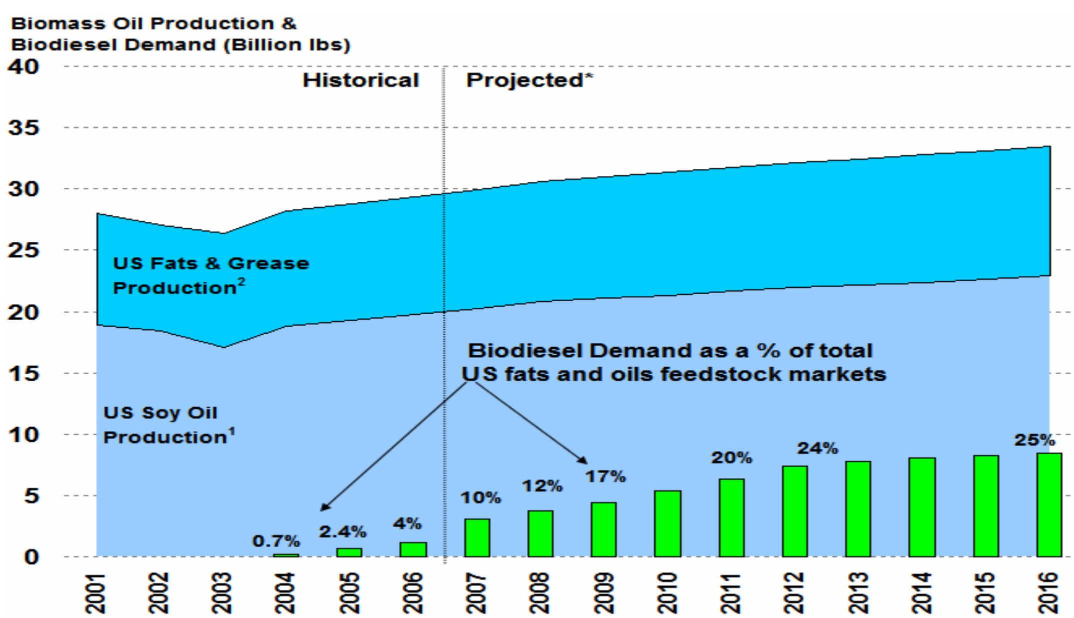


**Figure 5: US biomass oil production (soy oil and fats & greases)**

Sources: Historical data from Soystats (1) and National Renderers Assoc (2)

However, those feedstock supplies are also used in other markets and not expected to grow significantly over the next decade. The potential for a feedstock shortage to impact the growth of the biodiesel market is generally recognized, but it has not seemed to dampen the exuberance for building new FAME production facilities.

1.6. Research objectives, organization, and methodology

**Section 1** articulated the problem of feedstock limitations on the expansion of FAME biodiesel industry. The working hypothesis for this thesis is that feedstock limitations will continue to put pressure on producer profitability, and this will adversely impact the industry growth over the next decade. The main objectives for this research are:

- To investigate the market dynamics of the FAME biodiesel industry
- To build a system dynamics research model to help investigate how growth in this market (as represented by the total production capacity of US biodiesel suppliers) will be impacted by feedstock availability over the next decade

System Dynamics (SD) modeling (e.g. see Forrester, 1961; Meadows, 1970; Sterman, 2000) was preferred over other modeling tools because of the inherent heuristic nature of the SD model building process: illustrating the structure, causal relationships, and feedback loops. The research model constructed for this thesis will be referred to as the Biodiesel Industry Growth Simulator (BIGS).

In **Section 2**, I review the research and methods that have been used to analyze the potential for and the impacts of growth in the biofuel and bioenergy industries. Then,

I discuss how my research draws upon these other areas of research, then uses system dynamic modeling to take a unique look at this problem.

In **Section 3,** I define the model boundaries and structure and provide the background for understanding the growth dynamics of the biodiesel industry over the next decade. I discuss the biodiesel supply chain and build up the model sector-by-sector. Then I assemble the model sectors and discuss the important factors and interactions that could impact growth in the next decade. Finally, I conclude this section with a discussion of methods for testing the model structure and assumptions.

In **Section 4,** I outline how the model can be used to answer the research questions by postulating various scenarios and then simulating industry behavior over the next decade using the SD model. This will help to gain a better understanding of how realistic the current industry growth predictions are and how sensitive behavior is to various parametric and structural changes. I explore conditions under which the simulated biodiesel market can be expected to experience healthy growth, and the conditions under which this market might experience decline. The results will help identify conditions under which biodiesel production capacity can be expected to grow smoothly, and those conditions under which it could encounter “boom and bust” cycles.

In **Section 5**, I summarize the findings of this study and makes recommendations regard to policy, further research, and technology and market development.

## 2. Literature Review – Biodiesel Market Dynamics

The basis of this research draws upon four research areas: a) bioenergy assessment modeling; b) regional feasibility studies; c) SD modeling of industrial capacity and production; and d) SD modeling of the bioenergy markets. The rapid expansion of the bioenergy industries has prompted pressing questions such as: How much petroleum can biofuels ultimately displace? How fast can this occur? What will be the impacts of this rapid expansion?

To answer these and other important questions, many researchers from government agencies, academia, non-governmental organizations (NGOs), private consulting firms, and corporations have published assessments and projections for the future potential for biomass to provide transportation fuels, energy, products and power. Many of these assessments such as the often cited joint USDA-DOE Billion Ton Study[10] focus on a "point B" in the distant future -- often decades away – and tend to spend less time examining the dynamics of how we get from point A to point B. To help better understand the near-term transitional dynamics, US DOE Office of Biomass Programs has tasked a team of modelers to build the Biomass Transition Model based on System Dynamics (USDOE-OBP, 2006). This work will be critical for understanding the transition to second generation cellulosic biofuel technologies to displace gasoline, however, this effort does not focus on the specific near-term growth issues that the biodiesel industry is facing.

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[10] The USDA-DOE study (Perlack et al., 2005) titled "Biomass as Feedstock for Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion-Ton Annual Supply" assesses the ability of US agricultural and forestry industry to provide sufficient biomass feedstock for transportation fuels, electrical power generation, and bioproducts. Although the report detailed several different land use and biomass production scenarios with a wide variation in results, the optimum scenario which yield 1.3 billion tons of biomass annually is often cited as the ultimate potential to support massive expansion of the bioenergy industries.

2.1. Assessing the potential of bioenergy

In recent years, many studies (e.g. see English et al., 2006; Perlack et al., 2005; IEA, 2004) have been performed at the state, national, and international levels to assess the potential for and implications of expanding biofuel production. Much analysis of the biofuels industry potential in the US tends to focus gasoline displacement (with ethanol) and minimizes discussion of renewable diesel. Two earlier assessments of the biodiesel industry were performed by researchers at the NREL (Tyson et al., 2004) and Promar International (Promar, 2005). The NREL study optimistically concluded[11] that biomass oils can displace up to 10 billion gallons of petroleum by 2030 if incentives or mandates are used to promote fuels and bio-based products from biomass oils. In late 2005, the consulting firm Promar International was commissioned by the United Soybean Board (USB) to analyze the impact of the growth of the industrial use of soybean oil (biodiesel) would have on the soybean oil markets through 2012. They used a global econometric model to assess market impacts and their growth projections are shown with the other projections in Figure 6. More recently a study published by Nexant Consultants in December 2006 concludes that FAME biodiesel will "probably be a transition technology, capable of substituting for only a small fraction of global diesel demand" (Clark, 2006). The report also concludes that integrated thermochemical platforms (as discussed in section 1.5) will soon take the lead in renewable diesel production.

The latest ten-year agricultural outlook from the USDA issued in February 2007 (USDA-OCE, 2007) forecast biodiesel production would only rise to 700 million gallons per year and then plateau at this level due to increased price of feedstocks (Figure 6).

[11] In this estimate, NREL assumed a)canola would be planted on 30 million acres of current wheat acreage (wheat exports), b) 30 million acres of CRP and other pasture land would be used to grow oil crops, and c) 30 million acres of soybean land is converted to higher yielding oil seeds.

The USDA assumed that the current government support (tax credits) for biodiesel would continue, but they also modeled an alternative scenario in which the government support was allowed to expire and the biodiesel industry was shown to collapse almost completely. This USDA forecast also provides insight into the impacts of the rapid increase in corn acreage due to ethanol expansion.

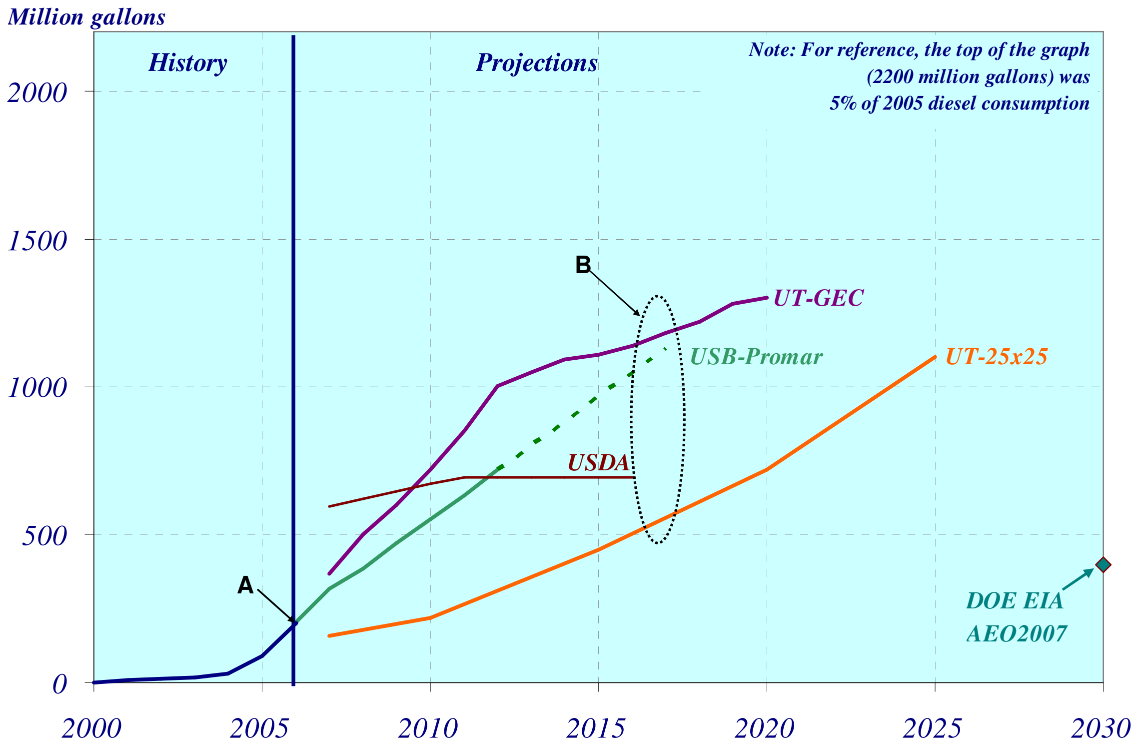



**Figure 6: Projections of biodiesel production compiled from various reports**

Sources: USDA-OCE (2007), Promar(2005), English et al. (2006), Ugarte et al. (2006), USDOE-EIA (2007)

As mentioned previously, the findings from the various biodiesel growth predictions do not give a clear or consistent picture of the industry future as seen in the trends shown in Figure 6. Included are data from the two reports produced by agricultural economists at the University of Tennessee (UT-GEC and UT-25x25). The UT-GEC projection was generated as a part of study commissioned by the Governor Ethanol Coalition that analyzed the agricultural impacts of a 60 billion gallon per year

Renewable Fuel Standard (RFS). The UT-25x25 projection was generated for a report commissioned by the 25 x ’25 Coalition to study the agricultural impacts of a generating 25% of US energy from renewable resources in the year 2025. Both of the University of Tennessee projections were developed for use with extensive national agriculture and energy models designed in coordination with government labs and agencies (English et al., 2006; Ugarte et al., 2006). Notice the AEO 2007 projection (data point shown on the bottom right for biodiesel production in 2030) contrasts dramatically with all the other projections (USDOE-EIA, 2007).

### 2.2. Biofuel feasibility studies

Feasibility studies are performed when companies are considering plant construction in a region and when state or regional authorities are promoting local economic development (e.g. see Carlson, 2006; Fortenberry, 2005; McMillen et al., 2005; Duff, 2004; Bowman, 2003; English et al., 2002; Shumaker et al., 2001). While these studies often provide a good overview of regional markets and economic impacts and are useful for private and public decision making, they do not adequately address the impacts on larger national markets and overall availability of feedstocks. Feasibility studies are valuable to this effort because they help us to build an understanding of the criteria that investors use to make plant investment and operational decisions. Understanding these micromotives will help us to better model the macrobehavior of the marketplace (Schelling, 1978).

### 2.3. System dynamics modeling of commodity markets

Since Jay Forrester published the landmark book Industrial Dynamics (1961), many researchers have used SD modeling to analyze industrial growth and the interactions in commodity markets. The model in this thesis is built upon basic feedback structure for industrial capacity growth and commodity production cycles proposed by Meadows' hogs model (1970) and Sterman's textbook, Business Dynamics (2000). Others researchers like Sandia National Laboratory's Stephen Conrad have also built upon Meadows' work by describing an initial crop model of corn production cycle and how it interacts with other market sectors (Conrad, 2004). Later, Conrad joined with colleagues to adapt this generic crop model structure for soybean production to help better understand the consequences of soy rust to US agriculture (Zagonel et al., 2005). These modeling efforts reinforce the research methodology used in this thesis and validate certain structural assumptions made in constructing the agricultural feedstock (soy oil) sector of the BIGS model.

### 2.4. System dynamics modeling of bioenergy markets

Key researchers at the national government research institutes have seen the potential of SD modeling tools to analyze the transitional dynamics of emerging bioenergy markets. As mentioned above, a team comprised of systems modelers and bioenergy experts from top government research laboratories are currently developing a SD model – named the Biomass Transition Model -- to better understand drivers and constraints on the large-scale deployment of biofuel production.[12] This extensive SD

[12] The Biomass Transition Model is sponsored by the US Department of Energy Office Biomass Programs (DOE-OBP). The initial model development, led by researchers at NREL, began in July 2005.

modeling effort focuses on the transition of the ethanol market from corn to cellulosic feedstock and should be a valuable resource for analysis of current and future policies. The current version of this model will not be completed until the end of fiscal year 2007, hence no official reports have yet been published formally documenting this work.[13] The model description and minutes from the intermediate model review workshops have been posted online for the general public (USDOE-OBP, 2006).

The development of the BIGS research model has drawn from all four research areas: bioenergy assessment modeling; regional feasibility studies; SD modeling of industrial capacity and production; and SD modeling of the bioenergy markets. This understanding has been synthesized with data and information from other biodiesel industry and feedstock market sources to create a working SD model to investigate the near-term growth in the biodiesel industry.  While these simulated behaviors are not a "crystal ball" into the future, this unique SD perspective may provide insights to industry leaders and policy-makers to improve understanding of the biodiesel industry.

[13] Version 1.0 of the model was peer-reviewed at a group session of industry experts in Washington DC in October 2006. The results of this modeling workshop are posted online at http://www.30x30workshop.biomass.govtools.us/documents/061106ScenarioModelWorkshopReport.pdf

3. Modeling the Biodiesel Industry

3.1. Biodiesel market overview

Recall that the purpose of this thesis is to investigate how biodiesel industry growth will be impacted over the next decade through its interaction with the feedstock markets. The purpose of this chapter is to define the boundary and structure of the Biodiesel Industry Growth Simulation (BIGS) SD model and then to explore the dynamic behavior and the causal relationships between the main actors in the market. A high level overview of the biodiesel supply chain (see Figure 7) highlights the important market sectors and interactions.

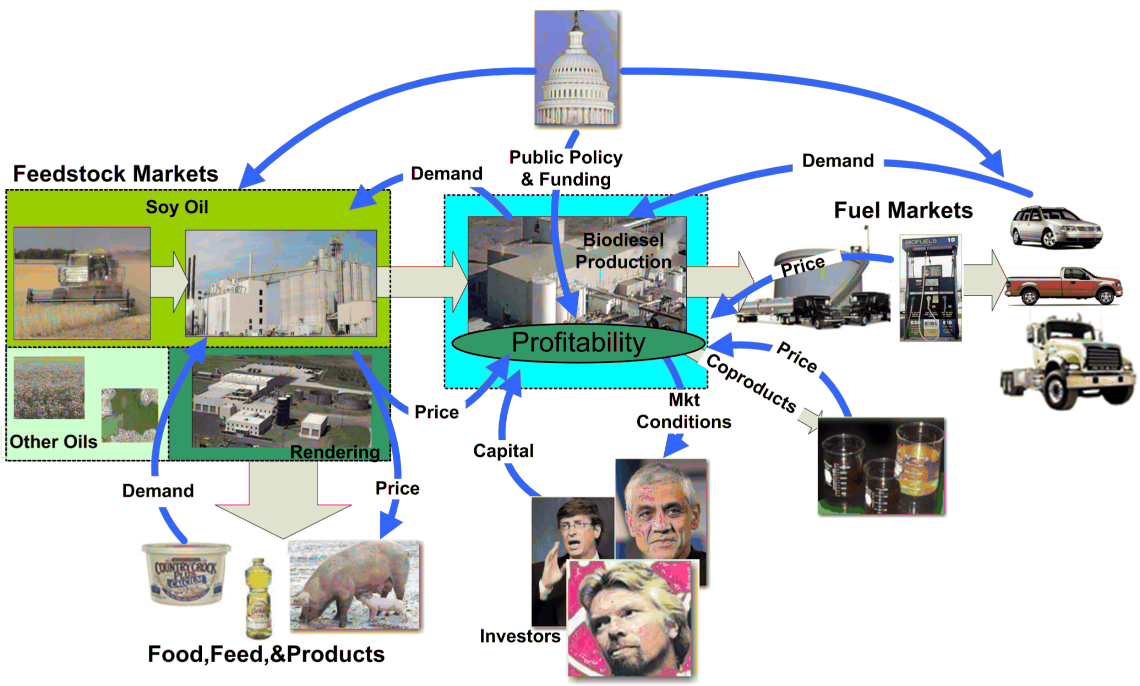


Figure 7: Biodiesel Market Overview

Beginning at the left, the feedstock markets provide oils and fats to the production facilities where it is converted into biodiesel fuel. Biodiesel fuel is then blended with petroleum diesel and sold as a transportation fuel (alternatively it also can be used to

displace heating oil or in industrial boilers). The growth of the biodiesel industry has been driven by state and federal public policies such as renewable fuel mandates and tax credits, high oil prices, and consumer awareness of energy security and environmental issues. The stock and flow diagram presented in Figure 8 shows the ***Exuberance*** reinforcing loop (R1) that has driven the industry growth in recent years and has been dominated by ***Perceived Future Profitability.*** The working hypothesis of this research is that the balancing feedback loops, ***Build*** and ***Produce*** (B1 and B2) will limit industry growth as ***Profitability*** is impacted by rising feedstock prices**.** In the model, ***Profitability*** is influenced endogenously by feedstock prices and exogenously by crude oil prices (reflected in the diesel price), co-products prices, and government interaction in the market (e.g., tax credits).

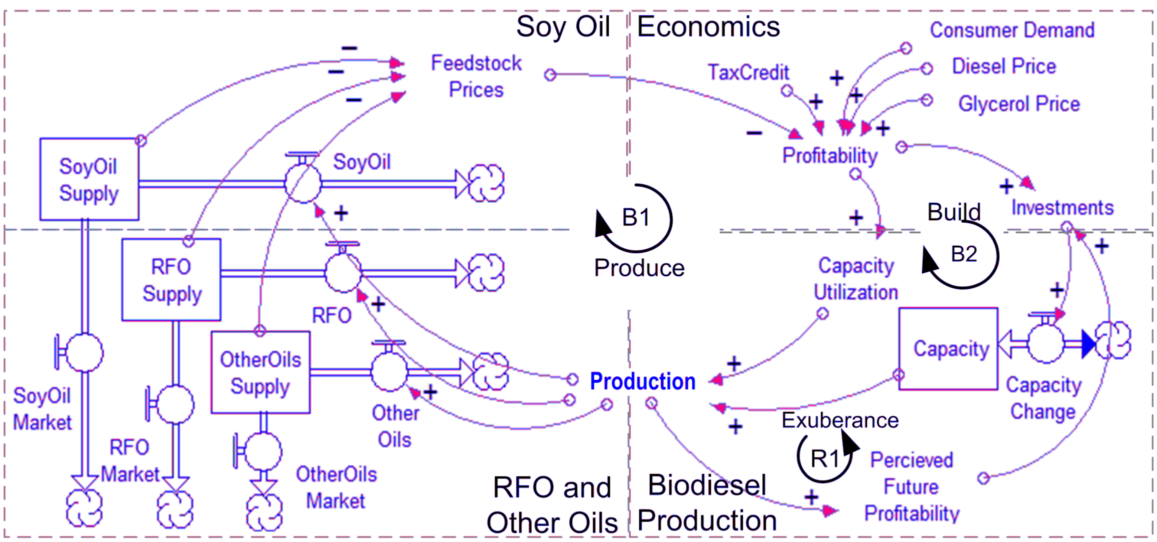



Figure 8: Biodiesel Model Main Feedback Loops

An increase in biodiesel ***Production*** will increase the demand for fats and oils. This will put upward pressure on ***Feedstock Prices*** as biodiesel demands an increasing market share**.** Increasing feedstock prices, in turn, will negatively impact ***Profitability.***

Decreasing ***Profitability*** will impact the decisions that investors and producers make with regards to capacity utilization and capital investments. The aggregated, high level SD stock-and-flow model diagram (Figure 8) is divided into sectors. In the following sections, these sectors are further examined, focusing on the important variables, causal relationships, and dynamic behavior.

3.2. Biodiesel production sector

Investors have been attracted to the biodiesel industry because they have seen an opportunity to make a profit and to enter a market where there is a high probability that demand will far exceed supply for the foreseeable future. Hence, industry players are investing in capacity that could produce ten times the demand seen in 2005 (Irwin, 2006). To help understand the dynamics of capacity growth, the biodiesel production capacity stock and flow diagram, based on the industrial capacity structure in Sterman (2000), is presented in Figure 9.

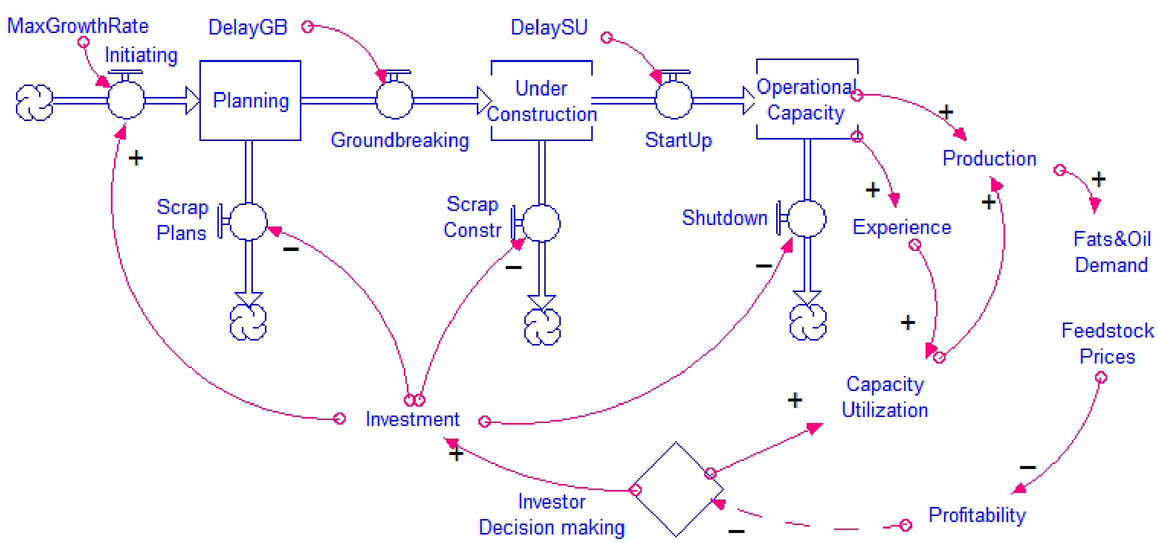


Figure 9: Stock and Flow Diagram – Biodiesel Production Sector

The three main stocks in this sector represent the aggregate industry production capacity at various stages in the "capacity pipeline" -- ***Planning***, ***UnderConstruction***,

and ***OperationalCapacity*** -- in millions of gallons of biodiesel per year. The investor decision-making process is modeled by using the current and anticipated profitability to determine the rate new capacity is added (***Initiating***). In an attempt to model real-world plant limitations such as construction/engineering bottlenecks, the ***Initiating*** rate is limited to a maximum growth rate. Investors also use this same profitability information when making decisions to shut down existing operating capacity or to scrap facilities that are under construction or in the planning phase. In the model, time delays were added to represent real-world market information and management decision-making delays. These delays in the system create an important dynamic during periods of rapid growth, as they allow the possibility that the investment in new biodiesel capacity can overshoot the actual long-term demand. This overcapacity could eventually lead to contraction (or possibly collapse) of the biodiesel production capacity. This is somewhat analogous to the boom and bust cycles in the electric power industry (discussed in Ford, 2002). In addition to the capacity stocks, the model variable ***CapacityUtilization*** (%) is adjusted endogenously by profitability and exogenously by accumulating operating experience. ***Production*** of biodiesel is modeled as the product of ***CapacityUtilization*** and ***OperationalCapacity.***

### 3.3. Biodiesel economics sector

In the real world, the profitability of individual biodiesel plants will be affected by many other factors such as plant size, location, capital installed cost, financing, and other operating costs (fixed and variable). But to simplify the modeling of industry profitability, I use the margin (as defined in Eq.1) as an aggregate indicator of overall industry profitability. For biodiesel production, the margin is:

**Margin = (Biofuel Price + Co-Product Price) – (Feedstock Price + Other variable costs) Eq. 1**

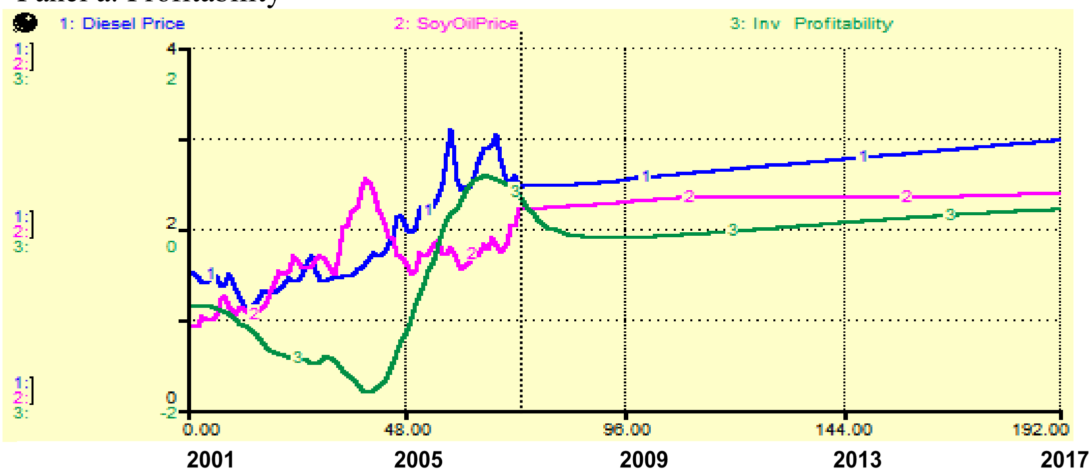
The feedstock makes up 70-80% of costs on average (vanGerpen et al., 2005). The other variable costs are much less significant and the model assumes them to stay relatively constant. The glycerol co-product assumptions are discussed in more detail in section 3.6.4. Simplified, the aggregate indicator of profitability is dominated by the difference between the biofuel price and the oil feedstock price.

Biodiesel is typically priced similar to that of a petroleum diesel blend component in order to be attractive in the blend component market. For that reason, in the model, I assume biodiesel will track diesel prices (plus an offset) for the calculation of the margin. Diesel price will be calculated from the AEO crude oil price projections (USDOE-EIA, 2007). The historical nationwide average price of biodiesel is difficult to track, but according to the sparse data compiled from quarterly price reports from the Alternative Fuel Data Center (USDOE-EERE, 2007) the price of biodiesel has been approximately $0.80 to $1.00 above the price of diesel over the past year and a half.

Since investors use current margin and anticipated future margin in the decision-making process, these two variables are combined in the composite variable ***InvProfitability***. To be profitable, this composite margin must exceed an aim or an acceptable minimum margin (***MarginMin)***. As the deviation from aim increases, the more attractive the market to potential investors and the greater the rate of growth in biodiesel production capacity. The investor decision making details are encapsulated the ***Investor Decision Block*** (Figure 9). The investor propensity to add or to decrease production capacity in is modeled through the use of a Proportional-Integral-Derivative (PID) controller, which acts on the difference between the Margin and the Minimum

Acceptable Margin (White et al., 2002). In addition, if the rate at which this difference is changing is positive, then higher margins are expected in the future, thereby further enhancing the attractiveness of the market. Under such conditions (high margins and higher anticipated margins), the rate at which investors enter the market can be very high indeed.

Panel a: Profitability




Panel b: Capacity stocks and Production

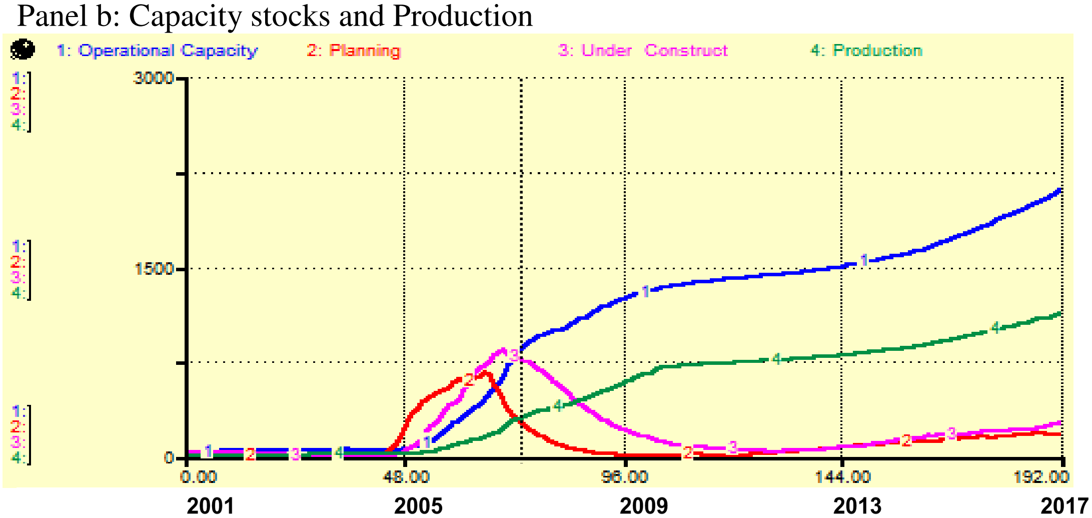



Figure 10: Biodiesel Industry Production and Capacity Dynamics

This mental model is supported by investor behavior in the market since 2004. The BIGS model behavior was calibrated using the industry data aggregate profitability and capacity data from 2001 through December 2006. Figure 10 shows both historic and simulated time trends that illustrate the response of the investor community to change in

biodiesel profitability. Panel (a) presents the historic and forecasted ***Diesel Price*** (1), ***SoyOilPrice*** (2), and the calculated aggregate ***InvProfitability*** (3)**.** Panel (b) presents the simulated impact that changes in ***InvProfitability***, panel (a), have on the industrial capacity stocks ***Planning***(2), ***UnderConstruction***(3), and ***OperationalCapacity***(1). Note that the rapid growth in capacity in the past two years fueled by the long, steep climb in ***InvProfitabiltity,*** panel (a). Also note, as it peaks in 2006 and then falls below zero in 2007/2008 timeframe the market attractiveness to investors diminishes. This is evident in the simulation as investors stop building new plants and/or scrap existing plans (see the simulated ***Planning***(2) and ***UnderConstruction***(3), curves in Figure 10, Panel (b)). As market conditions further deteriorate, new plant startups curtail and eventually existing plants are shuttered or production is scaled back. While it is too early to have confirmatory data to validate the dampened exuberance shown in the simulated trends in panel (b), these results are corroborated in anecdotal evidence in recent trade journal publications (Roberson, 2007).

### 3.4. Oil feedstock sectors

The choice of feedstock impacts operating costs (as discussed in the previous section) and the capital investment decisions that business leaders make when deciding to build a plant. Lower quality feedstocks require more processing equipment and, therefore, more investment. Having the option to process lower quality, cheaper feedstock may give the producer more flexibility, but the additional processing could increase the potential for yield or quality problems. Moreover, the use of lower quality feedstocks could reduce the amount of sale-able glycerol co-product produced (Kortba, 2006) -- decreasing a potential revenue stream for biodiesel producers. Capital

investment and operational decisions regarding feedstock usage are important to the profitability of each individual plant, but the BIGS model of aggregated industry decision-making focuses primarily on the impact that feedstock prices have on the margin. It is our working hypothesis that this balancing feedback presented as loops B1 and B2 in Figure 8 will limit the growth of the biodiesel industry.

Data from two studies (Eidman, 2006; Tyson et al., 2004) (shown in Table 2) indicate between 22 - 25 billion pounds of plant oils and between 9 - 13 billion pounds of animal fats, greases, and recycled cooking oils are produced annually in the US. These feedstocks could yield between 4.2 to 5.8 billion gallons per year of biodiesel which could displace approximately 11 - 15% of the current on-road diesel consumption (USDOE-EIA, 2006b). For reference, Figure 11 shows the prices for various fats and oils in mid-2006.

| | Eidman Estimate[14] 2000-2004 | | NREL Estimate[15] 2001 | |
|---|---|---|---|---|
| | Feedstock (billion lbs) | Biodiesel (million gals) | Feedstock (billion lbs) | Biodiesel (million gals) |
| Soybean Oil | 18.3 | 2378 | 18.9 | 2454 |
| Other Vegetable Oil | 4.5 | 588 | 6.0 | 780 |
| Rendered Fats& Oils | 9.3 | 1212 | 12.7 | 1645 |
| Other Sources | | | 6.9 | 898 |
| Total | 32.2 | 4178 | 44.5 | 5778 |

**Table 2: Estimates of US total domestic fats and oil production**

[14] Eidman (2006b) Table 8 - Pounds of oil are a five year average (2000-2004) from Bureau of the Census and Agricultural Marketing Service, USDA. The pounds of yellow grease and inedible tallow are a two-year averagefor 2002-2003 from US Department of Commerce, US Census Bureau. Current Industrial Report, M311K (03)-13, March 2005.

[15] Tyson et al. (2004) Table 11 -USDA ERS OCS and Outlook, October 2002. Bureau of Census, M311K-Fats and Oils: Production, Consumption and Stocks, 2002, July 2003. USDA ARS, Agricultural Statistics, 2003, Chapter III. Pearl, Gary. Biodiesel Production in the US, Australian Renderers Association 6th Int'l Symposium, July 25-27, 2001. Est from Wiltsee, G., "Urban Waste Grease Resource Assessment," NRELSR-570-26141. USDA ARS, Agricultural Statistics, Chapter XV. Render, Apr 2002, pg. 12.

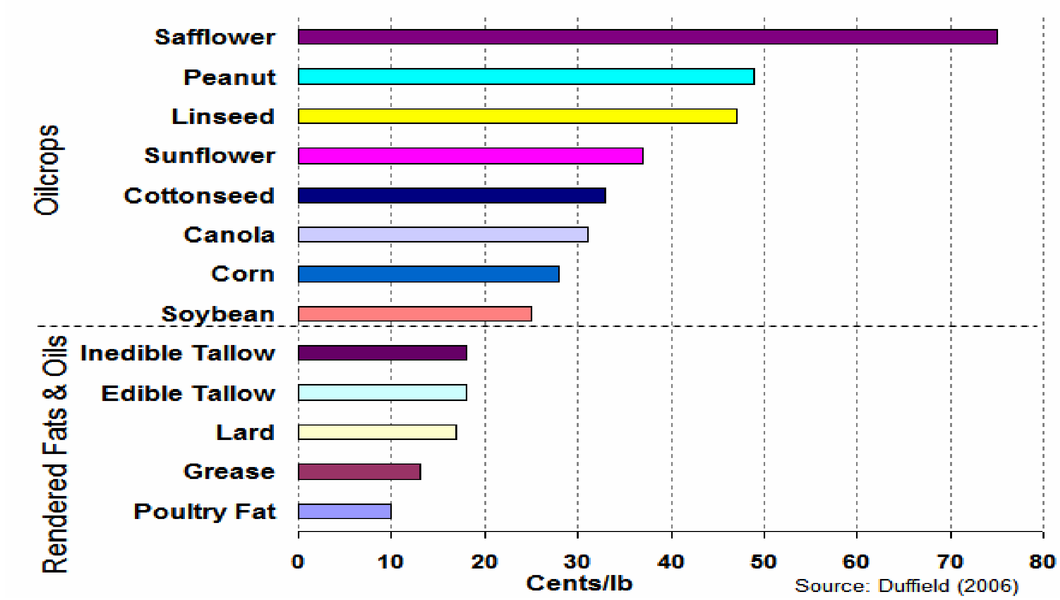



Figure 11: US Biodiesel feedstock prices (2006)

While it is theoretically possible that all the fats and oils in Table 2 could be converted to biodiesel, it is highly improbable because vegetable oils and animal fats are important ingredients for many other products such as baking and frying fats, animal feed, cooking and salad oils, margarine, and other edible products. In 2006, biodiesel demanded less than 5% of the entire US fats and oils market. How will these markets respond as demand from the biodiesel market rapidly increases and begins to demand a much greater percentage of the market for these feedstocks? Currently about 68% of biodiesel producers use soybean oil as a feedstock, but as seen in Table 3, biodiesel producers are shifting from soy oil to canola, other fats and oils, or multi-feedstock processing capabilities (Nilles, 2006). In the model, the percentage of biodiesel plants using soy only is ramped down over time, and this ramp rate is adjusted endogenously by the relationship between the soy and other oil prices.

| Fall 2006 | % of US Biodiesel Plant Capacity | |
|---|---|---|
| Feedstock | Operational Capacity | Under Construction or Expansion |
| Soy | 62.9 % | 51.5 % |
| Canola/Rapeseed | -- | 11.9 % |
| Multi-Feedstock | 20.2 % | 24.8 % |
| Animal Fats | 12.8 % | 10 % |
| Other | 4.1 % | 1.5 % |

**Table 3: US biodiesel capacity by feedstock**

Source: Biodiesel Magazine US & Canada Plant Map (Fall 2006)

### 3.4.1. Soybean oil market sector

Soybean oil has historically been available in large quantities at relatively low prices because it was considered a surplus product of the soybean meal crushing industry (USDOE-EIA, 2007). The stock and flow diagram modeling the planting, harvesting, crushing, and disposition of soybeans and soy oil are presented in Figure 12. Soybeans harvested in the US are exported, sold domestically as whole beans, or crushed to produce soy meal and soy oil. The amount of soybeans harvested each year in the US is dependent on many variables such as acres planted, yield, weather, and disease.

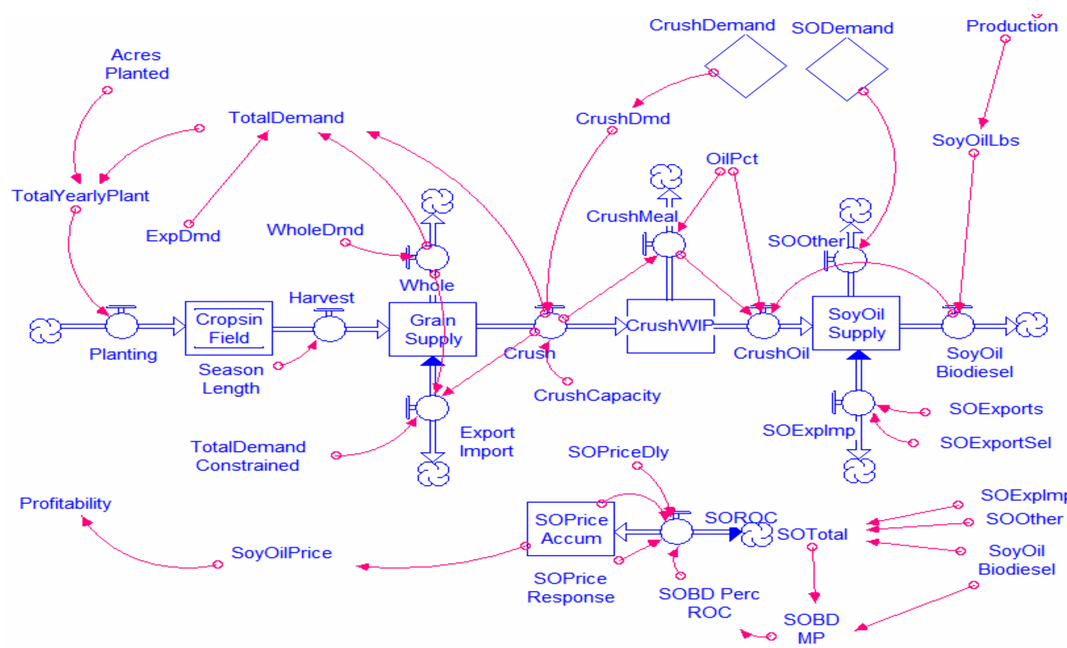



Figure 12: Stock and flow diagram – Soy oil production

Sectoral model testing results in Figure 13 how the behavior of the ***CropsinField*** and ***GrainSupply*** stocks in the soy oil production supply chain. The model structure shown in Figure 12 was verified using USDA data and was helpful in understanding the seasonal dynamics of the soybean and soy oil production supply chain. However, subsequent model testing confirmed that the seasonal harvest dynamics in Figure 13 occur over too short of a time span to impact the longer-term dynamics of interest in this research. Hence, a decision was made to simplify this structure by eliminating the planting and disposition of soy beans and focusing only on the crushing and soy oil disposition.

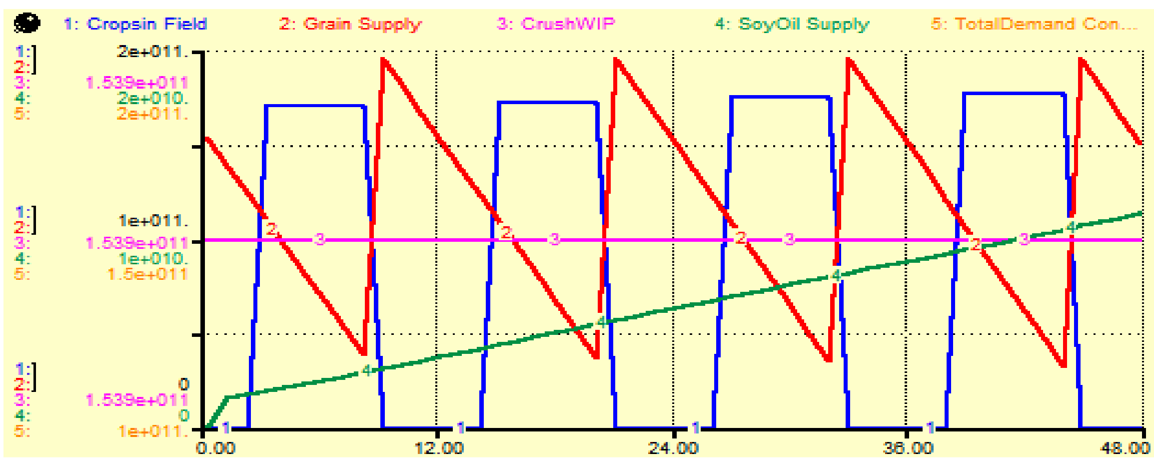


Figure 13: Soy production planting and harvesting dynamics

The simplified Soy Oil Sector stock and flow diagram finally used in BIGS model is presented in Figure 14. The biodiesel demand for soy oil (***SoyOilLbs)*** comes from the Biodiesel Production model sector, and the ***SoyOil Price*** completes the loop by providing feedback to the Biodiesel Production sector through its impact on ***Profitability***. The ***SoyOil Price*** is determined using the price setting stock and flow structure (discussed in Sterman, 2000; Whelan & Msefer, 1996) in which the price is adjusted by the ratio of

actual to perceived inventory coverage. The flow to biodiesel, ***SoyOilBiodiesel,*** is fed from the ***SoyOilSupply*** stock which also feeds the other users of soy oil (***SoyOilOthe***r and ***SoyOilExportImport***). Note that ***SoyOilExportImport*** flow is bi-directional which allows either export or import if desired.

In Figure 14, the ***Crush*** flow and the percentage of oil in the soybeans (***OilPct***) determine the amount of soy oil produced (***CrushOil*)*.** Depending on the future of soy meal and soy oil demand relationship, increasing the oil component of soybeans -- which historically average 18–19 % by weight (Ash et al., 2006) -- could be a alternative solution to provide more biodiesel feedstocks from soy. In all the scenarios explored, ***OilPct*** is kept constant, but further research could explore this option. Other important exogenous variables for determining the amount of soybeans crushed are ***Acres***, ***Yield, Crush Capacity***, and ***SoyExports.***

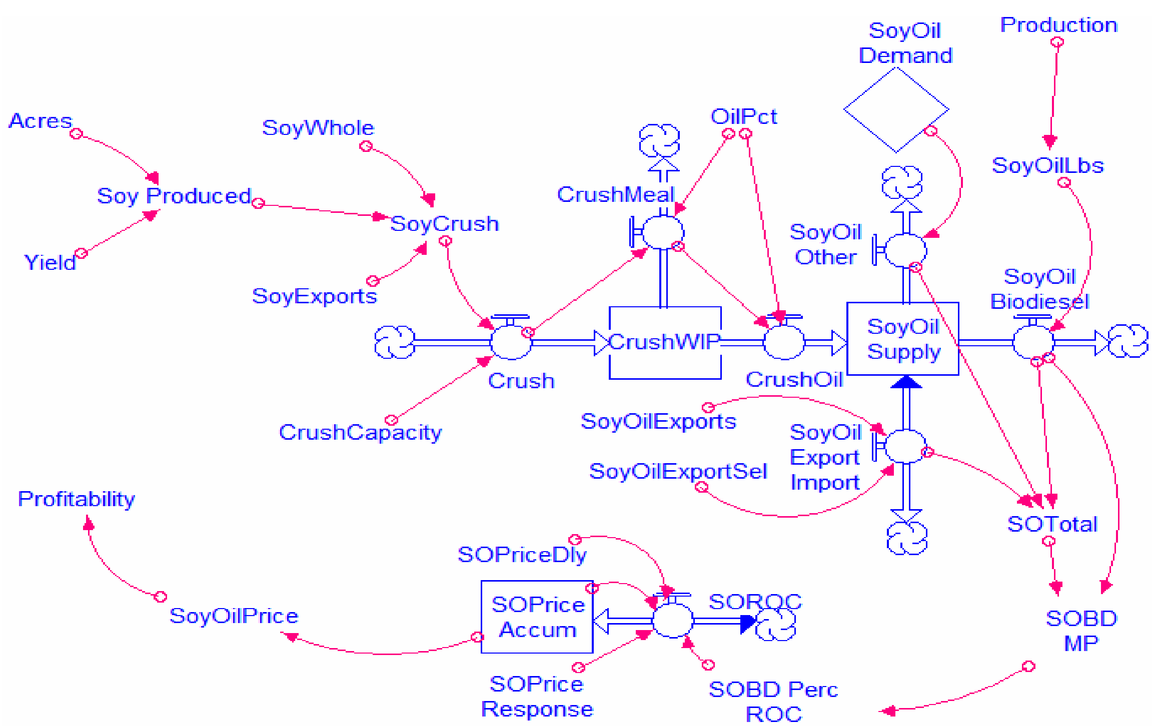



Figure 14: Stock and Flow Diagram – Simplified Soy Oil Sector

The percentage of the acreage for soybean planting will most likely be impacted by competition from other crops – corn in the short term and possibly energy crops such as switchgrass in the longer term -- as demand for ethanol continues to expand rapidly. In the model, the ***Acres*** variable will be an exogenous variable that can be set by the user to constrain the amount of soybean acreage in the US.

The average soybean yield, shown in Figure 15, is increasing at an accelerated rate due to improved cropping practices and technological advances. Increased yields allow farmers to harvest considerably more soybeans without significantly increasing acreage. These yield gains will be important to offset the downward trend in soybean acreage. US soybean growers set a new yield record in 2005 with 43.0 bushels per acre (USDA-OCE, 2007). In the model, it is assumed that yields continue to increase along a 25-year trend line (1980-2005) shown in Figure 15, but the user will be able to set yield trend through a graphical input block. Based on this trend, the average yield is projected to be approximately 46 bushels per acre by 2016.

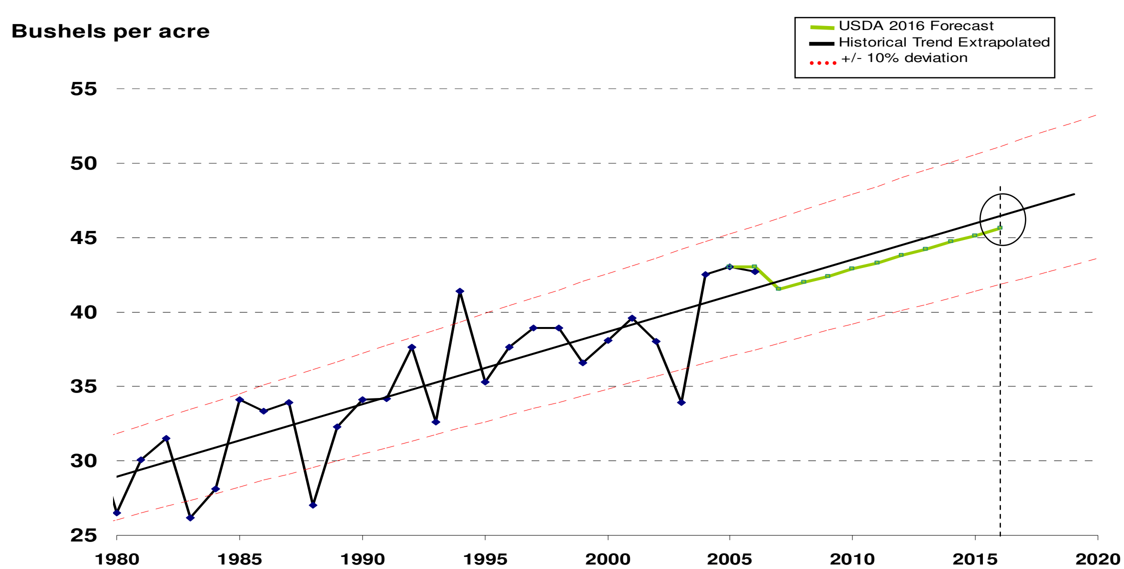



Figure 15: Soybean Yield US Average Historical and Trend
Source: USDA-OCE (2007), Soystats

To illustrate the impact of incremental yield growth, consider that an increase of just one bushel per acre from one year to the next results in an additional 68 million bushels of soybeans. After crushing, the soybean oil from an additional 68 million bushels of soy beans could be used to produce just over 100 million gallons of biodiesel. To better understand the magnitude of the flows in the soy sector, the historical (Soystats) and USDA forecast amounts (USDA-OCE, 2007) are presented in Figure 16.

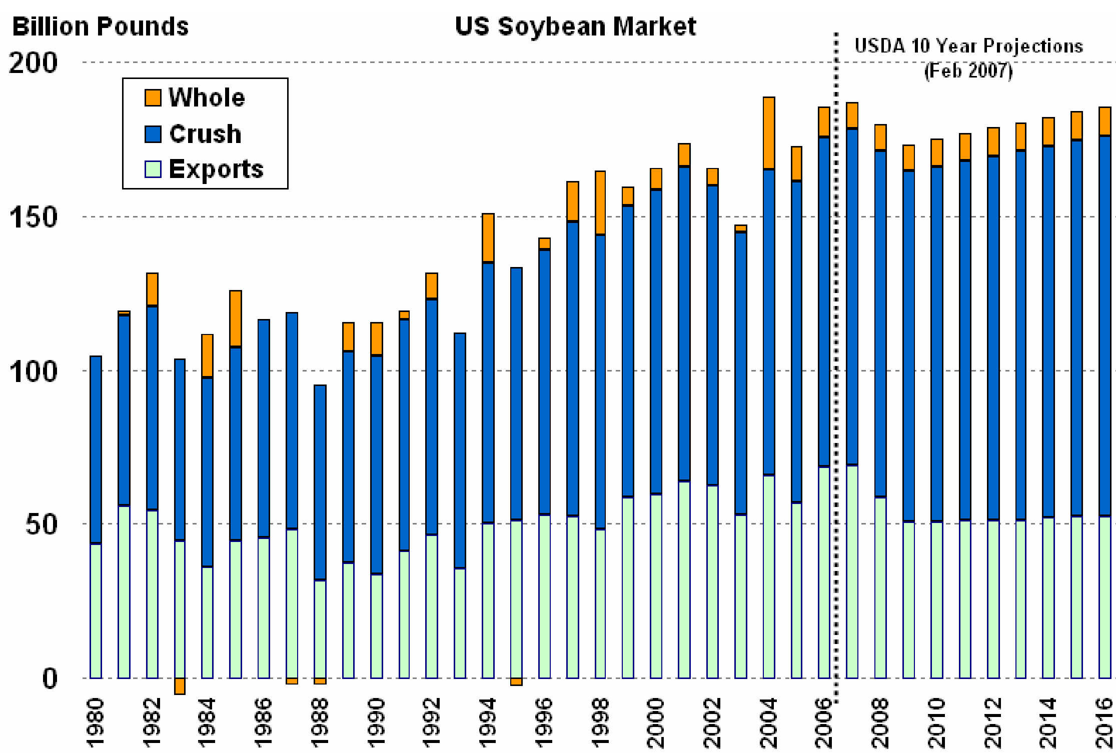



Figure 16: US Soybean Market Historical and Projections
Source: Soystats, USDA Agricultural Projections to 2016

In Figure 14, the ***SoyOilSupply*** stock feeds biodiesel, other (food, feed, and chemicals), and export markets. In the model, the ***SoyOilOther*** flow will be set to increase at historical growth rates and the ***SoyOilExportImport*** flow will be exogenously manipulated in the scenario testing.

3.4.2. Rendered fats and other oils market sector

The rendering industry produces fats and oils from byproducts of the food and animal processing industries. Products such as tallow, choice white grease (lard), poultry fat, and yellow grease are cheaper than virgin vegetable oil – selling for about half the price of soybean oil historically (Radich, 2001). Although they offer an economic advantage compared to soy oil, there is a limited supply of these oil feedstocks, and consumption is not limited to use as biodiesel feedstocks. Rendering industry products are important ingredients in animal feed, fatty acids, chemicals, and lubricants (Meeker, 2006), as seen in Figure 17. Domestically, sixty percent of rendered fats and oils go into animal feed and less than two percent is used for industrial uses such as biodiesel.

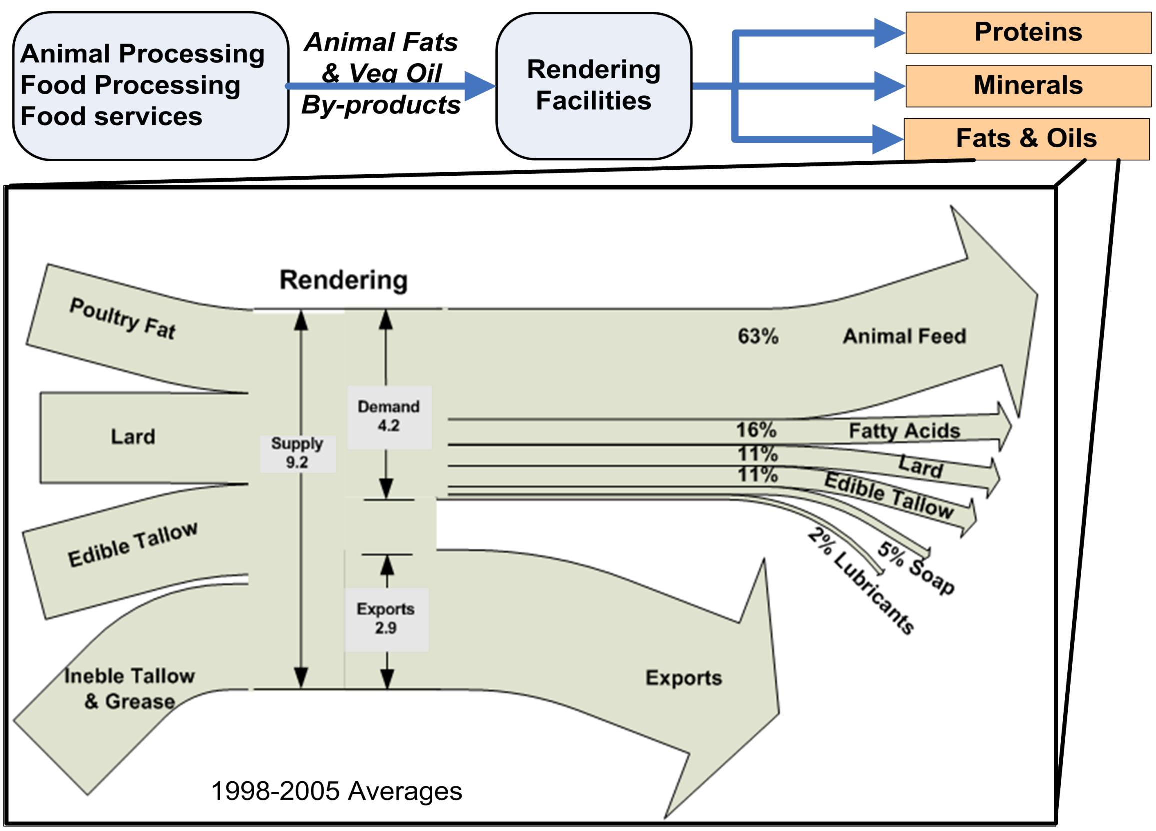



Figure 17: US Fats and Oils Overview
Source: Data compiled from the National Renderers Association

As seen in Figure 18, from 1998-2005, the domestic rendering industry produced nine billion pounds of inedible tallow and greases, edible tallow, lard, and poultry fat on average and has not demonstrated significant industry growth. The assumptions in the model are based on the industry continuing this minimal growth rate through the time period simulated.

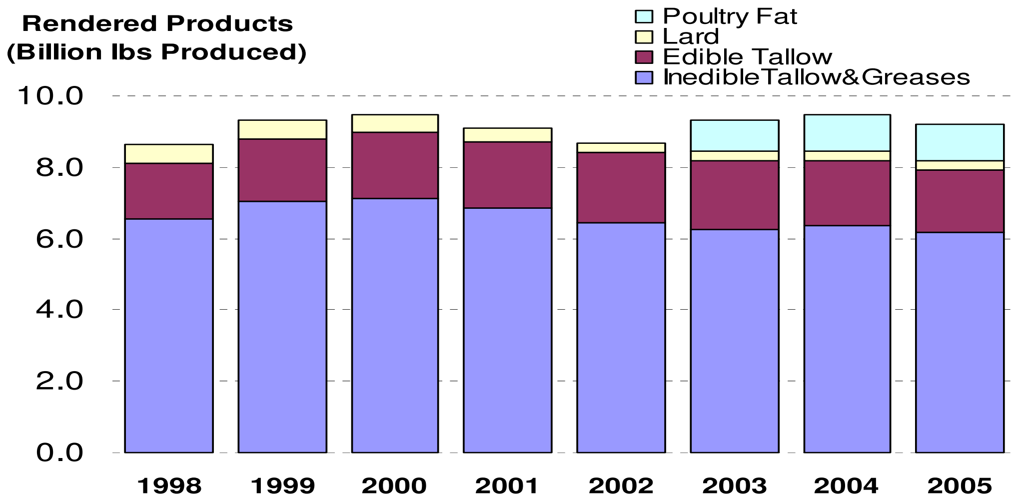



Figure 18: US Rendering Fats and Oils Production
Source: National Renderers Association

The stock and flow diagram modeling the rendered fats and other oils industry sector is presented in Figure 19. The biodiesel demand for rendered fats and other oils (***RFOLbs***) comes from the Biodiesel Production model sector. The ***RFOPrice*** completes the loop by providing feedback to the Biodiesel Production sector through it influence on ***Profitability.*** In the BIGS model, the model users will be able to set the industry growth rate, but in all scenarios I assume the industry growth rate will continue to grow at historical rates. In the BIGS model, the percentage of biodiesel plants using fats and oils (determined by the ***SoyUsage*** variable) is increased over time but is adjusted endogenously by the relationship between the ***SoyOilPrice*** and ***RFOPrice***.

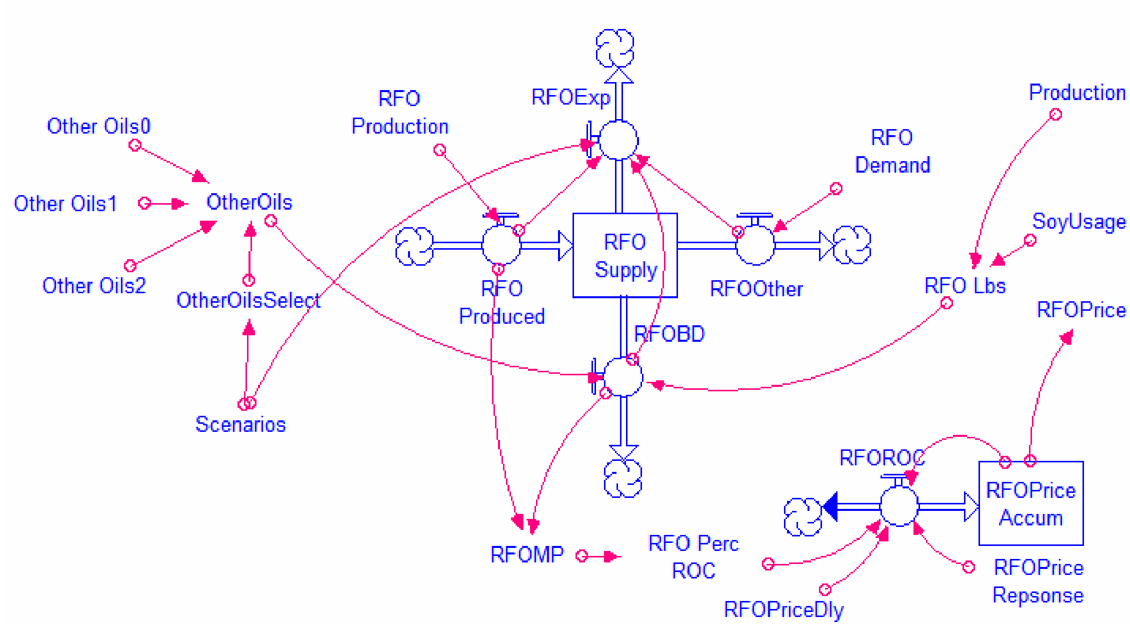



Figure 19: Stock and Flow Diagram – Rendered Fats and Other Oils

### 3.4.3. Other oil feedstocks

In addition to soybean oil and rendered fats and oils, there are other sources of natural oils that could be tapped to increase the supply of potential biodiesel feedstocks. Many in the industry, such as National Biodiesel Board president, Joe Jobe, cite “the availability of other oil sources” as one of the many factors that will support continued growth of this industry in the next decade (Bryan, 2007). In the sections below, I briefly review alternative triglyceride sources that could potentially provide additional FAME biodiesel feedstocks. Since there are many uncertainties around future availability, the total supply of these other alternate oil sources are aggregated in the ***OtherOils*** variable in the model (Figure 19). Alternate ***OtherOil*** scenarios can be selected using the ***OtherOilSelect*** variable, or the supply curves can be changed through the graphical input device to determine the overall impact on the system. As the amount of ***OtherOils***

increases, the price pressure will decrease on both ***SoyOilPrice*** and ***RFOPrice***. This will help to boost overall biodiesel industry profitability.

3.4.4. Other domestic oilcrops

Although soy is the dominate oil crop in the world (as seen in Figure 20) six other major oilseeds crops are produced around the world canola/rapeseed, cottonseed, peanut, sunflower seed, palm kernel, and copra (Pahl, 2005). Rapeseed is the favored biodiesel feedstock in Europe and Canola -- a genetic variation of rapeseed -- is gaining popularity in the US. Many US farmers are planting non-traditional oil crops such as Canola and camelina, but Canola currently only makes up one tenth of one percent of the oilseeds market in the US (Nilles, 2007). Ninety percent of this crop is grown in North Dakota. The recent construction of a ADM crushing facility and biodiesel plant in North Dakota is enticing farmers to grow more Canola, but it is estimated that demand at this one plant will not be satisfied entirely by domestic production.

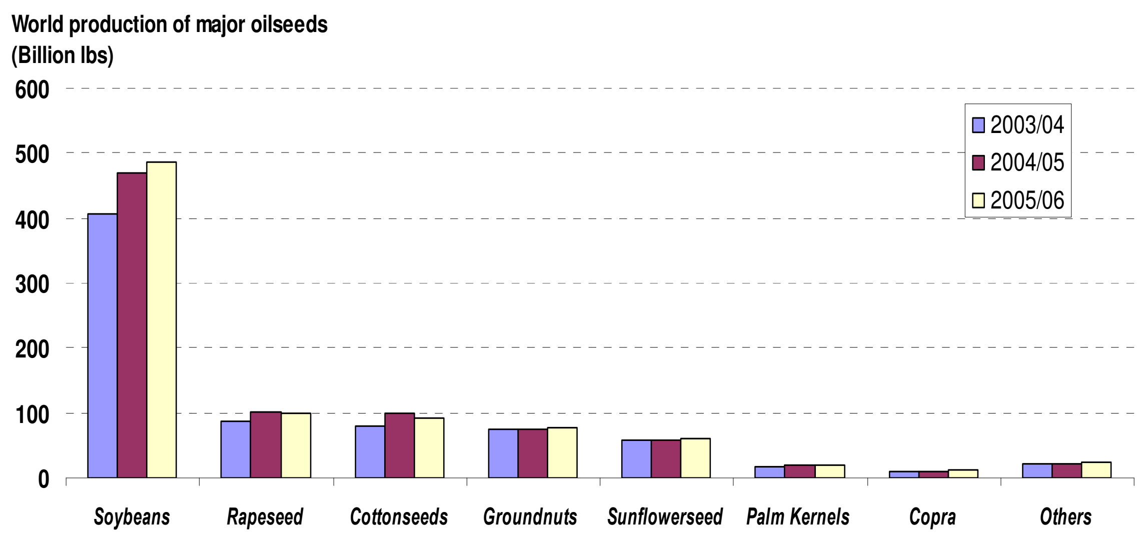



Figure 20: World Production of major oilseeds
Source: Food and Agriculture Organization (FAO) of the United Nations

Another hopeful domestic oil crop candidate is camelina. Farmers in the Midwest and plains states are considering camelina for a winter cover crop in place of winter wheat (Weber, 2007). The potential of these domestic oil crops will also be determined by acreage competition with the other major domestic crops.

#### 3.4.5. Imported oils

Palm Oil -- mainly imported from the Southeast Asian countries of Malaysia and Indonesia -- is rapidly becoming the biodiesel feedstock of choice throughout many regions of the world. Biodiesel production fed mainly by palm oil is beginning to take off throughout Asia – not only in Malaysia and Indonesia, but also India and China. In addition to feeding the Asian biodiesel demand, European and US producers are beginning to consider palm oil. Although it is attractive because of the price, concerns about deforestation and sustainable production methods have combined with cold weather quality issues to dampen some of the North American and European enthusiasm.

#### 3.4.6. Corn oil from ethanol production

At ethanol production facilities, corn oil can be extracted before processing or after fermentation and distillation (Bryan, M., 2006). One company, Greenshift, with a patent on this technology has proposed installing oil extraction equipment in dry mill ethanol production facilities at no charge to client ethanol producers in exchange for first rights of refusal for the oil extracted. Greenshift (2005) estimates that a 50 million gallon per year ethanol plant could extract enough corn oil support a 20 million gallons per year biodiesel plant. Hypothetically, if one quarter of the 60 to 80 ethanol plants being built

today were to install this capability, this could provide enough feedstock for 400 million gallons per year of biodiesel.

### 3.4.7. Waste fats and oils

About 10.5 billion animals are slaughtered and processed each year in the US (Meeker, 2006) and meat-processing facilities are required to use large volumes of water to rinse the meats as during processing. The waste water from this process contains about 5-20% fat and it is estimated that the concentrated Dissolved Air Flotation ("DAF") sludge from the poultry industry alone could provide 2.5 billion pounds per year of additional feedstock to the biodiesel industry (GreenShift, 2005). These 2.5 billion pounds of fat could be converted to 325 million gallons of biodiesel if it could be processed economically with good yields. Another potential source of feedstock is trap grease, which is collected, treated, and disposed of via land-filling, burning, composting, or anaerobic digesting (typically by waste water treatment facilities). According to researchers at NREL, approximately 13 lbs per person per year of trap grease is created in the US (Tyson et al., 2004). Theoretically, 3.8 billion pounds could be converted to 495 million gallons of biodiesel if it could be collected and processed economically with good yields. A few companies that are pursuing these waste feedstock options, but due to the difficulties involved in producing high quality biodiesel fuel from a low quality, highly variable, feedstock stream, the future for this feedstock option remains uncertain.

### 3.4.8. Algal oil

From 1978 through 1996, the Aquatic Species Program at NREL investigated algae with oil-content that could be grown specifically for the purpose of biofuels

production (Sheehan, 1998). In recent years, several companies such as GreenFuel Technologies (www.greenfuelonline.com), along with those in government and academia, have been trying to make large-scale bioenergy algae production a reality. Although the potential is promising -- estimates range up to 10,000 gallons of biodiesel per acre – nobody has scaled this technology to support a commercial size biodiesel facility. Due to the uncertainty in the future of this technology, it is not assumed that algal oil will contribute significantly to the amount of triglycerides available for biodiesel production in the next decade.

### 3.5. Diesel fuel market

Although diesel prices have recently been higher than gasoline prices, the demand for diesel fuel is growing at an annual rate of 2.5%, and vehicles in the US will consume approximately 65 billion gallons of diesel by 2030 (USDOE-EIA, 2007). Diesel fuel powers most of the medium and heavy duty on-road vehicles and most of the heavy duty off-road vehicles such as bulldozers and farm tractors. Light-duty diesel vehicles have been popular in Europe for a long time and they are making a comeback in the US. In addition to highway vehicles, diesel is also used in farm tractors, trains, boats, generators, and other heavy duty equipment. In the BIGS model, diesel fuel price is derived from the price of crude oil which is set exogenously. The model user will be able to select alternate crude oil forecasts – Low, High and User determined -- to determine the impacts on the biodiesel industry. The Low and Hi forecasts are based on the 2007 AEO crude oil price projections shown in Figure 21.

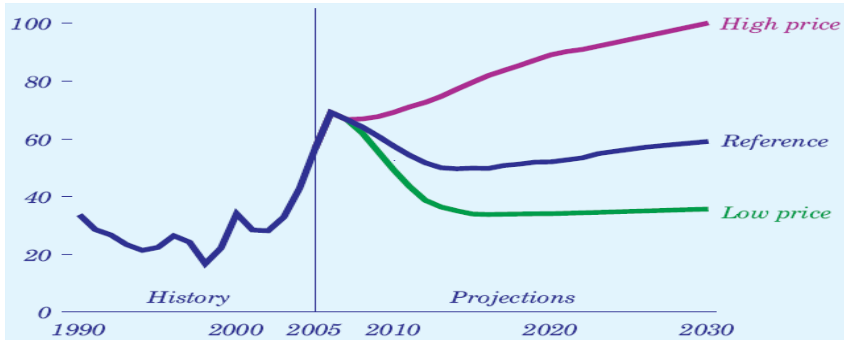



Figure 21: Crude oil prices in three AEO2007 cases
Source: EIA AEO 2007 (2005 $/bbl)

3.6. Putting it all together – Interactions and market dynamics

In the previous sections, the overall model boundaries, structure, and sectoral details including various feedstock, production, and product markets (shown in Figure 22) were described. Now, it is important to discuss the market interactions and other external factors that could impact behavior of the biodiesel market in the next decade.

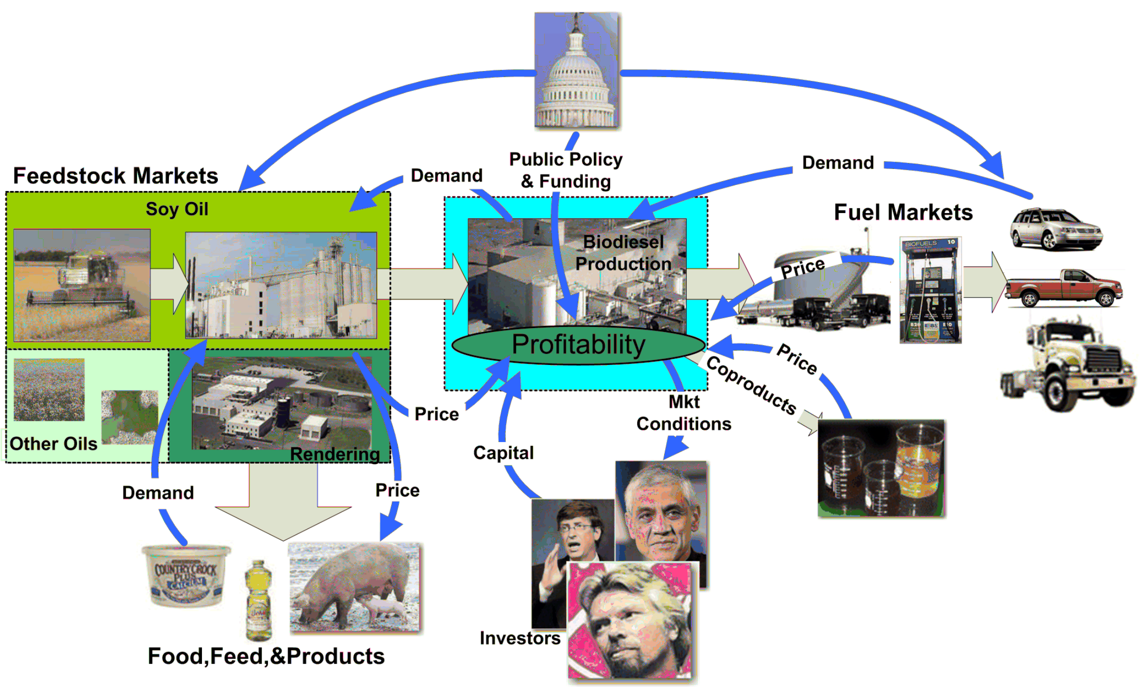



Figure 22: Biodiesel Market Overview

### 3.6.1. Ethanol competition

USDA forecasts that US farmers will plant more corn and less soy over the next decade to meet increasing demand from fuel ethanol (USDA-OCE, 2007). The USDA and University of Tennessee agricultural economists' alternate forecasts (English et al., 2006) are presented in Figure 23. The 2007 spring plantings intentions reported by the USDA on March 30, 2007, indicated corn acres will rise 15% from 2006 plantings to 90.4 million acres and soybean planted acres may drop 11% to 67 million acres (Wilson, 2007). This significant shift of acreage away from soy will most likely affect the price of soy oil and negatively impact the profitability of biodiesel producers.

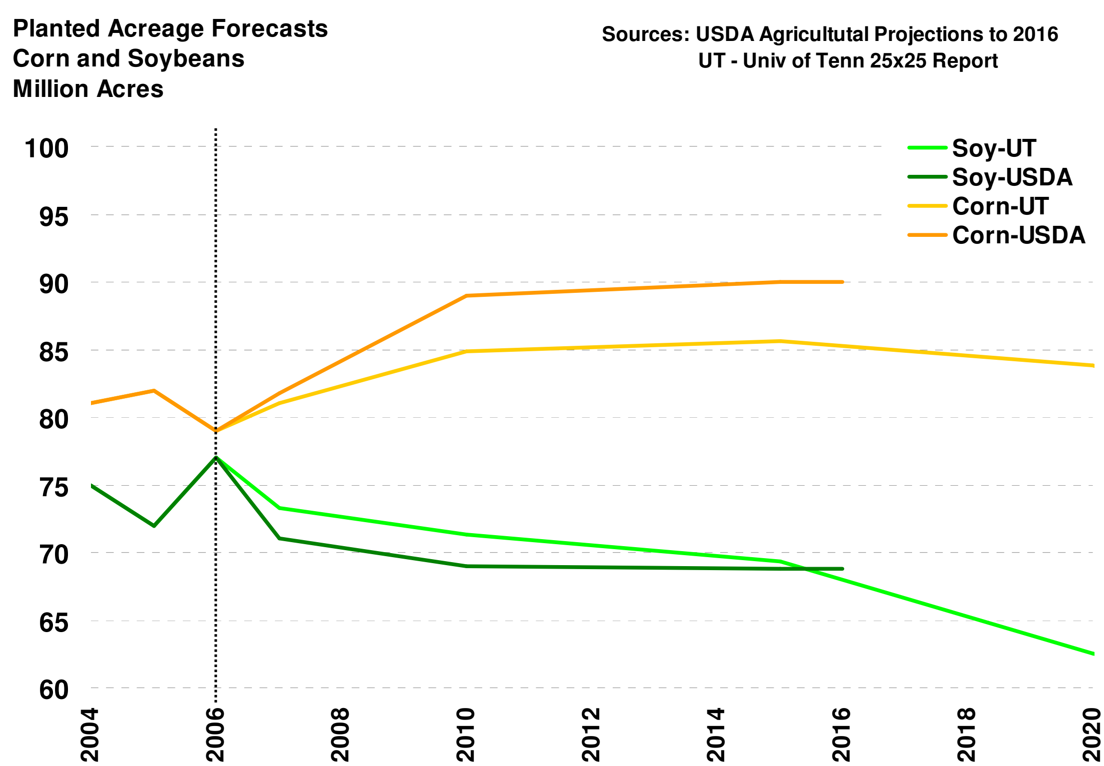



Figure 23: Decreasing US soy acreage
Source: USDA (2007), Univ of Tenn 25x25 report (2006)

Moreover, distillers grains, a co-product from the dry mill ethanol production process can be used as a substitute for soy meal in some animal feeding operations

(Davis, 2001). As ethanol production increases, the expanding supply of DDG will increasingly compete with soy meal and other protein oilseed meals. This is likely to result in lower oilseed meal prices and a possible decline in domestic soy meal consumption. The combined effects of decreased soy acreage and decreased demand for soy meal could have negative impacts on FAME biodiesel production. These impacts could possibly be partially offset by developing new technologies for the production of corn oil from the dry-mill ethanol process to be used for biodiesel production, as discussed earlier in Section 3.4.6. In addition, the acreage loss to corn can be offset by displacing wheat with soybean plantings and by bringing more land into production, but the impacts of these changes could also have unintended consequences.

### 3.6.2. Exports and imports

When introducing the 5 x ‘15 plan, the National Biodiesel Board stated that decreasing biomass oil exports would be a key factor for biodiesel growth (Bryan, 2007). More oil can be made available for domestic biodiesel production by decreasing the exports of both soy beans and soy oil and/or increasing imports. The US exports around one billion pounds of vegetable oil and approximately 2.5 billion pounds of rendered fats and oils annually (Soystats, 2005; Meeker, 2006). These feedstock exports could have some impact if redirected into the domestic market.

Biodiesel producers may begin to import more palm, canola, coconut, and other oils if the economics are favorable, but concerns about deforestation and sustainable production methods have combined with cold weather quality issues and domestic protectionism to dampen some of the enthusiasm in the US.

### 3.6.3. Crushing capacity and oil content

Both the domestic capacity to extract the oil from oilseeds – called crushing capacity – and the percentage of oil in the oilcrops will affect the amount of oil available in the market. The US exports about a third of its soybean crop annually (USDA-ERS, 2007), and crushing these soybeans domestically would produce enough soybean oil to produce 1.5 billion gallons of biodiesel. This would be beneficial for the biodiesel industry, but not for the soy bean crushers' margins as it would also produce a 67% increase in domestic meal. The industry crushing capacity was typically expanded based on the demand from the oilseed meal market. For soy, only 18.5% of seed by weight is oil, the remainder is sold into meal and other markets and has traditionally been the most valuable part of the bean. The demand for soy oil -- driven up by biodiesel production -- may pressure the industry to change their business models and add new crushing capacity.

### 3.6.4. Glycerol glut

Glycerol (also called glycerin) is a co-product of biodiesel production and can be sold in a crude or refined form. Refined glycerol is a commodity used in the production of hundreds of other products. Chemical industry analysts forecast the glycerol price to continue its current downward slide, and a serious overcapacity problem (Figure 24) is likely to develop as the biodiesel industry continues at its current growth rate (McCoy, 2001). If the overcapacity problem continues, biodiesel producers may soon be faced the problem of disposing of glycerol instead of selling it (Hamilton, 2007).

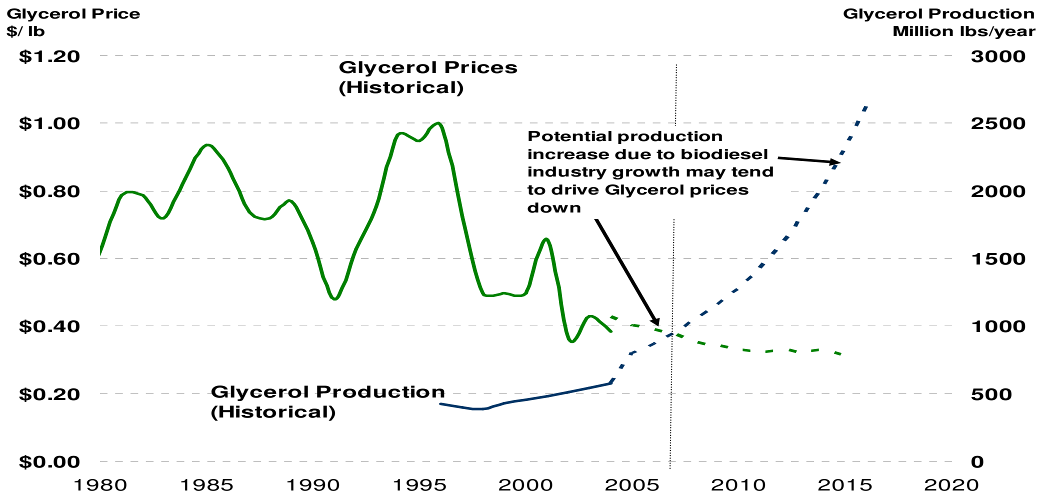



Figure 24: Glycerol Production and Prices – Historical and Projected
Source: Historical data - Bondioli (2003) and Tyson (2004)

The Department of Energy has recognized this issue and has created initiatives -- such as the "top 12" bio-based chemicals that may help new glycerol markets develop which help offset this price decrease (Gerard, 2006). Glycerol sales account for a small percentage of the revenues in the biodiesel industry. Therefore, their impact on the aggregate industry profitability is small compared to the other factors we are exploring. Although this will not be the primary focus in the simulation runs, the model does incorporate an exogenous glycerol price variable that will allow the user to explore this variable.

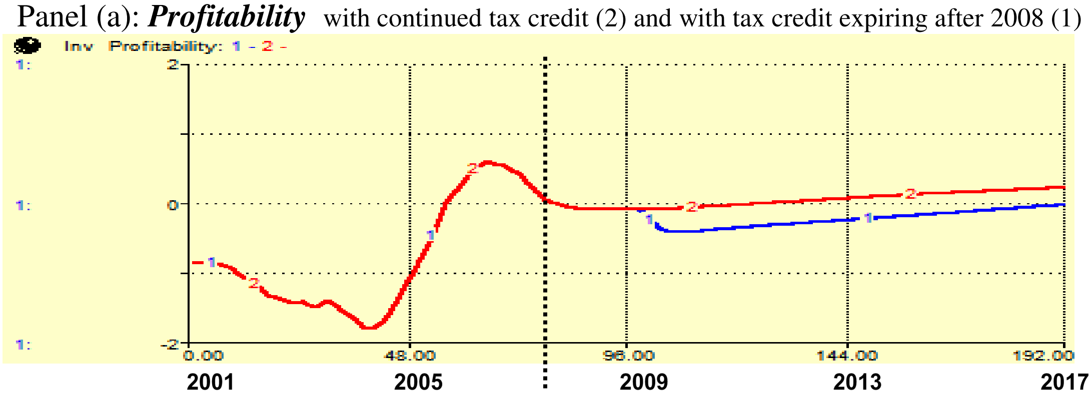
### 3.6.5. Government intervention in the markets

Effective, targeted public investments and policies at the federal and state level -- in the form of research funding, market-creating purchases and mandates, and producer price supports -- have helped to build a strong base for the biodiesel industry. The most well known of these market interactions is the biodiesel tax credit, which was enacted into law as part of the American JOBS Creation Act of 2004 and extended to end of 2008

by the Energy Policy Act of 2005 (Koplow, 2006). Fuel blenders received $1.00 credit for every gallon of soy biodiesel and half that amount for biodiesel produced using other oil sources. Market-based advocates are debating the efficacy and cost of biofuel subsidies, but these government subsidies have helped the industry develop and flourish and are still necessary for profitability. Although the future is not guaranteed, it is likely that the biodiesel tax credits will be extended.

The tax credit has been included in the model as an exogenous variable that can be manipulated to simulate the effects it has on the profitability of producers. The USDA (2007) in its most recent forecast to 2016 also assumed the current biofuel subsidies would remain in place but did run an alternate scenario in which the subsidies were not extended. In that scenario, the biodiesel industry almost entirely collapsed.

Panel (a): ***Profitability*** with continued tax credit (2) and with tax credit expiring after 2008 (1)




Panel (b): ***Operational Capacity*** with cont'd tax credit (2) and with tax credit expiring after 2008 (1)

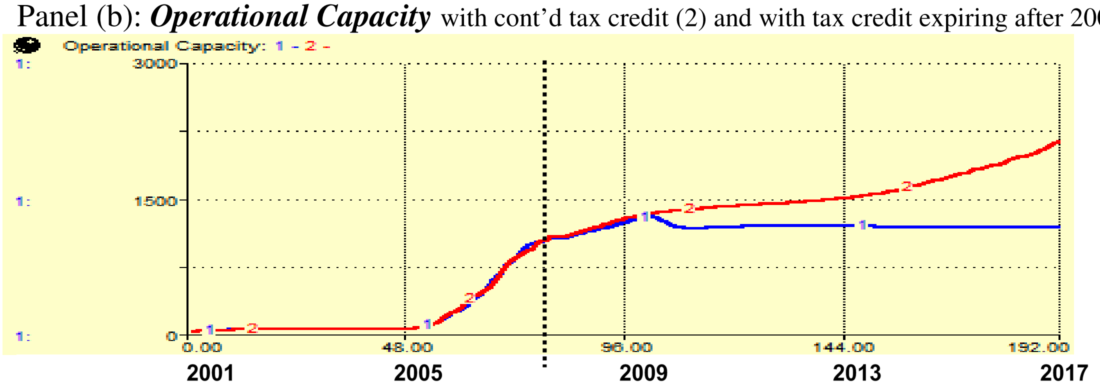


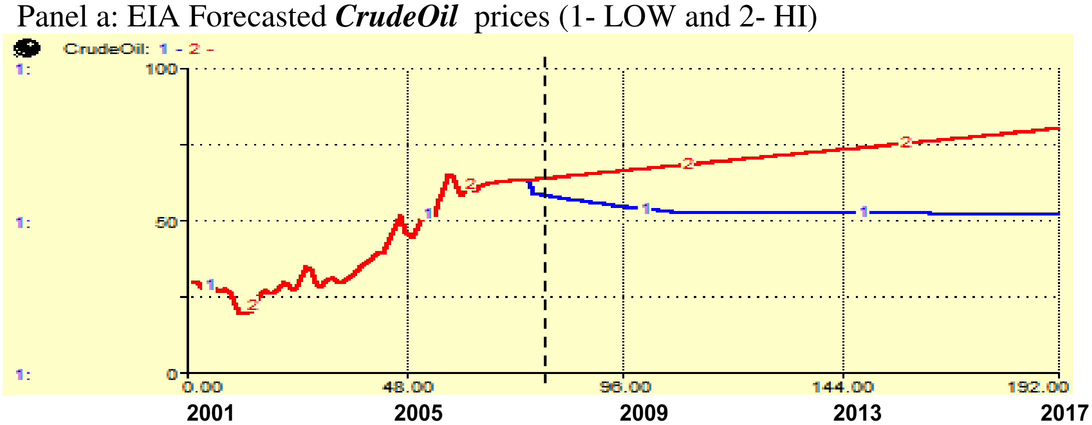

Figure 25: Impact of not extending the tax credit after 2008

The trends presented in Figure 25 are typical of many of the simulated scenarios in which the biodiesel tax credit was not extended after 2008. The ***Profitability*** (Panel (a), Trend line "1") drops off leading either to stagnation or to deflation in the industry ***Capacity*** (Panel (b), Trend line "1").

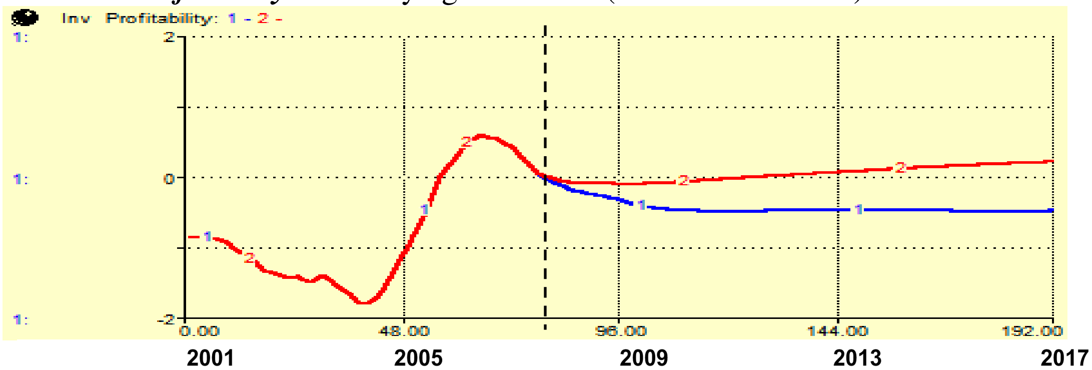
3.6.6. World oil prices

As discussed in Section 3.5, diesel prices which are dependent on crude oil prices have a direct impact on the biodiesel profitability. Elevated diesel prices over the past two years have sparked the current boom in the biofuels industry. Before the scenarios are developed and assumptions are made regarding crude oil prices, the system sensitivity to crude oil needs to be explored. The ***Profitability*** and ***Capacity*** trends in Panel (b) and (c) of Figure 26 are typical of most of the scenarios tested using the low ***CrudeOil*** price forecast. The ***Profitability*** would drop off and this would ultimately lead to the industry ***Capacity*** (and ***Production***) deflating.

Panel a: EIA Forecasted ***CrudeOil*** prices (1- LOW and 2- HI)



Panel b: ***Profitability*** with varying ***CrudeOil*** (1- LOW and 2- HI)




Panel c: ***Operational Capacity*** under the Baseline Scenario is shown here impacted by ***Profitability*** with different ***CrudeOil*** prices

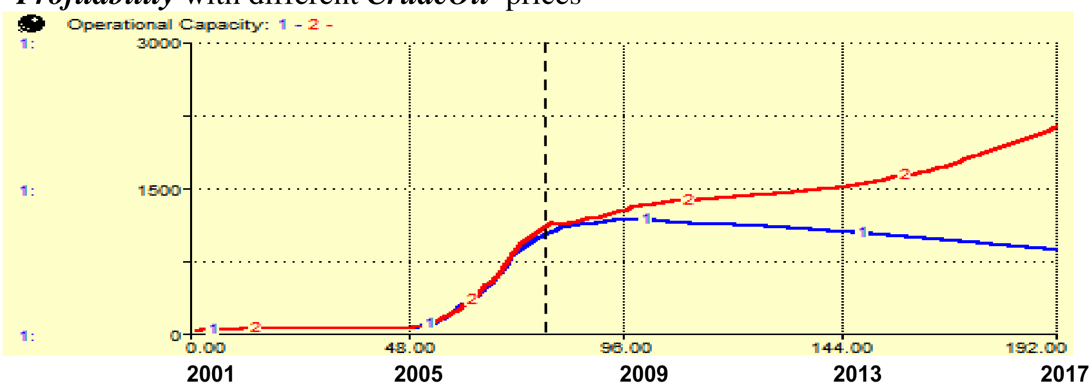



Figure 26: Impact of varying Crude Oil prices

### 3.6.7. Global biofuels growth

Although this thesis focuses on the US biodiesel industry, it is important to put it in context of the global biofuel industry growth. Although the EU biodiesel industry is larger and more mature than most regions, it is still exhibit strong growth behavior. These other global markets are excluded from this analysis, biodiesel industry expansion in Brazil, Argentina, China, India, Malaysia and Indonesia has driven global vegetable oil and fats inventories -- as indicated by the stocks-to-use ratio -- to thirty year lows (Baize, 2006a) and will continue to keep upward pressure on global vegetable oil prices for the near future.

## 3.7. Putting it all together – Testing and using the model

Above I defined the model scope and boundaries and examined the structure of the biodiesel industry and the interaction between sectors. Now I use the model to help answer the original research questions. Keeping in mind that models are simplifications of the real world and that "all models are wrong" (Sterman, 2001), one must demonstrate that this model is at least "right enough" to be useful for its stated purpose. For the young biodiesel industry, little historical data are available. Therefore, one must rely heavily on an understanding of the underlying industry structure and decision-making process and on sectoral testing using analogies provided by similar industries. Model assessment is often done with prescribed sets of tests, but in many cases, model testing becomes an iterative process of building, testing, using, sharing, explaining, and then updating based on the feedback one receives.

### 3.7.1. Face validity and structural assessment testing

In the process of building the BIGS model, I had numerous discussions with biofuel industry analysts that validated many parametric and structural assumptions made. These interactions with industry experts helped to qualitatively test the fit between the structure of the model and the essential characteristics of the real system. This is referred to as face validity testing (Sterman, 2000). Structural assessment testing, to verify whether the model is consistent with the real system relevant to the purpose (Sterman, 2000), was accomplished through discussion and interactions with key modelers from NREL. This interaction with system modelers responsible for the development of the Biomass Transition Model validated the methodology and much of the structure of the model. Finally, I was able to test dimensional consistency and other

hypothesis and key assumptions through extensive sectoral testing and sensitivity analysis.

### 3.7.2. Behavior reproduction tests

As an important part of the model building and testing process, I calibrated the biodiesel capacity and production sector using the historical prices of soybean oil and diesel to calculate the profitability as discussed in sections 3.2 and 3.3 and in Figure 10. This helped to validate the model by comparing the simulation results to historically observed conditions. Also, sensitivity analyses were used to determine which variables in the model have a major influence on the behavior when they are changed. In this way the modeler can identify which variables must be most carefully researched to confirm their numeric values. Moreover, sensitivity analysis is invaluable for analyzing various scenarios.

The price response of the soy oil sector was calibrated against the price projection in the USDA ten year forecast. In the latest ten year projections, in the USDA ten year projection (USDA-OCE, 2007), they modeled the impacts of the soy oil prices with and without the biodiesel tax credits. Using these projections, I was able to further calibrate the model by adjusting the parameters that impact the rates at which investors decide to build (or not to build) biodiesel plants and also the rate at which biodiesel producers ramp back production rates due to decreasing profitability. The recent investor behavior in the biodiesel market could be compared to behavior in a speculative bubble market. It is often hard to model this type of investor behavior, so calibrating the model against other projections (such as those from the USDA) is very helpful in building confidence in the model.

## 4. Dynamic Analysis of the Biodiesel Industry

In this section, the BIGS SD model described in Section 3 is used to investigate the impact of different market conditions on the biodiesel industry through 2016 and to gain insight into the original research questions. In Section 4.1, the STELLA™ user interface will be briefly reviewed enabling model users to interact with model and to run the various simulation scenarios. Section 4.2 establishes assumptions underlying a set of “core” scenarios including such features as availability of feedstock and other variables affecting profitability. Section 4.3 then presents results for the scenarios including production, capacity, and feedstock prices and market percentages.

### 4.1. User interface

The STELLA™ SD modeling program consists of four views (or layers) – *Equation, Model, Map,* and *Interface*. To interact with the Biodiesel Industry Growth Simulation, users will start at the main page on the Interface layer provided in Figure 27.

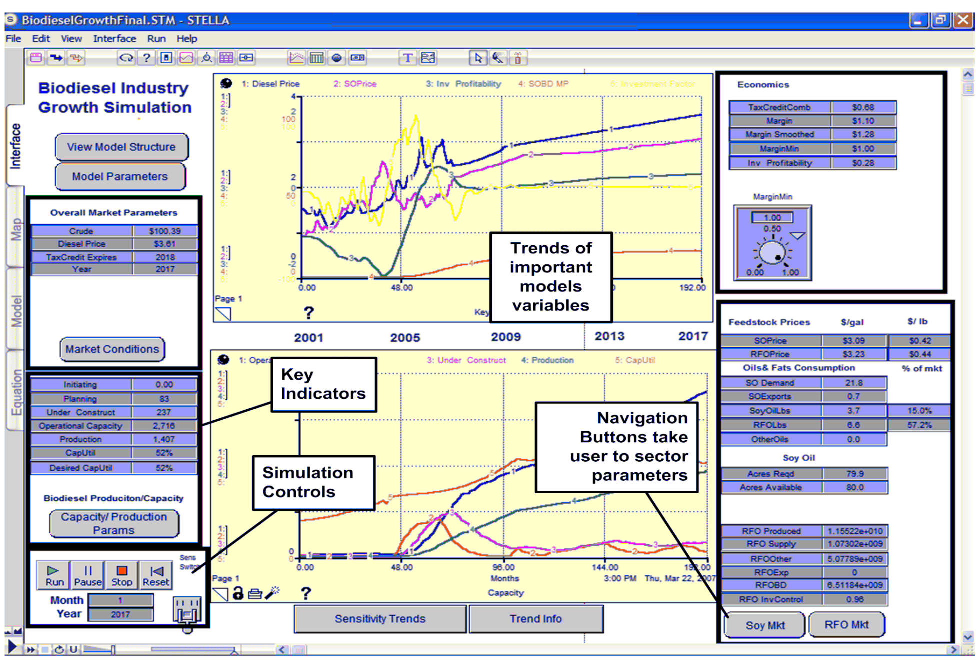
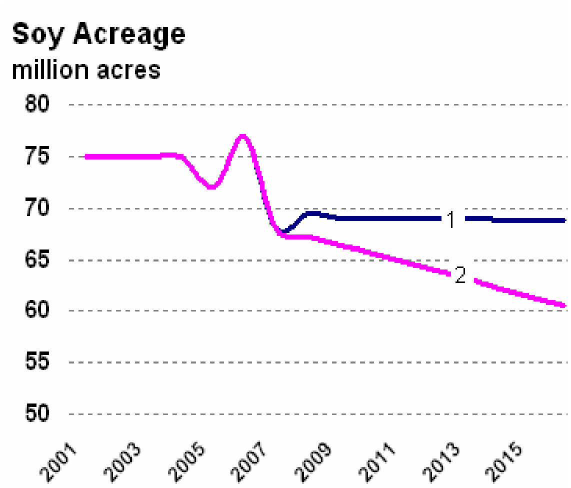



Figure 27: STELLA$^{TM}$ Biodiesel Industry Growth Simulation User Interface

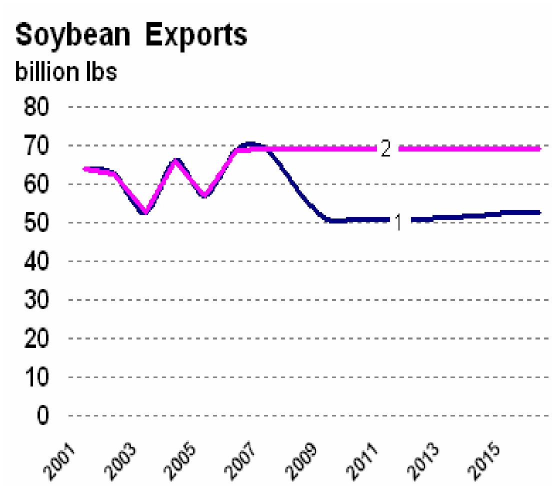
From this "flight simulator" display, the user can run scenarios, and view the model inputs and outputs or navigate to other displays and layers to view the model structure, set model parameters, and perform sensitivity analysis.

4.2. Scenario discussion

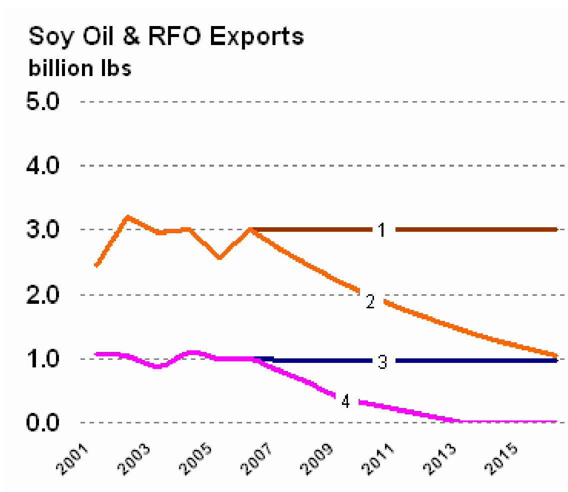
By simulating different scenarios, we can gain a better understanding of how realistic the current growth predictions are and how sensitive the industry is to changing various parametric and structural changes. Hence, I defined market conditions that would affect producer profitability by varying constraints on the availability of fats and oil feedstocks. The main exogenous variables manipulated in the scenarios impact the supply of oils and fats in the market. The first two variables impact soybeans available for crushing: soy acres planted (***Acres***) and soybean exports (***SoyExports***). The historic and future scenario trends for these two variables are shown in Figure 28. Panel (a) shows the USDA (USDA-OCE, 2007) ten year forecast (trend (1)) and University of Tenn 25x25 (English et al., 2006) soy acreage (trend (2)). Both forecasts show decreasing soy acreage but trend (2) drops significantly due to competition from energy crops such as switchgrass. Soybean exports are shown in panel (b) the USDA 2016 Forecast (trend (1)) and in trend (2) exports are held constant at current levels. The other exogenous variables that affect the amount of fats and oils supply are the exports (or imports) of soy and RFO oils (in panel (c)) and the availability of other oils in the market place (panel (d)). In panel (d) trend (2), it is assumes that other oils come into the market as imports, new oil crops, corn oil (ethanol), or through waste stream utilization with an 33% annual growth rate and will increase the supply up to 5 billion pounds per year in 2016. Panel (d) trend (2) assumes only a 5% annual growth rate in other oils.



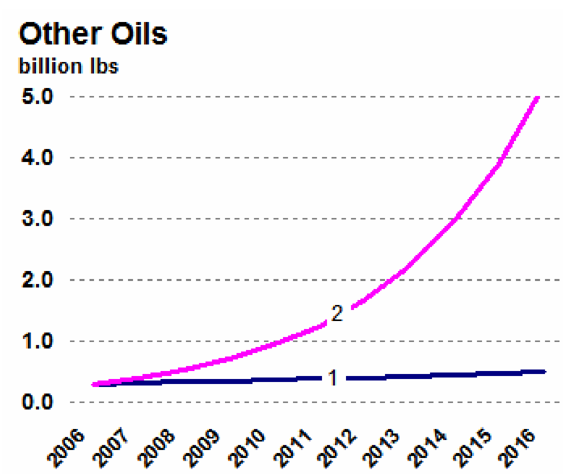

Panel a
(1 - USDA baseline, 2 – UT-25x25)




Panel b
(1 - USDA baseline, 2 – 2006 level)




Panel c
(1&3 – 2006 levels, 2&3 - Decreasing)




Panel d
(1 – 5% growth rate , 2 – 33% growth rate)

Figure 28: Variables affecting Biodiesel Oil Feedstock Supplies

The inputs for the key exogenous variables for three scenarios analyzed are summarized in Table 4. Based on discussions above, for all the scenarios, it is assumed that crude oil prices will continue to trend high and the federal biodiesel tax credit is extended through 2016.

| Scenario | Exogenous Variables Adjusted in each Scenario (see panels in Fig 27) | | | |
|---|---|---|---|---|
| | Soy Acres Planted (Panel a) | Soybean Exports (Panel b) | Fats and Oil Exports (Panel c) | Other Oils (Panel d) |
| Baseline | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Held at 2006 levels | Increasing at 5% per year |
| Five by Fifteen | Decreasing slightly per USDA baseline | Decreasing slightly per USDA baseline | Decreasing per trends in Fig.27 | Increasing at 33% per year |
| Constrained Oil | Decreasing (11% reduction by 2016) | Held at 2006 levels | Held at 2006 levels | Increasing at 5% per year |

**Table 4: Scenario Overview Table**

#### 4.2.1. Baseline scenario

The reference or business-as-usual scenario is based on the assumption that existing trends in the biodiesel market will continue on their current trajectories with no major shifts in the feedstock markets. This essentially represents the assumptions currently held by many investors interested the business of producing biodiesel. By examining this scenario, we can gain insight whether the growth of biodiesel industry can be sustained even if these assumptions are correct. The soy acreage is set per USDA 2016 forecast (USDA-OCE, 2007) and soy exports are fixed at 2005 levels. The exports of soy oil and RFO are also set at historical levels. The demand for soy oil and RFO are assumed to grow at historical growth rates. Other oils exhibit a small 5% annual growth.

#### 4.2.2. Five by fifteen Scenario

This scenario evaluate the assumptions underlying the National Biodiesel Board 5 by ‘15 goal (i.e. achieve 5% market share for diesel market by 2015). Most importantly, the

NBB projections postulate a sufficient growth in “other oil” feedstocks to support the 5% market share goal. Assuming the decline in soy oil production as projected by USDA, the model analysis suggests that a roughly 33% annual growth rate in “other oils” is required to achieve this goal (see Figure 28, Panel (d), Trend (2)). Hence, this scenario employs such an increase. The results are useful in evaluating how realistic the NBB 5 x ‘15 goal actually is. Exports of soy oil and RFO oils will also be decreased as shown in the trends in Figure 28. Although the NBB assumes additional soy acreage may come from CRP and pasture lands, this scenario assumes soy acreage will more closely follow the USDA 2016 baseline. The other oils in this scenario may come from corn, canola and palm oil as they enter the market through new technologies, increased domestic production and increased oil feedstock imports to meet the increasing demand from biodiesel. Also other waste streams fat sources will be tapped.

#### 4.2.3. Limited biomass oil scenario

In this scenario, it is assumed that soy acreage will significantly decrease due to increased corn and switchgrass planting for ethanol production and other bioenergy uses. This scenario (shown in Figure 28 Panel a) uses the acreage assumptions developed by the agricultural economists at the University of Tennessee as a way to meet 25% of the nation’s transportation and electricity needs with renewable energy (English et al., 2006). Also in this scenario, it is assumed that exports are maintained at 2006 levels and no significant increases in other oils occur.

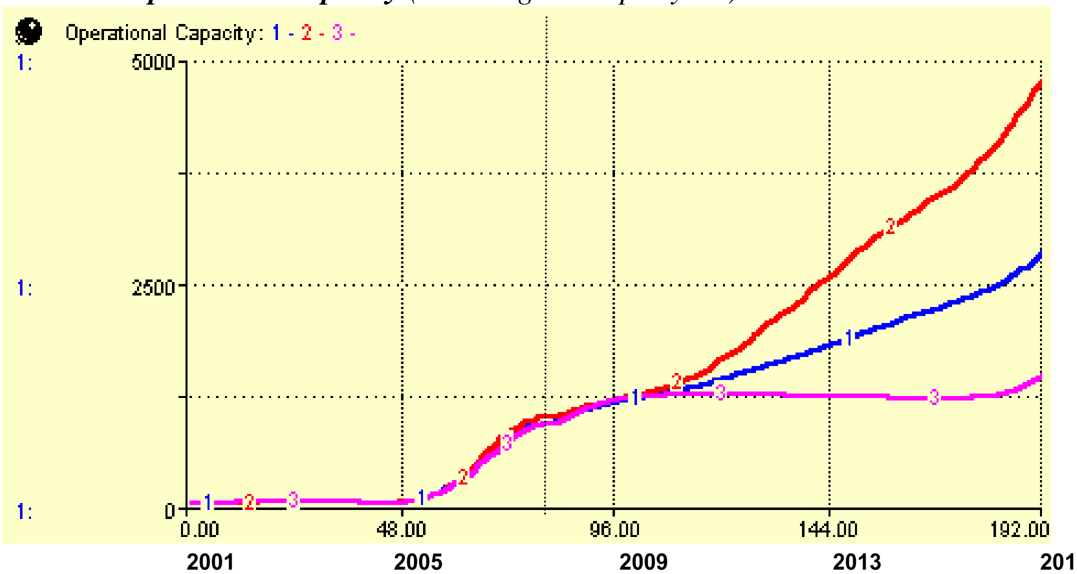
4.3. Scenario results

The projections presented in this section are dependent on assumptions about the availability of FAME biodiesel feedstocks discussed in the section above. The core assumptions are intended to set a reasonable context for assessment of the various growth behaviors in the US biodiesel industry as indicated by biodiesel industry capacity and production and soy oil and rendered fats and oils prices and market share. Capacity and production projections for the three core scenario are depicted in panels (a) and (b) in Figure 29. These projections suggest that biodiesel production, could possibly hit the industry goals of 5% market share (panel (b) trend (2)) by 2015 but, only under ideal conditions. In the Limited Biomass Scenario, the production plateaus at approximately 700 million gals per year (Figure 29, panel (b) trend (3)) which is consistent with the USDA model results (USDA-OCE, 2007). The Baseline scenario in Figure 29 trend (1) shows production capacity is slightly over 2.5 billion gallons per year wh production at approximately 1.5 billion gallons per year. This production level is consistent with the UT-GEC report (Ugarte et al., 2006), discussed in section 2, and possibly the Promar study, if extrapolated to 2016.

In all cases, there will be a slowing of growth in the next three years as production comes on line and rising feedstock prices cut into producer profitability (seen in Figure 30). Soy and rendered fats & oils prices and their impact on the investor profitability for the three core scenario are depicted in panels (a) and (b) in Figure 30. As expected, the acreage constraints in the Limited Biomass Oil scenario have a major impact on soy prices as seen in (Figure 30, panel (a) trend (3)).

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: ***OperationalCapacity*** *(million gallons per year)*




Panel b: ***Production*** *(million gallons per year)*

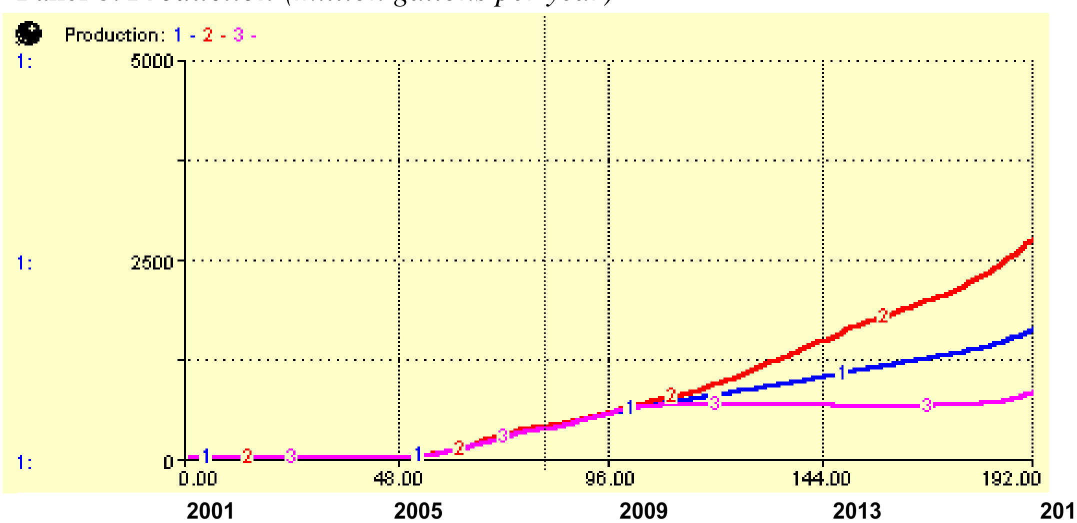
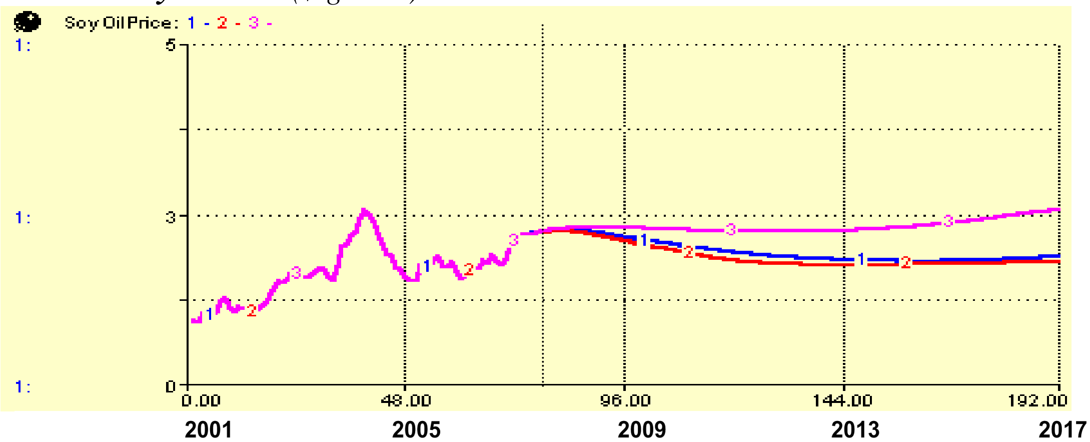


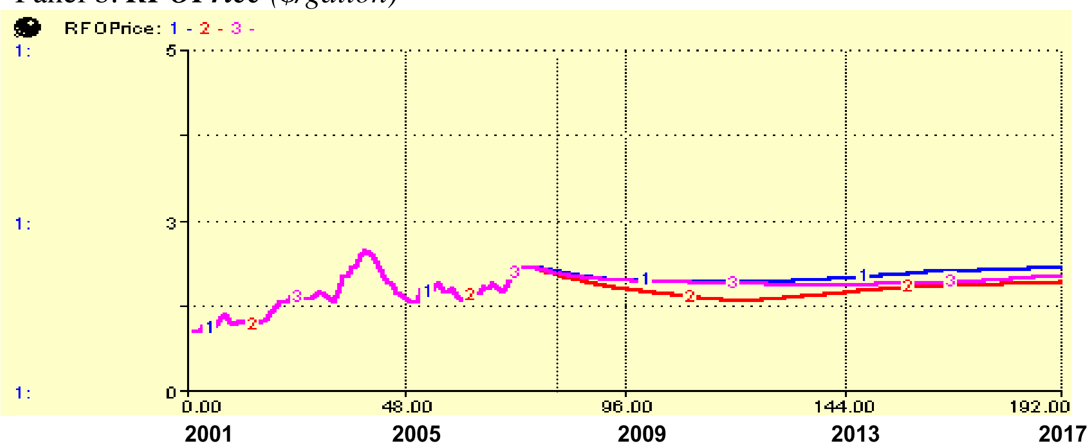

Figure 29: Biodiesel Capacity and Production under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: ***SoyOilPrice*** *($/gallon)*




Panel b: ***RFOPrice*** *($/gallon)*




Panel c: ***Inv Profitability****($/gallon)*

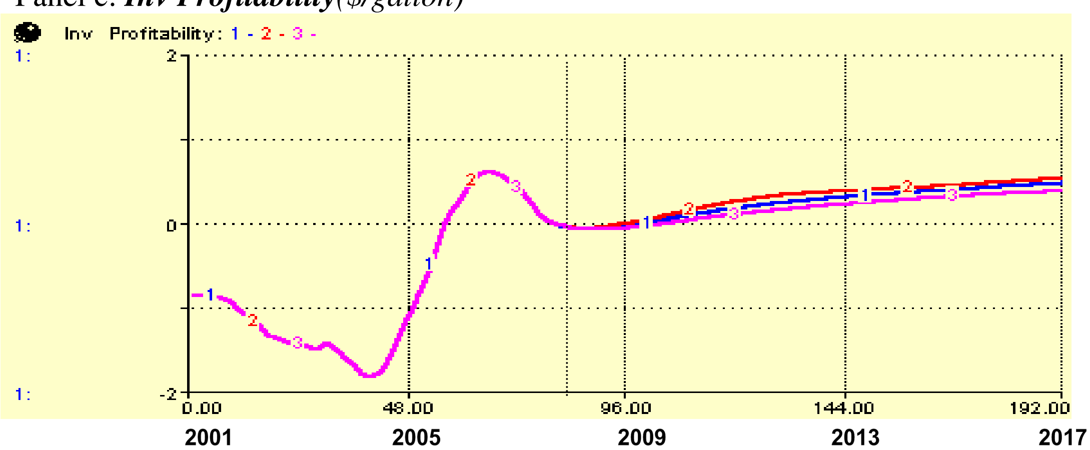
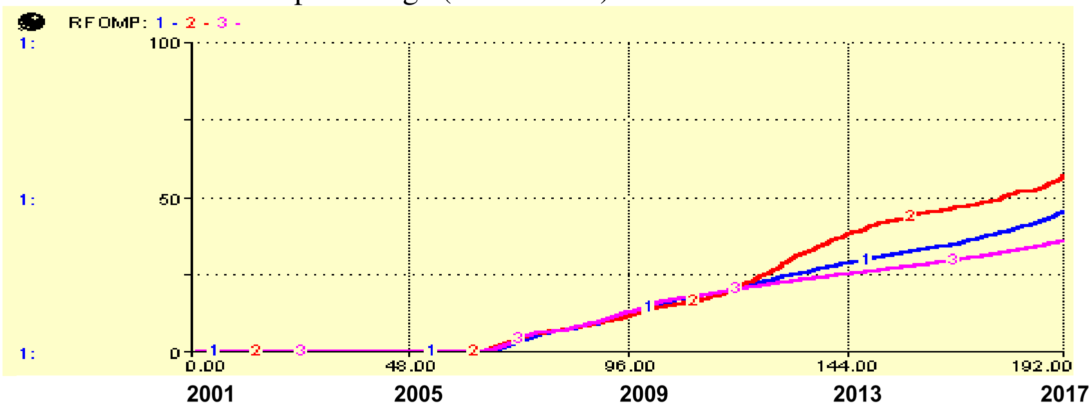



Figure 30: Feedstock prices and profitability under alternative scenario assumptions

**Index:** **Baseline ----1----** **5x15 Scenario ----2-----** **Limited Biomass Oil -----3----**

Panel a: RFO market percentage (to biodiesel)




Panel b: Soy Oil market percentage (to biodiesel)

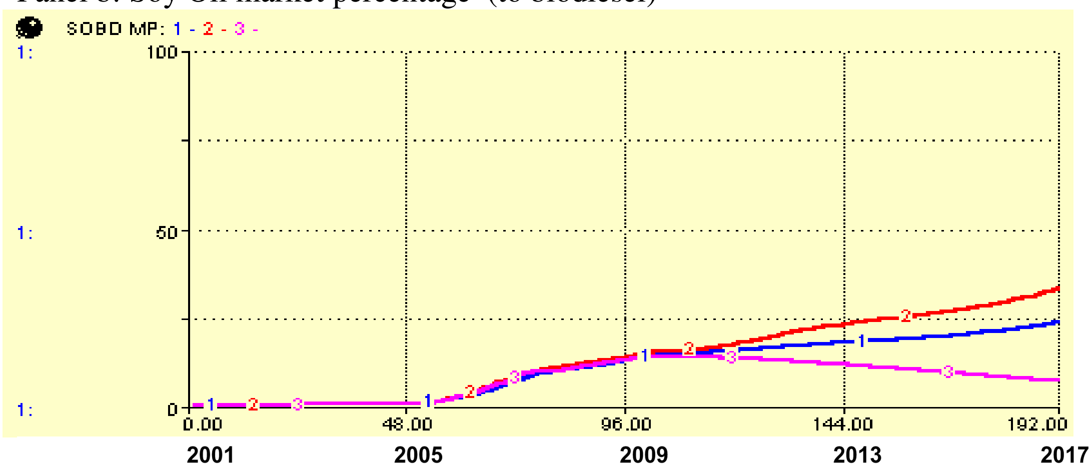



Figure 31: Feedstock Market Percentage under alternative scenario assumptions

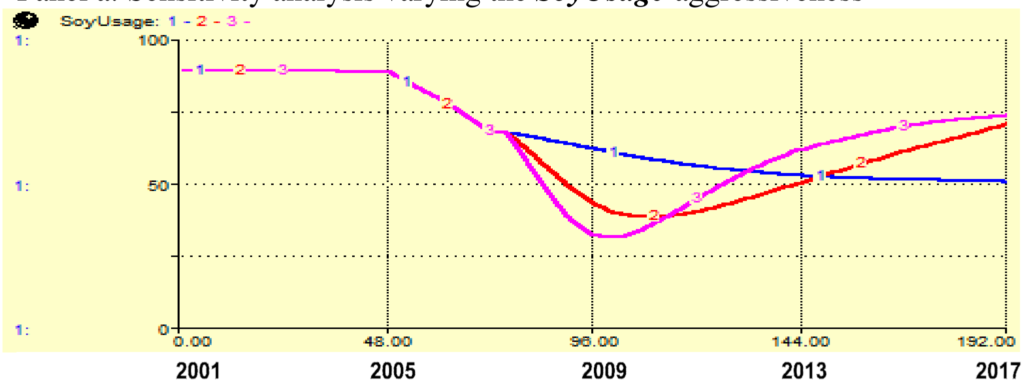
The share of the feedstock markets that biodiesel demand is claiming is show in Figure 31 (soy oil-panel (b), rendered fats and oils-panel (a)). When soy oil supply is impacted by soy acreage constraints in the Limited Biomass Scenario, the amount of soy used for biodiesel feedstock drops off significantly (panel (b), trend (3)) due to high prices. In the other two scenarios, the soy biodiesel market percentage gradually increases to 25-35% of the market. In panel (a), biodiesel takes from 35-60 % of the RFO market share. In reality, this may not be practical, given the elasticities of the other markets.

As these scenarios are evaluated, other factors come into play and other assumptions are also plausible. For example, the industry has been gradually diversifying its feedstock sources and by shifting away from dependence on soy to multi-feedstock facilities. To explore the effect that this shift has on the industry growth, a sensitivity analysis was performed under the baseline scenario and varying the aggressiveness of the ***SoyUsage*** variable. The trends in Fig 31 panel (a) show the varying rate of aggressiveness at which producers are shift from using soy to other feedstocks. The results of the sensitivity analysis shown in Figure 32, reveal that if the industry aggressively moves away from soy in the next three to four years (trend lines (2) and (3) in Panel (a), Figure 32), then a rapid increase in rendered fats and oils market share (***RFOMP***) trend lines (2) and (3) in Panel (b) will occur. The will cause the RFO price to increase and the SoyUsage will be adjusted endogenously as seen when trend lines (2) and (3) in panel (a) reverse direction and begin to increase the soy usage. The simulation indicates that these lower soy oil prices could trigger another boom in construction and more capacity growth towards the end of the simulation run as seen in panel (c) trend lines (2) and (3).

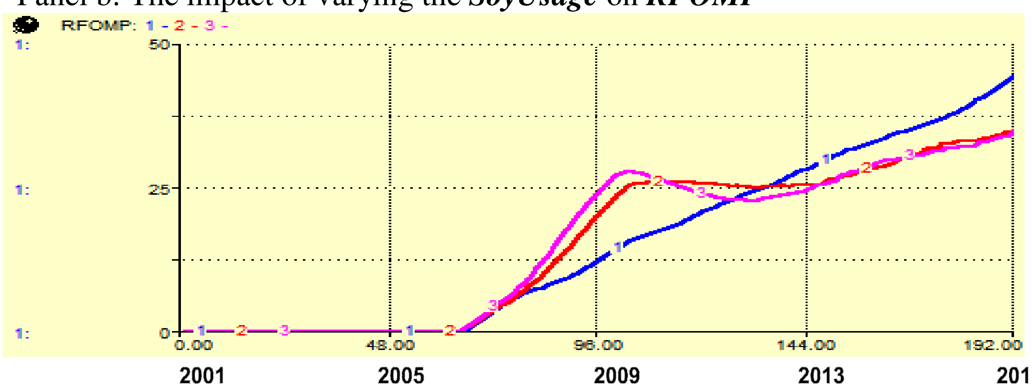
By developing scenarios that affected producer profitability by varying constraints on the availability of fats and oil feedstocks and then using BIGS model to simulate the industry grow, we have gained a better understanding of how realistic the current growth predictions. The sensitivity analyses above provide examples of how the BIGS model can be used to explore the dynamics interactions between different factors that affect growth in the biodiesel industry and help better understand how sensitive the industry is to changing various parametric and structural changes.

**Index:** **SoyUsageChg(3%/yr) (1), Soy UsageChg (13%/yr) (2), Soy Usage Chg(20%/yr)(3)**

Panel a: Sensitivity analysis varying the ***SoyUsage*** aggressiveness




Panel b: The impact of varying the ***SoyUsage*** on ***RFOMP***




Panel c: The resultant effect on industry ***OperationalCapacity***

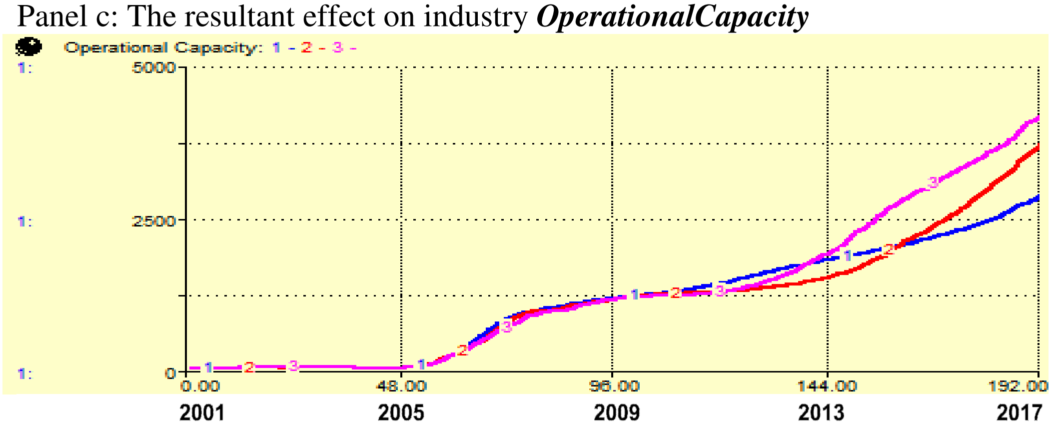



Figure 32: Baseline Scenario- varying the Soy Usage Parameter

## 5. Recommendations and Conclusions

The objective of this study is to investigate the market dynamics of the FAME biodiesel industry through the use of a SD research model. Conceptualization of the model structure, key parametric assumptions and relationships between them was informed by literature review and discussions with key personnel in the biodiesel industry. Simplifications and assumptions to model structure and parameters are integrated by means of these discussions. Simulation of various scenarios helped to help explore the bottlenecks in feedstock availability and sensitivity of industry growth to various parameters over the next decade. The future of FAME biodiesel is, indeed, not clear and could take many different routes depending on market conditions, government actions, and as we thoroughly investigated, on the availability of affordable oil feedstocks.

A key finding from this study is that many of the scenarios run indicate that industry may experience a plateau of capacity growth in the next few years because of decreased profitability. In fact, only in the most optimum of feedstock and market conditions -- high oil prices, extension of tax credits, reduced exports and 33% annual growth rate of new sources of fats and oils – will the market reach five percent of diesel market penetration. Realistically, growth of the FAME biodiesel industry beyond that in the ten year period studied is not likely. As hypothesized, the dampening of the industry growth is influenced heavily due by increases of feedstock prices. The price increases are brought about by the rapid increase in the feedstock market share of biodiesel and influenced also by agricultural pressures from corn ethanol. Analysis of the various scenarios also finds that decreasing soy usage by increasing multi-feedstock capability

may temporarily delay the pending feedstock squeeze but unless significant amount of other oils become available in the short term the industry will be severely limited.

## 5.1. Recommendations

### 5.1.1. Explore other renewable diesel alternatives

Although the scope of this thesis does not include exploring the transition of the renewable diesel industry to non-FAME alternatives, it is important that this task be addressed urgently. To raise the low feedstock ceiling that will soon limit FAME biodiesel to somewhere less than one tenth of the diesel market, the biodiesel industry must embrace change and quickly expand to production technologies that are not solely dependent on fats and oils. These technologies -- such as biomass gasification/Fischer-Tropsch diesel -- can open the door to a broader and more diverse array of feedstock choices. Although diesel is a smaller piece of the transportation fuel pie, the growth of the diesel market combined with the potential for other non-renewable alternatives to displace petroleum diesel demand appropriate attention to this matter. The EIA projects that by 2030, fuels derived from coal (Coal-To-Liquids or CTL) will account for 93% of non-petroleum diesel alternatives (USDOE-EIA, 2007a) -- making up 7 percent of the total distillate pool. Liquid coal is produced from domestic feedstocks but only the fuels produced from renewable resources give us real energy security by significantly reducing our greenhouse gas emissions.

SD modeling efforts could be used to help policy makers and industry leaders envision a renewable diesel future with multiple production pathways. As discussed previously, several government agencies and labs are collaborating to develop a SD-based Biomass Transition Model (USDOE-OBP, 2006) to help simulate the evolution of

the ethanol industry to lignocellulosic feedstock sources. The learnings from this model will help to inform policy makers and industry players in their decision making process. It is important that similar modeling efforts include the future of renewable diesel pathways.

### 5.1.2. Maintain government interaction in the markets

As demonstrated in the model testing, if the current biodiesel tax credit is not extended the production of biodiesel may drop off quite rapidly because producers will have difficulty being profitable. These businesses will not continue production for long if they are losing money. The results of the simulation in this thesis concurred with the USDA industry collapse simulated in the most recent ten year outlook (USDA, 2007a). Therefore, until alternative renewable diesel pathways become established and renewable feedstock supplies markets are stable, effective, targeted public investments in the form of research, market-creating purchases and mandates, and tax credits should be provided for emerging biodiesel technologies and industries. However, these government policies should promote and support the production and uses of biodiesel that meet appropriate performance standards -- such as lifecycle greenhouse gas emissions -- not just specific feedstock types.

### 5.1.3. Promote sustainable development of new oilcrops

There are possible benefits to producing a diverse array of oil crops that can be used for biodiesel production. For example, planting camelina as a winter cover crop will reduce soil erosion and give the farmers a crop that has a higher value in the market. The need for further research into these matters is recognized by the government and industry.

Researchers at the Danforth Center in St. Louis (Hamilton, 2007) are trying to understand what is needed to achieve a 5% market share for biodiesel.

Increasingly, oil palm could begin to play a major role in US biodiesel industry development. In addition to palm oil, new oilseed crops such as the perennial Jatropha can provide income for rural farming communities in India while providing another valuable source of biomass oil that can be turn in to fuel. Many in the US and Europe are concerned that oilcrops from the tropics, may not be grown in a sustainable manner. To avoid replacing unsustainable fossil fuels with unsustainable biofuels, the international community must act quickly to establish global sustainability standards for biofuels.

### 5.1.4. Understand the dynamics of the domestic oilseed industry

The domestic crushing industry – which extracts oil from oilseeds – is undergoing a rapid transition driven by international competition in China and Argentina. It is also by the changes of the end use of its products (soy meal and soy oil) domestically which are influenced by the rapid growth of the biodiesel and ethanol industries. Many of the old business models for soybean crushing are being “flipped on their head” by a rapidly changing market environment where soybean meal is losing value and soy oil is gaining. One recent industry trend is to locate crushing facilities at or near biodiesel production facilities to reduce costs for the biodiesel producers. This issue is ripe for analysis using SD modeling methods similar as performed in this thesis.

### 5.1.5. Develop other non-conventional sources of oil

There are many exciting possibilities for sources of new biomass oil to raise the FAME biodiesel feedstock ceiling such as corn oil, oil from algae, and other under-

utilized waste oils. Research, development, and deployment should be supported at appropriate levels.

## 5.2. Conclusion

Understanding current and future growth in the biodiesel industry requires taking a holistic view of the industry and analyzing key factors that influence profitability. Exploring various scenarios using SD modeling and simulation can be extremely helpful in developing a deeper understanding of the rapidly changing biofuels industry. This thesis described the formulation of a SD model to simulate the behavior of the FAME biodiesel industry and as hypothesized the industry will most likely hit a feedstock ceiling in the next decade and remain only a small fraction (less than 10%) of the non-petroleum diesel replacement market.

# Appendix A: US Biodiesel Plant Listing

**Table 5: US biodiesel plant listing - Jan 2007**

(Source: Biodiesel Magazine online plant listing, last updated 3-Jan-2007)

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Independence Renewable Energy Corp. | Claiborne | AL | soy oil | 40 | Under Construction | |
| Alabama Biodiesel Corp. | Moundville | AL | soy oil | 10 | Operational | N/A |
| Alabama Bioenergy | Bridgeport | AL | soy oil | 10 | Operational | Nov-06 |
| Arkansas Soy Energy Group LLC | Dewitt | AR | soy oil | 3 | Under Construction | |
| FutureFuel Chemical Co. | Batesville | AR | soy oil | 24 | Operational | N/A |
| Patriot BioFuels | Stuttgart | AR | soy oil/animal fats | 3 | Operational | N/A |
| Bay Biodiesel LLC | San Jose | CA | virgin oils/yellow grease | 5 | Under Construction | |
| Energy Alternative Solutions Inc. | Gonzales | CA | tallow | 1 | Under Construction | |
| Simple Fuels LLC | Vinton | CA | yellow grease | 2 | Under Construction | |
| Bio-Energy Systems LLC | Vallejo | CA | virgin oils/yellow grease | 2 | Operational | N/A |
| Biodiesel Industries-Port Hueneme | Ventura | CA | multi-feedstock | 3 | Operational | N/A |
| Imperial Western Products | Coachella | CA | yellow grease | 7 | Operational | N/A |
| LC Biofuels | Richmond | CA | canola oil | 1 | Operational | N/A |
| American Biofuels Corp. o | Bakersfield | CA | soy oil/tallow/waste vegetable oil | 5 | Not Producing | N/A |
| American Agri-Diesel | Burlington | CO | soy oil | 6 | Operational | N/A |
| BioEnergy of Colorado | Denver | CO | soy oil | 10 | Operational | N/A |
| BioFuels of Colorado | Denver | CO | soy oil | 5 | Operational | N/A |
| Rocky Mountain Biodiesel Industries | Berthoud | CO | multi-feedstock | 3 | Operational | N/A |
| Bio-Pur Inc. | Bethlehem | CT | soy oil | 0.4 | Operational | N/A |
| Mid-Atlantic Biodiesel | Clayton | DE | multi-feedstock | 5 | Operational | N/A |
| Purada Processing LLC | Lakeland | FL | multi-feedstock | 18 | Operational | N/A |
| Renewable Energy Systems Inc. | Pinellas Park | FL | recycled vegetable oil | 0.5 | Operational | N/A |
| Middle Georgia Biofuels | East Dublin | GA | soy oil/poultry fat | 2.5 | Operational | Sep-06 |
| US Biofuels Inc. | Rome | GA | multi-feedstock | 10 | Operational | N/A |
| Pacific Biodiesel Inc. | Honolulu | HI | yellow grease | 1 | Operational | N/A |
| Pacific Biodiesel Inc. | Kahului | HI | yellow grease | 0.2 | Operational | N/A |
| Central Iowa Energy LLC | Newton | IA | multi-feedstock | 30 | Under Construction | |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| East Fork Biodiesel LLC | Algona | IA | soy oil/animal fats | 60 | Under Construction | |
| Freedom Fuels LLC | Mason City | IA | soy oil/animal fats | 30 | Under Construction | |
| Iowa Renewable Energy | Washington | IA | soy oil | 30 | Under Construction | |
| Riksch Biofuels | Crawfordsville | IA | multi-feedstock | 9 | Under Construction | |
| Sioux Biochemical Inc. | Sioux Center | IA | corn oil/animal fats | 1.5 | Under Construction | |
| Western Dubuque Biodiesel | Farley | IA | soy oil | 30 | Under Construction | |
| Ag Processing Inc. | Sergeant Bluff | IA | soy oil | 30 | Operational | N/A |
| Cargill Inc. | Iowa Falls | IA | soy oil | 37 | Operational | N/A |
| Clinton County Bio Energy | Clinton | IA | soy oil | 10 | Operational | N/A |
| Mid-States Biodiesel LLC | Nevada | IA | multi-feedstock | 0.5 | Operational | N/A |
| Renewable Energy Group | Ralston | IA | soy oil | 12 | Operational | N/A |
| Soy Solutions | Milford | IA | soy oil | 2 | Operational | N/A |
| Tri-City Energy | Keokuk | IA | multi-feedstock | 5 | Operational | N/A |
| Western Iowa Energy | Wall Lake | IA | soy oil-animal fats | 30 | Operational | N/A |
| Blue Sky Biodiesel LLC | New Plymouth | ID | multi-feedstock | 12 | Operational | N/A |
| Biofuels Company of America LLC | Danville | IL | soy oil | 45 | Under Construction | |
| American Biorefining Inc. | Saybrook | IL | soy oil | 10 | Operational | N/A |
| Columbus Foods Co. | Chicago | IL | soy oil | 3 | Operational | N/A |
| Incobrasa Industries Ltd. | Gilman | IL | soy oil | 30 | Operational | Dec-06 |
| Stepan Co. | Joliet | IL | multi-feedstock | 21 | Operational | N/A |
| e-Biofuels LLC | Middletown | IN | soy oil | 25 | Under Construction | |
| Louis Dreyfus Agricultural Industri | Claypool | IN | soy oil | 80 | Under Construction | |
| Evergreen Renewables LLC | Hammond | IN | soy oil | 5 | Operational | N/A |
| Integrity Biofuels | Morristown | IN | soy oil | 5 | Operational | N/A |
| Owensboro Grain Biodiesel | Owensboro | KY | soy oil | 50 | Under Construction | |
| Griffin Industries | Butler | KY | soy oil/tallow/yellow grease | 2 | Operational | Dec-98 |
| Allegro Biodiesel Corp. | Pollock | LA | soy oil | 15 | Operational | N/A |
| Maryland Biodiesel | Berlin | MD | soy oil | 0.5 | Operational | N/A |
| Bean's Commercial Grease | Vassalboro | ME | waste vegetable oil | 0.25 | Operational | N/A |
| Ag Solutions Inc. | Gladstone | MI | soy oil | 5 | Operational | N/A |
| Michigan Biodiesel | Bangor | MI | soy oil | 10 | Operational | N/A |
| FUMPA Biofuels | Redwood Falls | MN | soy oil/animal fats | 3 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Minnesota Soybean Processors | Brewster | MN | soy oil | 30 | Operational | N/A |
| SoyMor | Glenville | MN | soy oil | 30 | Operational | Aug-05 |
| Ag Processing Inc. | St. Joseph | MO | soy oil | 28 | Under Construction | |
| Great River Soy Co-op | Lilbourn | MO | multi-feedstock | 5 | Under Construction | |
| Natural Biodiesel Inc. | Braggadocio | MO | multi-feedstock | 5 | Under Construction | |
| Prairie Pride Inc. | Nevada | MO | soy oil | 30 | Under Construction | |
| Mid-America Biofuels LLC | Mexico | MO | soy oil | 30 | Operational | N/A |
| Missouri Better Bean LLC | Bunceton | MO | soy oil/animal fats | 4 | Operational | N/A |
| Missouri Bio-Products Inc. | Bethel | MO | soy oil | 2 | Operational | N/A |
| Scott Petroleum Corp. | Greenville | MS | multi-feedstock | 20 | Under Construction | |
| CFC Transportation Inc. | Columbus | MS | soy oil | 1 | Operational | N/A |
| Channel Chemical Corp. | Gulfport | MS | soy oil | 5 | Operational | N/A |
| Earth Biofuels | Meridian | MS | multi-feedstock | 2 | Operational | N/A |
| Evans Environmental Energies | Wilson | NC | multi-feedstock | 3 | Under Construction | |
| Filter Specialty Inc. | Autryville | NC | soy oil/yellow grease | 1 | Under Construction | |
| Blue Ridge Biofuels | Asheville | NC | multi-feedstock | 1 | Operational | N/A |
| Foothills Bio-Energies LLC | Lenoir | NC | soy oil | 5 | Operational | N/A |
| Piedmont Biofuels | Pittsboro | NC | yellow grease/animal fats | 1 | Operational | Sep-06 |
| All-American Biodiesel | York | ND | soy oil/canola oil | 5 | Under Construction | |
| Archer Daniels Midland | Velva | ND | canola oil | 85 | Under Construction | |
| Magic City Biodiesel LLC | Minot | ND | canola oil | 30 | Under Construction | |
| Beatrice Biodiesel LLC | Beatrice | NE | soy oil | 50 | Under Construction | |
| Northeast Nebraska Biodiesel | Scribner | NE | soy oil | 5 | Under Construction | |
| Horizon Biofuels Inc. | Arlington | NE | animal fats | 0.4 | Operational | Sep-06 |
| Fuel:Bio One | Elizabeth | NJ | undeclared | 50 | Under Construction | |
| Environmental Alternatives | Newark | NJ | soy oil | 13 | Operational | N/A |
| Biodiesel of Las Vegas | Las Vegas | NV | multi-feedstock | 30 | Under Construction | |
| Infinifuel Biodiesel | Wabuska | NV | multi-feedstock | 5 | Under Construction | |
| Bently Biofuels | Minden | NV | multi-feedstock | 1 | Operational | N/A |
| Biodiesel of Las Vegas Inc. | Las Vegas | NV | soy oil | 3 | Operational | N/A |
| GS Fulton Biodiesel | Fulton | NY | soy oil | 5 | Under Construction | |
| North American Biofuels Company | Bohemia | NY | trap grease | 1 | Operational | N/A |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Alternative Liquid Fuel Industries | McArthur | OH | multi-feedstock | 6 | Under Construction | |
| Jatrodiesel Inc. | Dayton | OH | multi-feedstock | 5 | Under Construction | |
| American Ag Fuels LLC | Defiance | OH | soy oil | 3 | Operational | N/A |
| Peter Cremer | Cincinnati | OH | soy oil | 30 | Operational | N/A |
| Earth Biofuels | Durant | OK | multi-feedstock | 10 | Operational | N/A |
| Green Country Biodiesel Inc. | Chelsea | OK | soy oil | 2 | Operational | N/A |
| OK Biodiesel | Gans | OK | soy oil | 10 | Operational | N/A |
| Sequential-Pacific Biodiesel LLC | Salem | OR | yellow grease | 1 | Operational | N/A |
| Lake Erie Biofuels | Erie | PA | multi-feedstock | 45 | Under Construction | |
| Agra Biofuels Inc. | Middletown | PA | soy oil | 3 | Operational | N/A |
| Biodiesel of Pennsylvania Inc. | White Deer | PA | multi-feedstock | 3.6 | Operational | Jan-07 |
| Keystone Biofuels | Shiremanstown | PA | soy oil | 2 | Operational | Jan-06 |
| United Biofuels Inc. | York | PA | soy oil | 1 | Operational | N/A |
| United Oil Co. | Pittsburg | PA | multi-feedstock | 2 | Operational | Dec-04 |
| Southeast BioDiesel LLC | North Charleston | SC | multi-feedstock | 6 | Under Construction | |
| Carolina Biofuels LLC | Taylors | SC | soy oil | 5 | Operational | N/A |
| Midwest Biodiesel Producers | Alexandria | SD | soy oil | 7 | Operational | N/A |
| Freedom Biofuels Inc. | Madison | TN | multi-feedstock | 12 | Under Construction | |
| Agri Energy Inc. | Lewisburg | TN | soy oil | 5 | Operational | N/A |
| Memphis Biofuels LLC | Memphis | TN | multi-feedstock | 36 | Operational | N/A |
| Milagro Biofuels | Memphis | TN | soy oil | 5 | Operational | N/A |
| NuOil Inc. | Counce | TN | soy oil | 1 | Operational | Nov-05 |
| Big Daddy's Biodiesel | Hereford | TX | multi-feedstock | 30 | Under Construction | |
| BioSelect Galveston Bay | Galveston Island | TX | multi-feedstock | 20 | Under Construction | |
| Global Alternative Fuels LLC | El Paso | TX | multi-feedstock | 5 | Under Construction | |
| Green Earth Fuels LLC | Houston | TX | multi-feedstock | 43 | Under Construction | |
| Biodiesel Industries of Greater Dal | Denton | TX | multi-feedstock | 3 | Operational | N/A |
| Brownfield Biodiesel LLC | Ralls | TX | multi-feedstock | 2 | Operational | Jul-06 |
| Central Texas Biofuels | Giddings | TX | vegetable oils | 1 | Operational | N/A |
| GeoGreen Fuels | Gonzales | TX | soy oil | 3 | Operational | N/A |
| Huish Detergents | Pasadena | TX | tallow/palm oil | 4 | Operational | N/A |
| Johann Haltermann Ltd. | Houston | TX | soy oil | 20 | Operational | N/A |
| Momentum Biofuels Inc. | Pasadena | TX | soy oil | 20 | Operational | N/A |
| Organic Fuels LLC | Houston | TX | multi-feedstock | 30 | Operational | Apr-06 |
| Pacific Biodiesel Texas | Carl's Corner | TX | multi-feedstock | 2 | Operational | Aug-06 |

| Plant Name | City | State | Feedstock | Capacity (MM GPY) | Status | Startup |
|---|---|---|---|---|---|---|
| Safe Fuels Inc. | Conroe | TX | soy oil | 10 | Operational | N/A |
| Smithfield Bioenergy LLC | Cleburne | TX | animal fats | 12 | Operational | Jan-06 |
| SMS Envirofuels Inc. | Poteet | TX | soy oil | 5 | Operational | Jun-06 |
| South Texas Blending | Laredo | TX | beef tallow | 5 | Operational | N/A |
| Sun Cotton Biofuels | Roaring Springs | TX | cottonseed oil | 2 | Operational | N/A |
| Better BioDiesel | Spanish Fork | UT | multi-feedstock | 3 | Operational | Sep-06 |
| Reco Biodiesel LLC | Richmond | VA | soy oil | 10 | Under Construction | |
| Chesapeake Custom Chemical | Ridgeway | VA | soy oil | 5 | Operational | N/A |
| Virginia Biodiesel Refinery | New Kent | VA | soy oil | 2 | Operational | N/A |
| Biocardel Vermont LLC | Swanton | VT | soy oil | 4 | Under Construction | |
| Imperium Grays Harbor | Grays Harbor | WA | multi-feedstock | 100 | Under Construction | |
| Seattle Biodiesel | Seattle | WA | virgin vegetable oils | 5 | Operational | N/A |
| Best Biodiesel Cashton LLC | Cashton | WI | multi-feedstock | 8 | Under Construction | |
| Sanimax Energy Biodiesel | De Forest | WI | multi-feedstock | 20 | Under Construction | |
| Walsh Biofuels LLC | Mauston | WI | multi-feedstock | 5 | Under Construction | |
| Renewable Alternatives | Howard | WI | soy oil | 0.365 | Operational | N/A |
| A C & S Inc. | Nitro | WV | soy oil | 3 | Under Construction | |

Appendix B: Biodiesel Chemistry and Process Diagram

*Transesterification* is the process of reacting a triglyceride molecule with an excess of alcohol in the presence of a catalyst (KOH, NaOH, $NaOCH_3$, etc.) to produce glycerol and fatty esters. The chemical reaction with methanol is shown schematically below.

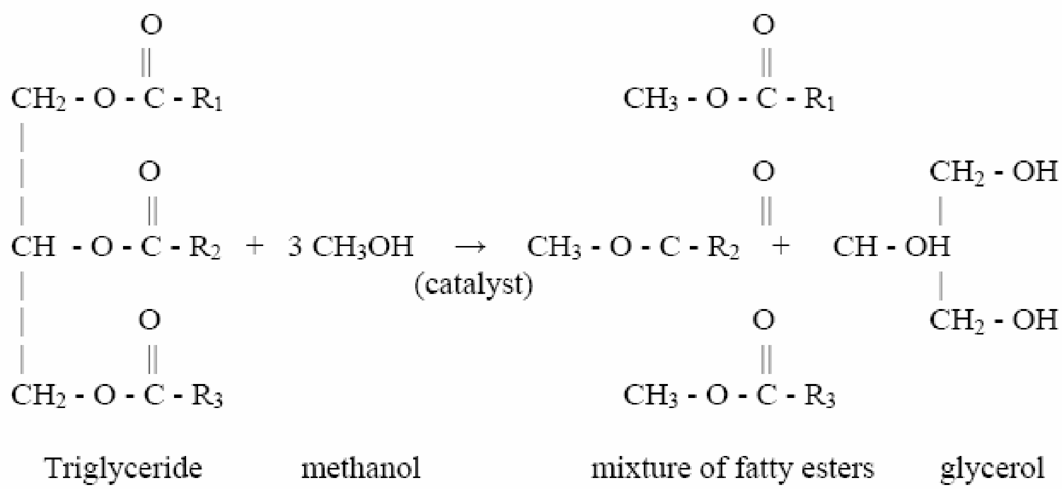



Figure 33: FAME biodiesel chemistry
Source: van Gerpen et al. (2004)

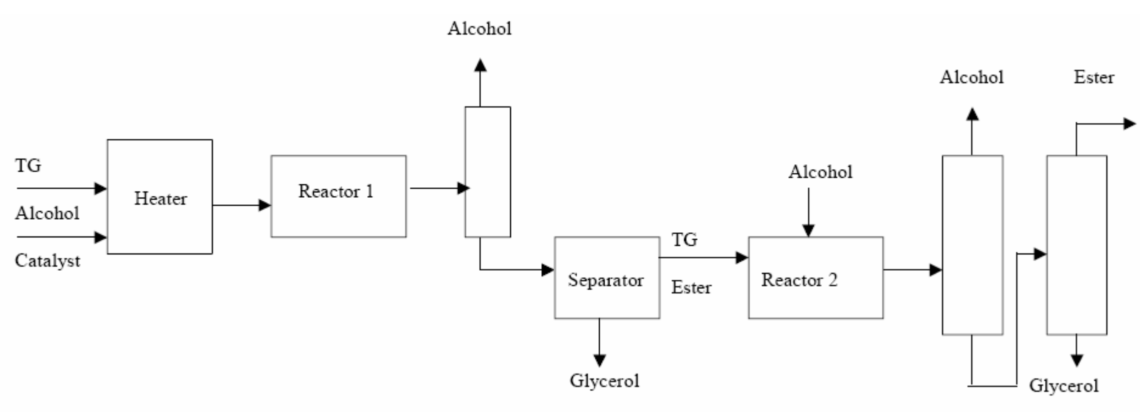
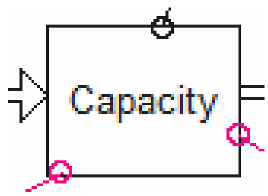
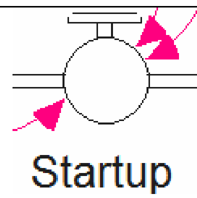
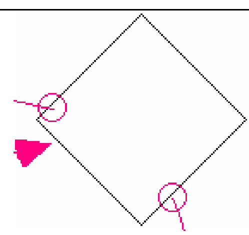
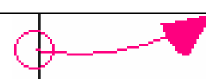



Figure 34: Process flow diagram - Plug flow reactor (typical)
Source: van Gerpen et al. (2004)

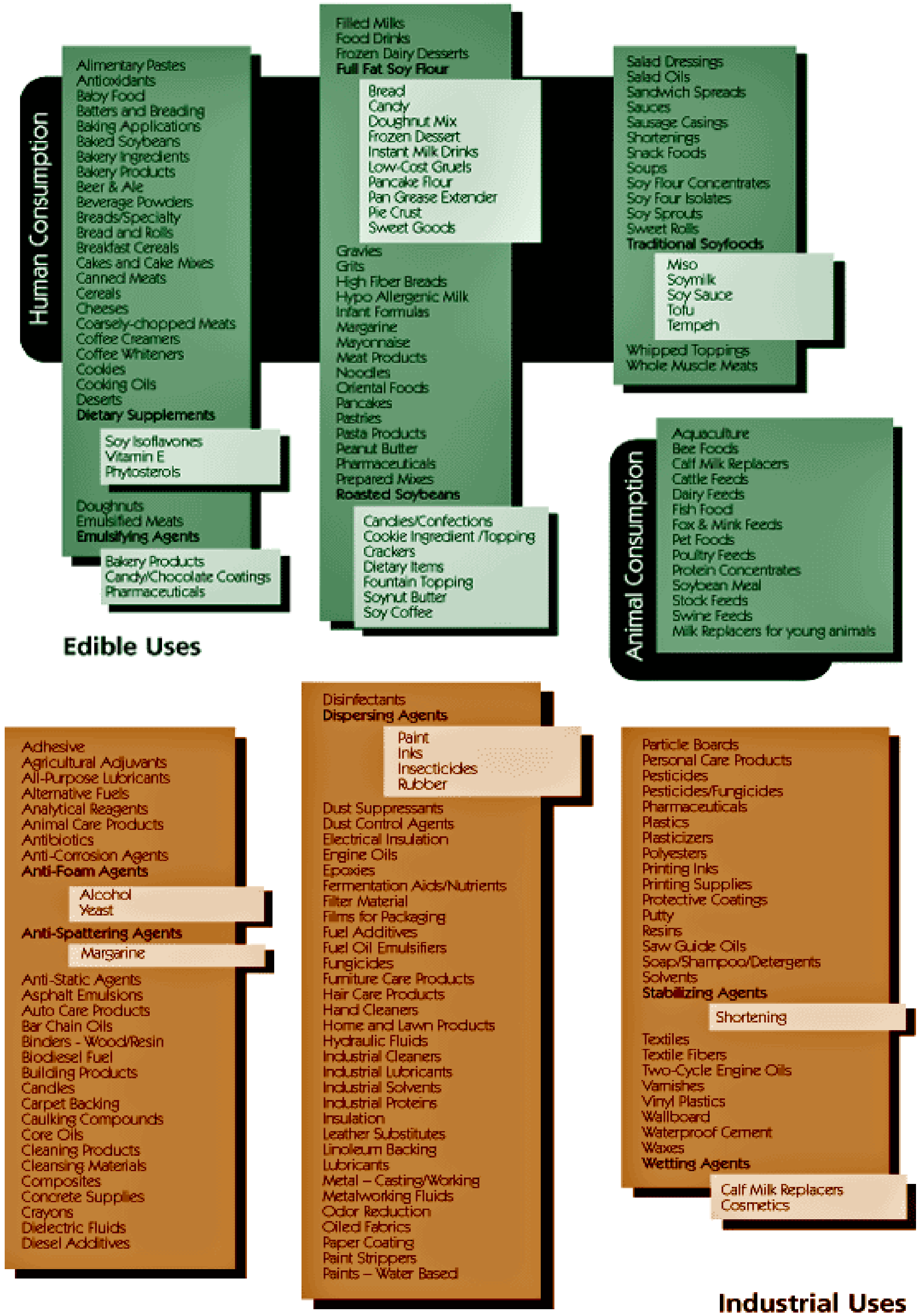
Appendix C:  STELLA™ Stock and Flow Symbology

**Table 6: STELLA™ stock and flow overview**

| Name | Symbol | Use |
|---|---|---|
| **Stocks** |   | Accumulates the "stuff" you are modeling such as money, materials, capacity, energy, etc. (flows in – flows out). Stocks can also be linked to other model components using connectors. |
| **Flows** |   | Defines the rate at which the "stuff" moves in and out of the Stocks |
| **Converters** |   | Variables and constants that are all the other model variables that are not Stocks or Flows.  STELLA™ provides a large library of built-in calculations and graphical user input. |
| **Decision Blocks** |  | Used to encapsulate important decision making processes in the model. |
| **Connectors** |  | Links model components |

Appendix D: Soybean Uses

Figure 35: Soybean Usage
Source: American Soybean Association



References

American Soybean Association (ASA) Web site. Accessed on Feb 14, 2007. http://www.asa.org

Ash, M., Livezey, J., & Dohlman, E. (2006, April). *Soybean Backgrounder*. Outlook Report No. (OCS-200601). Retrieved August 23, 2006, from US Department of Agriculture, Economic Research Service Web site: http://www.ers.usda.gov/publications/OCS/apr06/OCS200601/

Baize, J. (2006a, February 17).*The Outlook and Impact of Biodiesel on the Oilseeds Sector*. Presented at USDA Outlook Conference in Arlington, VA. Retrieved January 25, 2007 from http://www.usda.gov/oce/forum/2006_speeches.htm

Baize, J. (2006b, October 18). *The global biodiesel industry: A road to riches or an impending train wreck?* Presented at the 2006 American Fats & Oils Association Annual Meeting in New York. Retrieved March 18, 2007 from http://www.afoaonline.org/annualmeeting/slides/AFOA_keynote_presentation_10-18-06.ppt

Biodiesel Magazine. (2007). *Online US biodiesel plant list.* Retrieved Feb 14, 2007 from Biodiesel Magazine Web site. http://www.biodieselmagazine.com/plant-list.jsp

Blondeau, J., Pon, G., Bresciani, S., & Reaney, M. (2006). *Bio-Oils Market Study-Executive Summary*. Retrieved February 18, 2006 from http://res2.agr.ca/saskatoon/result/biooils-biohuile_e.htm#glycer

Bondioli, P. (2003, May 15). *From oilseeds to industrial products: present and next future of oleochemistry*. Presented at International South Europe Symposium Non-Food Crops: From Agriculture to Industry, Bologna, Italy. Retrieved February 20, 2006 from http://www.ienica.net/italyseminar/oils/bondiolipresentation.pdf

Bonnardeaux, J. (2006). *Glycerin Overview*. Retrieved March 25, 2007, from Government of Western Australia Department of Agriculture and Food Web site: http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/SUST/BIOFUEL/GLYCERINOVERVIEW.pdf

Bowman, M. S. (1999). *Applied Economics Analysis*. Upper Saddle River, NJ: Prentice Hall.

Bowman, K. (2003). *Economic Impact of Soy Diesel in Kentucky.* Retrieved February 12, 2006 from http://www.biog-3000.com/PDFs/NEW%20files/biodieselstudy.pdf

Broehl, J. (2006, February 17). The US biodiesel industry matures. *RenewableEnergyAccess.com*. Retrieved February 20, 2006 from http://www.renewableenergyaccess.com/rea/news/story?id=43614

Bryan, M. (2006, Feb 2006). Corn oil extraction can help sustain biodiesel industry growth. *Biodiesel Magazine,* 3 (2).70.

Bryan, T. (2007, Mar 2007). Will 2 billion gallons be a floor or a ceiling? *Biodiesel Magazine,* 4 (3). 8.

Caparella, T. (2005, October 2005). Minnesota mandate takes effect, and IRS clarifies tax incentive issues. *Render Magazine.* Retrieved March 20, 2006 from http://www.rendermagazine.com/October2005/BiodieselBulletin.html

Carlson, R. (2006). *Prospects for Expansion of the Soy-based Biodiesel Industry in Minnesota*. Agricultural Utilization Research Institute. Marshall, Minnesota. Retrieved February 14, 2007 from http://www.auri.org/research/diesel/pdfs/Executive%20Summary%20Bio-Diesel%20Study%20December%2006.pdf

Clark, G. (2006, December 31). Biodiesel is transitional technology says Nextant. *Biofuel Review*. Retrieved from http://www.biofuelreview.com/content/view/705/

Collins, K. (2006, August 26). *Economic Issues Related to Biofuels*. Written testimony to U.S. Senate Committee on Appropriations Subcommittee on Agriculture, Rural Development, and Related Agencies. Retrieved October 26, 2006, from the USDA, Office of the Chief Economist Web site: http//:www.usda.gov/oce/newsroom/congressional_testimony/sentstbiofuels8-26-06_.doc

Collier, C. A., & Glagola, C. R. (1998). *Engineering economic and cost analysis* (Third ed). Menlo Park, California: Addison-Wesley.

Conrad, S. H. (2004, July 25). *The dynamics of agricultural commodities and their responses to disruptions of considerable magnitude*. Proceedings of the 2004 International Conference of the System Dynamics Society. Oxford, England.

Conway, R. (2007, February 23). *Roger Conway: Office of Energy Policy New Uses/USDA*. Presented at the Texas AG Forum Austin, Texas. Retrieved March 23, 2007, from http://agforum.tamu.edu/2007presentations/Conway.pdf

Dale, B. E. (2004, February 23). *Feed protein coproduction with large scale biofuels: Some land resource perspectives & likely economic impacts*. Presented at Role of Biomass in America's Energy Future, Washington, D. C. Retrieved August 26, 2006 from http://engineering.dartmouth.edu/rbaef/meeting/dale_ppt.pdf

Davis, K. S. (2001, September 11). *Corn Milling, Processing and Generation of Co-products.* Presented at the Minnesota Nutrition Conference Technical Symposium. Retrieved from http://www.distillersgrains.org/files/grains/K.Davis--Dry&WetMillProcessing.pdf

Davis, S.C. & Diegel, S.W. (2006). *Transportation Energy Data Book*. ORNL-6974. (Edition 25 of ORNL-5198). Center for Transportation Analysis. Oak Ridge National Laboratory. U.S. Department of Energy. Oak Ridge, TN.

De La Torre Ugarte, D. G., English, B.C., Jensen, K., Hellwinckel, C., Menard, J., and Wilson, B. (2006). *Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion*. Retrieved Jan 7, 2007, from Governors Ethanol Coalition Web site : http://www.ethanol-gec.org/information/Ethanolagimpacts.pdf

Duff, B. (2004, November 16). *Biofuels Project Development: Biodiesel Feasibility Studies*. Presented at the Virginia Biodiesel Conference, Harrisonburg, Virginia. Retrieved March 15, 2006 from http://www.cisat.jmu.edu/biodiesel/presentations/Feasibilty%20Studies%20-%20Duff%201120a%20presentation.ppt

Duffield, J. A. (2006, September 8). *Biodiesel Supply: How Much Can We Produce?* Presented at the Air Quality and Alternative Transportation Fuel Forum, Washington DC.

Edmonds, J., & Reilly, J. M. (1985). *Global energy: Assessing the Future*. New York: Oxford University Press.

Eidman, V. (2006a, 1st Qtr 2006). Renewable Liquid Fuels: Current Situation and Prospects. *Choices,* 21(1). Retrieved March 16, 2006 from http://www.choicesmagazine.org/2006-1/biofuels/2006-1-03.html

Eidman, V. (2006b, June 27). *The Economics of Energy Production in Agriculture*. Paper presented at the “Energy in Agriculture: Managing the Risk” Conference, Kansas City, Missouri. Retrieved January 10, 2007, from Farm Foundation Web site: http://www.farmfoundation.org/projects/documents/Eidmanpaperwithgraphs.pdf

English, B., Jensen, K., & Menard, J. (2002). *Economic Feasibility of Producing Biodiesel in Tennessee*. Retrieved November 14, 2005 from University of Tennessee, Department of Agricultural Economics Web site: http://beag.ag.utkedu/pp/biodiesel.pdf

English, B., De La Torre Ugarte, D. G., Hellwinckel, C., Menard, R. J.,Wilson, B., Roberts, R., and Walsh, M.E. (2006). *25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts*. Retrieved December 1, 2006 from University of Tennessee, Agricultural Policy Analysis Center Web site: http://www.agpolicy.org/ppap/REPORT%2025x25.pdf

Environmental Protection Agency (EPA). (2006*). Renewable Fuel Standard Draft Regulatory Impact Assessment*. Retrieved November 1, 2006, from EPA Fuels and Fuel Additives Website: http://www.epa.gov/oms/renewablefuels/420f06060.htm

Food and Agriculture Organization of the United Nations (FAO) Web site. Accessed January 15, 2007 online at http://faostat.fao.org/

Ford, A. (2002, June 2002). Boom & bust in power plant construction: Lessons from the California electricity crisis. *Journal of Industry, Competition and Trade.* 2(1). Retrieved September 28, 2005, from Washington State University, School of Earth and Environmental Sciences Website: http://www.wsu.edu/~forda/JournalofIndustry.pdf

Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge MA: Productivity Press.

Forrester, J. W. (1971). *World dynamics*. Cambridge, MA: Wright-Allen Press, Inc.

Forrester, J. W. (1975). Collected Papers of Jay W. Forrester. Cambridge MA: Productivity Press.

Forrester, J. W. (1968). *Principles of systems*. Cambridge, MA: Wright-Allen Press, Inc.

Fortenberry, T. (2005). *Biodiesel Feasibility Study: An Evaluation of Biodiesel Feasibility in Wisconsin*. University of Wisconsin-Madison, Department of Agricultural & Applied Economics, Staff Paper No. 481.

Gerard, B. (2006, Jan 2006). Feedstock change is hot and poppin'*, Chemical Processing Magazine*. Jan 2006. Retrieved March 23, 2006 from http://www.chemicalprocessing.com/articles/2006/010.html

Gorley, V. (2006, February 15). Harvest Provides Fuel for Soybean Farmer. *Charlottesville Daily Progress.*

Greene, N. (2004). *Growing energy: How Biofuels Can Help End America's Oil Dependence.* Retrieved July 17, 2006, from Natural Resources Defense Council Web site: http://www.nrdc.org/air/energy/biofuels/biofuels.pdf

GreenShift Corporation (2005, December 22). *GreenShift's Mean Announces 30 Million Gallon Biodiesel Plant in North-Eastern Indiana*. Press Release. Retrieved January 1, 2006 from: http://www.greenshift.com/news.php?id=101

Haas, M.J., Mcaloon, A.J., Yee, W.C., Foglia, T.A. (2006). *A process model to estimate biodiesel production costs*. Bioresource Technology. 97:671-678.

Hamilton, J. (2007, March 28). *NBB and EPA: Where are we going together?* Presented at the EPA Mobile Sources Technical Review Subcommittee Meeting in Arlington, Virginia.

Howell, S., & Weber, A. (2005, March 17). *Biodiesel Plant Investment: Making the Correct Decisions.* Presented at the Iowa Farm Bureau Soy Biodiesel Meeting. Retrieved November 12, 2006, from Iowa Farm Bureau Web site: http://www.iowafarmbureau.com/programs/commodity/energy/Biodiesel%20Plant%20Development%20Considerations.ppt

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science Basis. Summary for Policymakers*. Retrieved February 10, 2007, from the Intergovernmental Panel on Climate Change Web site: http://www.ipcc.ch/SPM2feb07.pdf

International Energy Agency (IEA) (2004), *Biofuels for transport: An international perspective.* Retrieved August 15, 2006, from the International Energy Agency Web site: http://www.iea.org/books

Irwin, L. (2006, Oct 2006). Forecasting the Future. *Ethanol Producer Magazine,* 12 (8). 24.

Jaffe, S. (2005). Biodiesel: A new way of turning plants into fuel. *Technology Review.* Retrieved November 12, 2006 from http://www.technologyreview.com/articles/05/06/wo/wo_060705jaffe.asp?trk=nl

Jones, A., Seville, D., & Meadows, D. H. (2002). Resources sustainability in commodity systems: The sawmill industry in the northern forest. *System Dynamics Review, 18*(2), 171-204.

Koplow, D. (2006). *Government support for ethanol and biodiesel in the United States: Biofuels – at what cost?* Retrieved January 5, 2007 from Earth Track Web site: http://www.earthtrack.net/earthtrack/library/biofuels_subsidies_us.pdf

Kortba, R. (2006, February 2006). Everything under the sun. *Biodiesel Magazine.* 3(2), 28-34.

McClinton, L. (2006, February 2006). Converting bio-diesel co-products into value. *Bio-Prospects,* 3(1). Retrieved August 23,2006 from http://www.agwest.sk.ca/publications/documents/BPFeb06_000.rtf

McMillen, S., Shaw, P., Jolly, N., Goulding, B., Finkle, V., & Broehl, J. (2005). *Biodiesel: Fuel for thought, fuel for Connecticut's future*. Retreived February 11, 2006, from Connecticut Center for Economic Analysis Web site: http://ccea.uconn.edu/studies/Biodiesel%20Report.pdf

McCoy, M. (2006, Feb., 6). Glycerin Surplus: Plants are closing, and new uses for the chemical are being found. *Chemical & Engineering News*, 84 (6). p. 7 , Retrieved from http://pubs.acs.org/isubscribe/journals/cen/84/i06/html/8406notw3.html

Meadows, D. L. (1970). *Dynamics of Commodity Production cycles.* Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. L., Behrens, William W. III, Randers, Donella H., Naill, R. F., Randers, J., & Erich K. O. Zahn. (1974). *Dynamics of growth in a finite world*. Cambridge, MA: Wright-Allen Press, Inc.

Meadows, D. H., Randers, J., & Meadows, D. L. (2004). *Limits to growth: The 30-year update.* Vermont: Chelsea Green.

Meeker, D. L (2006). *Essential rendering: all about the animal by-products industry*. Arlington,Virginia: Kirby Lithographic Company, Inc.

National Biodiesel Board (NBB) Web site. Accessed on Feb 7, 2007. http//:www.biodiesel.org

National Corn Growers Association (NCGA) Web site. Accessed on Feb 14, 2007. http//:www.ncga.org

National Renderers Association Web site. Accessed on May 30, 2006. http://www.renderers.org/Statistics/98-05%20prodn-consum.pdf

Neville, D., Wright, D., Rice, P., Sweitzer, S., Jones, A., & Hamilton, H. et al. (2003). *Commodity systems challenges: Moving sustainability into the mainstream of natural resource economies.* Vermont: Sustainability Institute. Retrieved August 21, 2005 from http://www.sustainabilityinstitute.org/pubs/SustainableCommoditySys.2.1.pdf

Nilles, D. (2007, Feb. 2007). NBB stresses quality while aiming for 5 percent market penetration by 2015. *Biodiesel Magazine.* 4(2), 55.

Organisation for Economic Co-operation and Development (OECD). (2005). *Agricultural market impacts of future growth in the production of biofuels*. Working Party on Agricultural Policies and Markets. Paris: OECD. Retrieved from http://www.oecd.org/dataoecd/58/62/36074135.pdf

Orr, J. (2004). *Exploiting clean energy for profit: The Outlook on the Current Biofuels Industry*. Retrieved August 12, 2006, from http://www.newfarm.org/features/0604/biofuels/index.shtml

Pahl, G. (2005). *Biodiesel: growing a new energy economy*. White River Junction, VT: Chelsea Green Publishing.

Pearl, G. (2004, Aug 2004). Rendering 101: Raw material, rendering process, and animal by-products. *Render Magazine.* Retrieved September 15, 2006, from http://www.rendermagazine.com/August2004/Rendering101.pdf

Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J. & Erbach, D.C. (2005) *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Oak Ridge Natl. Lab., Oak Ridge, TN), ORNL Publ. No. TM-2005-66.

Promar International (2005). *Evaluation and Analysis of Vegetable Oil Markets: The Implications of Increased Demand for Industrial Use on Markets and USB Strategy.* Retrieved December 10, 2006, from http://www.unitedsoybean.org/Library/Studies.aspx

Radich, A. (2002). *Biodiesel Production Methods, Costs and Available Capacity*. Retrieved February 23, 2006, from http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/

Reaney, M. J., Furtan, W. H., & Loutas, P. (2006). A Critical Cost Benefit Analysis of Oilseed Biodiesel in Canada. Retrieved March 31,2007, from the BIOCAP Canada Web site://www.biocap.ca/rif/report/Reaney_M.pdf

Renewable Fuels Association (RFA). (2007). U.S. fuel ethanol industry biorefineries and production capacity. Retrieved March 7, 2007, from Renewable Fuels Association Web site: http://www.ethanolrfa.org/industry/locations/

Riley, W. W. (2004). *The Canadian biodiesel industry: An analysis of potential feedstocks.* Paper prepared for the Biodiesel Association of Canada. Retrieved December 15, 2006 from http://www.greenfuels.org/main/biodiesel/pdf/res/102004_Potential_Feedstock_for_Canadian_Biodiesel_Industry.pdf

Roberts, P. (2004). *The end of oil: On the edge of a perilous new world*. New York: Houghton Mifflin.

Roberson, R. (2007, March 22). North Carolina biodiesel plant won't happen. *Southeast Farm Press.* Retrieved April 11, 2007 from http://southeastfarmpress.com/biofuels/032207-biodiesel-carolina/

Rowland, Robert C. (1997). *United States policy on renewable energy use: An overview of the issues related to increasing renewable energy use in the United States.* Lincolnwood, IL: The National Textbook Company.

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York: W.W. Norton & Co.

Sheehan, J., Dunahay, T., Benemann, J., & Roessler, P. (1998). *A look back at the US Department of Energy's aquatic species program: Biodiesel from Algae.* (Report No. NREL/TP-580-24190). Golden, CO: National Renewable Energy Lab.

Shumaker, G. A., McKissick, J., Ferland, C., & Doherty, B. (2001). *A study on the feasibility of biodiesel production in Georgia.*

Soy stats Web site. A reference guide to important soybean facts & figures. Accessed on March 14, 2006. http://www.soystats.com

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world.* McGraw-Hill/Irwin.

Sterman, J. (2002, Winter 2002). All models are wrong: reflections on becoming a systems scientist. *System Dynamics Review*, 18(4), 501–531.

Stroup, R. L. (2004, Jan/Feb 2004). Feedstock Considers for Future US Producers. *Biodiesel Magazine.*1(1).

Tesch, T., Descamps, P.T.& Weiler, R. (2003, September 21).The COSMOPAD modelling framework: Conceptual system dynamics model of planetary agricultural & biomass development. Presented at the Conference Digital Earth2003, BRNO, Czech Republic.

Tickell, J. (2003). *From the fryer to the fuel tank: the complete guide to using vegetable oil as an alternative fuel*. New Orleans, LA: Joshua Tickell Media Productions.

Tickell, J. (2006). *Biodiesel America*. USA: Yorkshire Press.

Tyson, K. S., Bozell, J., Wallace, R., Petersen, E., & Moens, L. (2004). *Biomass oil analysis: Research needs and recommendations*. (Report No. NREL/TP-510-34796). Golden, CO: National Renewable Energy Lab.

US Department of Agriculture, Economic Research Service (USDA-ERS). (2007). *Oil Crops Situation and Outlook Yearbook*. Retrieved January 12, 2007 from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1288
.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2004). *2002 Census of Agriculture: United States Summary and State Data,* Volume 1, Geographic Area Series, Part 51. Retrieved March 23,2006, from http://www.nass.usda.gov/Census_of_Agriculture/index.asp.

US Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). (2006). *Statistical Highlights of United States Agriculture, 2005/2006.*Retrieved Aug 27, 2006, from http://www.nass.usda.gov/Publications/Statistical_Highlights/2006/STATHI2006.PDF

US Department of Agriculture, Office of the Chief Economist. (USDA-OCE) (2007). *USDA Agricultural Projections to 2016.* World Agricultural Outlook Board, Long-term Projections Report OCE-2007-1 February 2007 Retrieved March 1, 2007, from http://www.ers.usda.gov/publications/oce071/oce20071.pdf

US Department of Energy, Energy Efficiency and Renewable Energy-Alternative Fuels Data Center (USDOE-EERE). (2007). Clean Cities alternative fuel price reports. Accessed on Feb 5, 2007: http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2007). *Annual Energy Outlook 2007 with Projections to 2030*. DOE/EIA-0383. Retrieved February 15, 2007, from http://www.eia.doe.gov/oiaf/aeo/index.html

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006a). International Energy Annual 2004. Retrieved March 10, 2007 from http://www.eia.doe.gov/iea/

US Department of Energy, Energy Information Administration (USDOE-EIA). (2006b). Energy Information Administration (EIA). Petroleum Overview, 1949-2002. Table 5.1. in Annual Energy Review. Retrieved January 15, 2007 from http://www.eia.doe.gov/emeu/aer/petro.html

US Department of Energy, Office of Biomass Programs (USDOE-OBP) (2006) Biomass Transition Model Workshop Website. Accessed November 15, 2006. http://30x30workshop.biomass.govtools.us/default.aspx?menu=model

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2005). *Building a Successful Biodiesel Business.* Golden, CO: National Renewable Energy Lab.

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004). *Biodiesel Analytical Methods August 2002 - January 2004.* (Report No. SR-510-36240). National Renewable Energy Lab.

Wang, M. (2007). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model Version 1.7. Retrieved March 10, 2007, from the US Department of Energy, Argonne National Laboratory Web site: http://www.transportation.anl.gov/software/GREET/

Weber, J. A. (2007). MARC IV Consulting. Telephone conversation with Steve Bantz March 12, 2007.

Whelan, J., & Msefer, K. (1996). *Economic Supply and Demand.* Retrieved from http://sysdyn.clexchange.org/sdep/Roadmaps/RM6/D-4388.pdf

White, A. S., Yan, Y. C. , Akpunar, E., & Hock, K. K. (2002, July). *Control Strategies for Inventory Management*. Proceedings of the 2002 International Conference of the System Dynamics Society. Palermo, Sicily, July 2002.

Wilson, J. (2007). US Farmers Plan Biggest Corn Planting Since 1944. *Bloomberg.com*. Retrieved March 30, 2007, from http://www.bloomberg.com/apps/news/?pid=20670001&refer=home&sid=ag_W9jQ.1Aoc

Young, N. (2006, January 2006). *Biodiesel & industrial demand for soy oil: study conducted to examine implications for soybean farmers & USB strategy*. Presented at the Qualsoy Board Meeting. Retrieved April 10, 2006, from http://www.unitedsoybean.org/studies_pdf/2005_Promar_Qualsoy.ppt

Zagonel, A. A., Conrad, S. H., & Kaplan, P. G. (2005, July 17). *Modeling the impact of loss in U.S. soybean production resulting from soy rust disease.* Presented at the 23rd International Conference of the System Dynamics Society, Boston, MA. Retrieved February 19, 2006, from the System Dynamics Society Web site: http://www.albany.edu/cpr/sds/conf2005/proceed/proceed.pdf

Zeman, N. (2007, Feb. 2007). Crazy for camelina. *Biodiesel Magazine.* 4(2), 60.