Understanding U.S. Biodiesel Industry Growth using System Dynamics Modeling

Steven G. Bantz and Dr. Michael L. Deaton

Abstract—**The production capacity of the biodiesel industry is experiencing exponential growth. Demand is driven by environmental, social, and economic factors and helped along by government mandates and incentives. Suppliers are having difficulty keeping up with demand. The U.S. production capacity has grown by a factor of ten in the past two years, and between thirty and forty new plants are currently in or near construction phase. Continued strong growth of biodiesel production capacity depends on producer/supplier profitability, which will be influenced by several factors such as biomass oil feedstock prices, product/co-product prices, production technologies, and government regulations/incentives. How, why, and to what extent will the growth of the biodiesel industry be influenced by these factors? To explore possible answers to these questions, we describe the formulation of a system dynamics model of the U.S. biodiesel marketplace. The construction and use of this model will provide a framework for understanding the causal-loop/feedback structure and dynamics of this industry and how changes in key variables (e.g. feedstock price or change in government incentives) impact growth. Using system dynamics modeling, we envision and put into perspective the possible growth behavior scenarios for this industry over the next decade.**

I. Introduction

IN his 2006 State of the Union address, President Bush pronounced that the U.S. is "addicted to oil" and that biofuels may be part of the solution to our problem [2]. Like all complex problems, there is not one easy answer to our dependence on fossil fuels, and solutions should address both the supply and the demand sides of the equation. The solutions need to be multi-faceted, economically feasible, and sustainable. To displace a portion of our petroleum–based fuel consumption, ethanol and biodiesel are growing at a rapid pace. In this paper, we describe a system dynamics model to better understand the complexities of the growing biodiesel market and to elucidate the dynamics that could lead either to the successful growth or to a possible "bust" of that market. The exponential growth trajectory based on current plant capacity growth [1] is shown in Fig. 1 as trend line (A) (capacity is the maximum potential for production and not the actual production). Industry analysts are skeptical that this trajectory can be continued for an extended period because of feedstock limitations [3]. Hence, we explore the dynamics that could lead to various growth patterns (Fig 1). Will the production capacity grow smoothly (B), or will it encounter "boom and bust" cycles (C)? Will explosive growth occur in the near future (E) because of some new technological advance or unforeseen market shift? Or will it grow too fast, exhibiting an "overshoot and collapse" behavior (D)? Under what conditions might each of these trajectories be realized? The growth scenarios that the model enables us to envision are not predictions of the future but provide starting points for discussion of alternative outcomes.

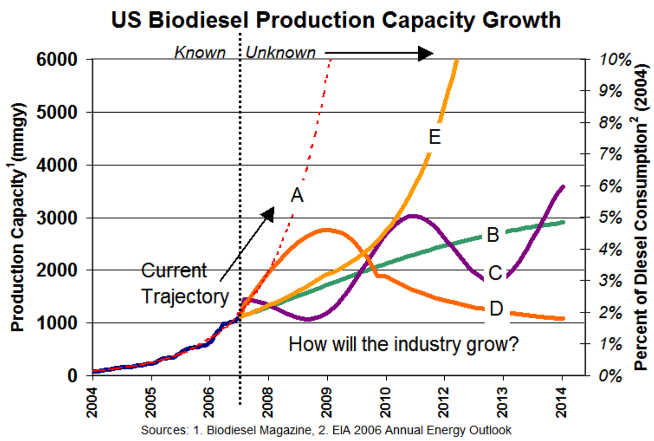

Fig. 1. Scenarios of future behavior patterns of biodiesel industry growth.

This research employs a holistic or ***systems*** view of the U.S. biodiesel industry - an approach not found in the numerous individual, state, or regional feasibility studies [4],[5]. Biodiesel industry participants and government officials should find this analysis useful for understanding the dynamics that are likely to drive this industry over the next several years. With this understanding, they may influence policy and business decisions to help this industry continue its strong growth pattern.

In the following sections, we outline the conceptual framework, on which the model is based, and describe the ongoing modeling process. We begin by defining the problem that this research addresses: to determine the impact of several key factors on the viability of the biodiesel industry. First we summarize the recent and anticipated growth in biodiesel production capacity. Then we describe the production process in order to establish the rationale for paying special attention to the feedstock supply. Next we formulate a system dynamics analysis of the problem by outlining those causal relationships and feedback dynamics that will likely play a significant role in the future of the industry [6]. These dynamic relationships are incorporated into a running model that is currently being tested, verified, and validated.

II. BACKGROUND

Biodiesel is produced by chemically modifying renewable, biologically based (biomass) oil or fats by reacting them with methanol+catalyst and then separating/purifying the reaction products as shown in Fig 2. This reaction also produces glycerol and fatty acids as co-products. Biodiesel can be used to displace petroleum-based fuel in diesel engines, which account for approximately 22% of the fuel consumed in the transportation sector [7]. It can be also be used in other combustion equipment (e.g., boilers and heaters) as a replacement for petroleum distillate oil fuels. As seen in Fig. 2, the current conventional feedstock sources for producing biodiesel are oil crops (e.g., soybean, canola), waste vegetable oils from restaurants and other food processing plants, or animal fats. Proposed unconventional (not yet commercially available) feedstock sources include oil extracted from wastewater sludge, algae, and corn oil from ethanol processing.

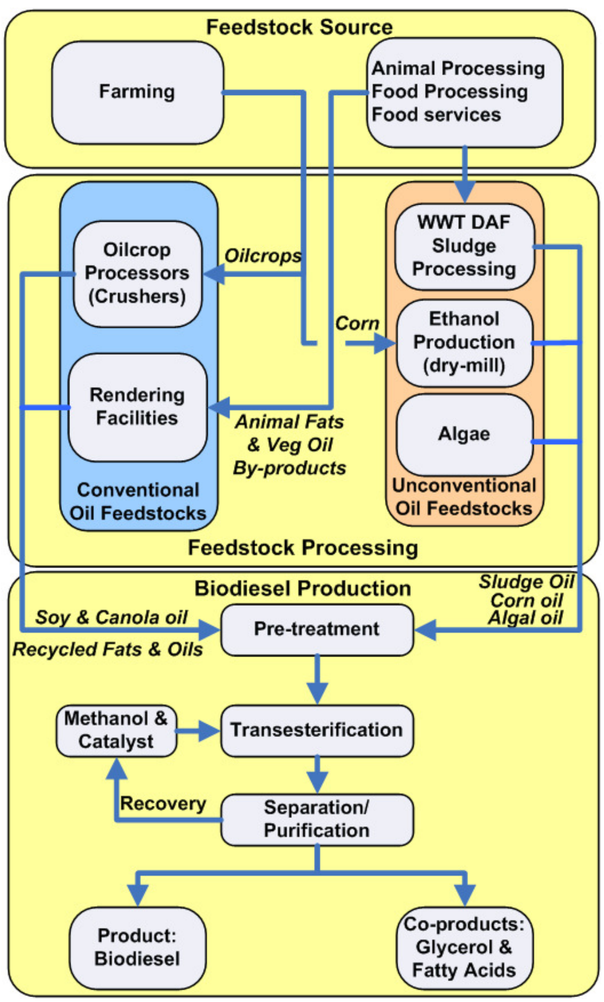

Fig. 2. Biodiesel Production Process and Feedstock Sources

The continued growth in biodiesel production capacity will be affected most by factors that impact the profitability of the producers and suppliers, mainly:

- Biomass oil feedstock availability
- Biodiesel/diesel and glycerol prices
- Government regulations and incentives

Of particular interest is the first item – biomass oil feedstock availability. As shown in Fig. 3, in 2004, biodiesel demand accounted for less than 1% of the total biomass oil produced in the U.S. By the end of 2007, as new biodiesel plants come online, the biodiesel demand for biomass oil will require an additional 20% more than the projected total biomass oil production. If the supply does not grow to meet the additional demand, supply shortages and price increases will occur.

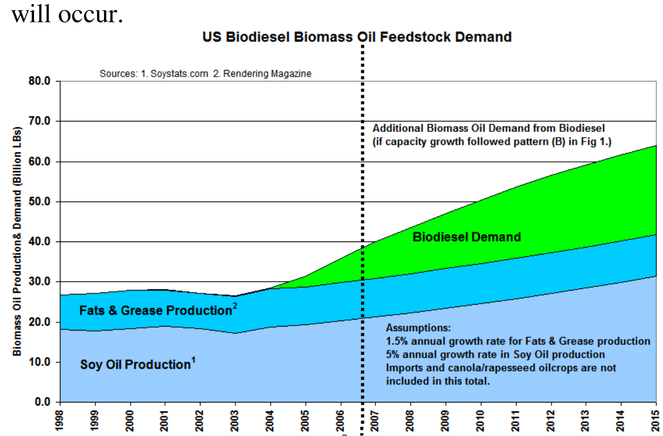

Fig. 3. Biomass oil production with additional biodiesel demand

Scientists at the National Renewable Energy Lab (NREL) forecast that the agriculture industry will be flexible enough to respond to this demand change and cite the 25% increase in soy production from 1998-2003 [8]. However, a study by Promar International [9] suggests that this demand increase will cause global vegetable oil prices to rise significantly. This 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 operation profitable. To be sure, many have recognized this problem and are shifting new plants to multi-feedstock processing capability (i.e., they can process cheaper, lower quality feedstocks). However, those feedstocks supplies are also used in other markets and not expected to grow significantly [10]. The potential for a feedstock shortage to impact the growth of the biodiesel market is generally recognized [11], but, to date, few understand the extent or size of the risk.

III. MODEL CONCEPTUALIZATION

A. *Biodiesel Industry Growth*

Two sources of information can help us envision the future behavior of the biodiesel industry: historical data and knowledge of the structure/dynamics of the current system. Importantly, a system dynamics approach differs from other economic modeling approaches by including feedback.

When conceptualizing a model to help solve a problem,

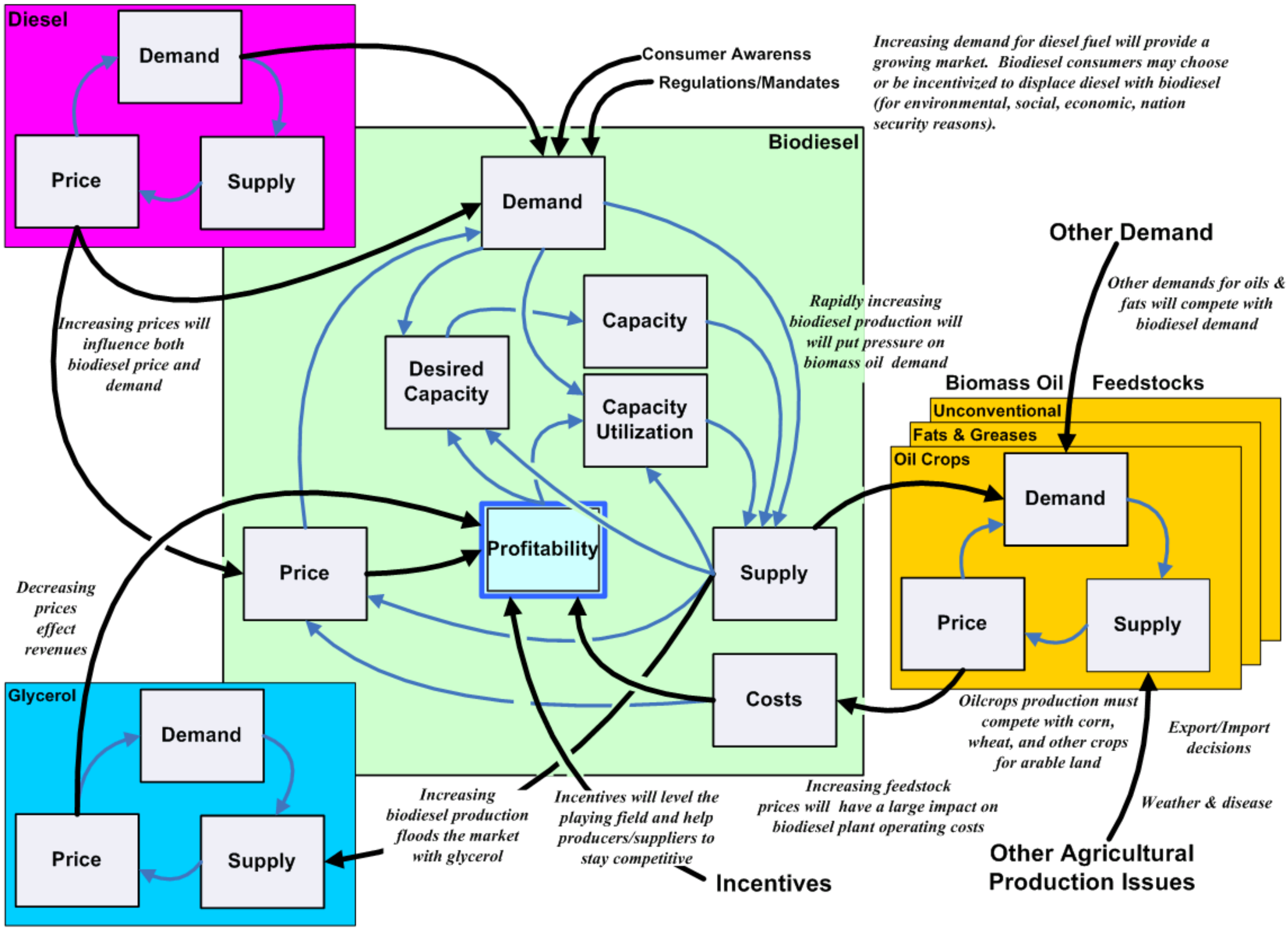

Fig. 4. Biodiesel Market Overview Diagram shows the interconnections between biodiesel and other markets-diesel,biomass oil feedstocks, and glycerol

one must ask: How is the system structured? What are the boundaries of the system? What are the key input and output variables? What is important and what is not? [6]. In Fig. 4, we illustrate the important market sectors and interrelationships that directly impact the U.S. biodiesel industry. In the following sections, we examine these causal relationships and their impact on the specific variables in the biodiesel industry.

B. Growth Drivers

Before examining the factors potentially limiting biodiesel industry growth, let us examine Fig. 4 to better understand what is driving the current exponential growth. The market for diesel/distillate fuels (upper left segment in Figure 4) is growing at a rate faster than other fuel segments [7]. The impetus to switch to a renewable replacement to meet a portion of this demand is influenced by many factors such as concerns about U.S. energy security, consumer awareness of environmental and economic issues, and other regulations/mandates that promote use. Government efforts over the past several years have created the demand "suction" for biodiesel, which has paid off because it has attracted many investors who see an opportunity to enter a market where the demand outstrips the supply. Moreover, these producers/suppliers are currently rewarded by various incentives aimed at leveling the playing field for a fledgling industry. The result has been a ten-fold increase in production capacity over the past two years and another thirty to forty new plants currently in or near construction phase [1]. Will there be enough biomass feedstocks to meet this need?

C. Biomass Oil Feedstocks

The current conventional biomass feedstocks can be virgin vegetable oil crops, animal fats, or waste oils and greases. Why is the biomass feedstock issue so important to this industry? First, the choice of feedstock affects the capital investment decisions that business leaders make when deciding to build a plant. The lower quality feedstocks require more processing equipment and, therefore, more investment if multiple feedstock flexibility is desired. Second, on average 70-80% of operating costs are in the feedstocks [11]. Therefore, having the option to process lower quality, cheaper feedstock may help keep production profitable, but we must also consider the negative impacts of using lower quality feedstock. For example, using certain lower quality feedstocks will affect the amount of sale-able glycerol co-product produced [11]. This, in turn, would decrease potential revenue streams. Furthermore, lower quality feedstocks may have detrimental effects on the performance of the biodiesel fuel in cold temperatures [10]. Also, since lower quality feedstocks require more processing, the potential for product quality problems is higher. The greatest uncertainty is the future availability/price of the various types of biomass oil feedstocks. The availability can be increased through yield improvements, increased planted acres, alternative oil crops (e.g.,canola, jatropha), new biomass oil resources (e.g., algae) or a change in demand by other users [10].

D. Agri-production Interactions: Ethanol-Biodiesel

Although biodiesel and ethanol use different biomass feedstocks (oil vs. starch), both industries impact one another because they compete for the same acreage for crop production and, in some cases, for the same end-use markets. For example, a co-product from the dry mill ethanol production process, dry distillers grains (DDG), can be used as a substitute for soy meal in animal feed [12]. As the ethanol production increases, the production of DDG increases and takes away animal feed market share from soy meal. Therefore, the production of ethanol could have an impact on soybean oil production by a) decreasing the soy meal demand, and b) decreasing the acres planted in soy. This reduction in the soy acres planted is seen in the planted crop area trends forecasted by the U.S.D.A. [13]. However, the data for the 2006 planting season indicate plant acres for soy increasing by 5% and corn decreasing by 3% [14]. If our hypothesis and the U.S.D.A. forecast prove true, soybean production will decrease resulting in higher soy oil prices. These negative effects can be minimized by a) increasing cellulosic ethanol production in order to shift the ethanol feedstock away from corn and make more arable land available for soy or other oil crops, or b) developing new technologies for the production of corn oil from the drymill ethanol process to be used for biodiesel production [15].

E. Glycerol Glut

Glycerol is a co-product of biodiesel production and can be sold in a crude or refined form. Refined glycerol is more expensive to produce, but it is also much more valuable on the market. Additional capital investment is required for refining capability. Refined glycerol is a commodity and is used in the production of hundreds of other products, but the glycerol price has been dropping in the past few years. Many in the chemical industry forecast the price to drop off even more and a serious overcapacity problem to develop as the biodiesel industry continues at its current growth rate [16]. The Department of Energy is currently promoting R&D for new uses of glycerol as one of the "top 12" bio-based chemicals [17]. This initiative may increase demand for glycerol and, thereby, help offset this price decrease.

F. Government Incentives

Currently, several federal and state incentives that affect biodiesel producer and distributor profitability are in place. Mainly, the Commodity Credit Corporation (CCC) provides feedstock rebates to biodiesel producers, and the Internal Revenue Service offers federal excise tax credits to fuel blenders. These government subsidies, made possible by persistent lobbying, have helped the industry flourish and are still necessary for profitability. Market-based advocates are continuously arguing for the removal of these subsidies, so the future is not guaranteed. We include these incentives in the model, along with other mandates and regulations, as exogenous variables that can be manipulated to simulate the effects they may have on the profitability of producers.

G. Diesel and Biodiesel Prices

Most consumers view diesel fuel as a commodity: the cheapest price wins. But biodiesel is a bit like organic food: many people are willing to pay a premium for the perceived benefits (to farmers, the economy, the environment, or national security). Therefore, the price/demand relationship is not straightforward to model. To further complicate the issue, the consumer purchase decision is not just "biodiesel vs. petrodiesel," because a majority of the biodiesel purchased will be blended with petrodiesel (2, 5, 10, & 20 percent). Hence, the blend price at the pump will be mostly dependent on petrodiesel, which is dependent on crude oil and on short-term supply issues. While rising diesel prices should dampen the overall demand for diesel, they should also increase the demand for biodiesel and allow suppliers to ask for a higher price. Ultimately, the biodiesel price must be high enough for producers to cover their manufacturing costs and for distributors to cover their added blending costs and for everyone to make a profit. The system dynamics model discussed in the next section provides the flexibility to experiment with various feedback structures and to understand complex causal relationships.

IV. Model Formulation, Testing, and Assessment

A. System Dynamics Model Overview

Now we need to turn these verbal and mental models into a working model, so that we can further examine the dynamics and run different simulation scenarios. Using system dynamics modeling methods and the software modeling tool STELLA™, we are able to model the Supply-Demand-Price and other causal relationships in a way that simply explains the feedback mechanisms and dynamics involved [18]. For organizational and troubleshooting purposes, the model is broken up into sectors that roughly follow the layout of the biodiesel market overview diagram shown in Fig 4. The STELLA™ model of the Biodiesel sector is shown in Fig 5. Much of the overall market structure is based on the stock and flow model developed by Sterman in [7]. As seen in Fig. 5, the biodiesel sector is split into two main stock and flow sections. In the capacity section, we model the construction, startup, operation, and shutdown of production capacity. This represents the cumulative U.S. plant capacity in million gallons per year (mmgy). In the remainder of this sector, we model the production and inventory of biodiesel and co-product glycerol.

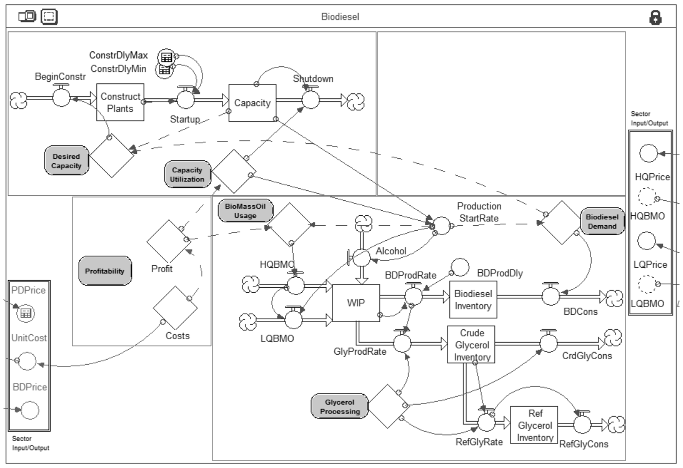

Fig. 5. STELLA™ Model Biodiesel Sector

The development and testing of the soy oil market sector (Fig. 6) provides insight into the agricultural planning, inventory management, time delays, and export/import issues that make an agricultural supply chain so complex.

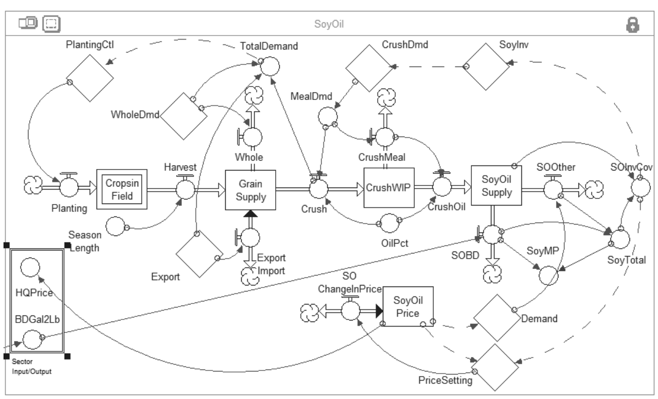

Fig. 6. STELLA™ Model Soy Oil Market Sector

B. Decision Blocks – Command and Control of the Model

In the STELLA™ decision blocks, we modeled the decision-making processes of the people in the industry. In formulating the model, we made assumptions that aggregated the micromotives of the individuals and the properties of the plants into macrobehaviors [19]. Future development of this model might include segregation of some of the model sections in order to use Agent-Based modeling techniques. In the decision blocks, policy is based on assessment of current and future profitability and sales-to-capacity ratios. For example, in the Oil Usage decision block, shown in Fig. 5, we model the decision making process of plant managers and engineers who will attempt to minimize production costs by using the cheaper feedstock, if possible. This decision is constrained by the reality that not all plants have the capability to process lower quality feedstocks.

C. Model Testing and Assessment

Keeping in mind Sterman's quote, "All models are wrong" [20], we must now demonstrate that our model is at least "right enough" to be useful. Model assessment can be 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 from users. For a young industry such as biodiesel, little historical data are available. Therefore, one must rely heavily on the analogies provided by similar industries and on an understanding of the underlying industry structure and decision-making process. The next step in the modeling process is to run scenarios and to review the simulation behavior with industry participants. The dashboard display in Fig. 7 shows the interface used to run different scenarios and to view model input and output.

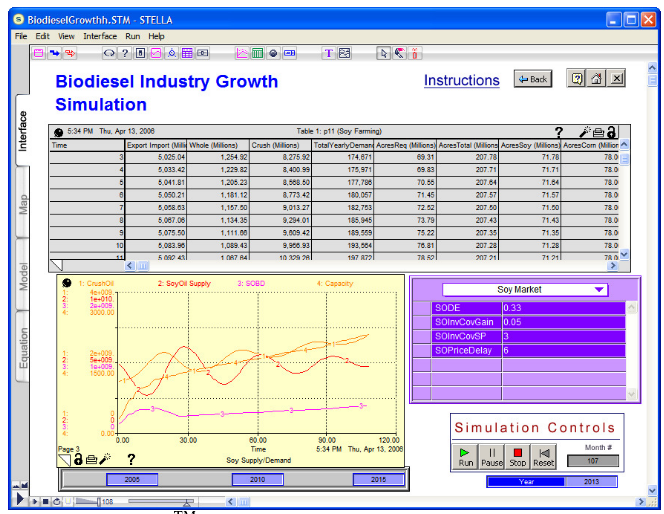

Fig. 7. STELLA™ Biodiesel Industry Growth Simulation User Interface

V. Conclusion

Understanding current and future growth patterns of the biodiesel industry requires taking a holistic view of the industry and analyzing key factors that influence profitability. Exploring various scenarios using modeling and simulation can be extremely helpful in understanding the rapidly changing biofuel industry and energy markets. In this paper, we describe the formulation of a system dynamics model to simulate the behavior of the U.S. biodiesel industry over the next decade. However, because of the uncertainty involved, these scenarios should be viewed as benchmarks or conditional statements about the way the biodiesel industry may develop.

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