EFFECTS OF CHANGES IN U.S. ETHANOL PRODUCTION FROM CORN GRAIN, CORN STOVER, AND SWITCHGRASS ON WORLD AGRICULTURAL MARKETS AND TRADE

A Dissertation

by

JODY LYNN CAMPICHE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2009

Major Subject: Agricultural Economics

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Approved by:

Co-Chairs of Committee,	Henry L. Bryant
	James W. Richardson
Committee Members,	Bruce A. McCarl
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ABSTRACT

Effects of Changes in U.S. Ethanol Production from Corn Grain, Corn Stover, and Switchgrass on World Agricultural Markets and Trade. (May 2009)

Jody Lynn Campiche, B.S.; M.S., Oklahoma State University

Co-Chairs of Advisory Committee: Dr. Henry L. Bryant
Dr. James W. Richardson

The renewable energy industry continues to expand at a rapid pace. New advances in cellulosic ethanol technologies have the potential to reduce our dependency on foreign oil. The evolution of these new biofuel markets could have significant effects on future production levels, market prices, and world trade levels for various agricultural commodities. Alternative scenarios involving new biofuel technologies, primary factor availability, and government policy will result in very different outcomes for the agricultural economy. The interactions of current and new biofuel technologies, including conventional ethanol production (from corn grain) and cellulosic ethanol production (from corn stover and switchgrass), and the agricultural economy were examined in a general equilibrium framework. Various outcomes were examined with attention primarily focused on (1) trade offs among competing uses of agricultural commodities, (2) changes in the output of major agricultural producers competing with the U.S., (3) effects on the livestock industry, (4) profitability of the agricultural industry, (5) changes in input costs, including land rents, and (6) changes in land use patterns.

Results indicated that advances in cellulosic ethanol technology led to less grain ethanol production and more stover ethanol production in the United States. The production of switchgrass ethanol was not economically feasible under any scenario, which was expected due to the availability of lower priced corn stover. Overall, it was expected that a decrease in the costs of cellulosic ethanol production would lead to a higher increase in total U.S. ethanol production than actually occurred. As a result, the effects on the world economy were smaller than expected.

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I am so thankful that I was able to go through the Ph.D. program with Lindsey Higgins. I can’t thank her enough for everything that she has done for me. She is the most caring person that I know and I am truly going to miss her. We have shared so many experiences over the past four years and I know that we will be lifelong friends.

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success to my parents, as they instilled a strong work ethic. Through their guidance, I learned that there are no limits to what I can accomplish.

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CHAPTER I

INTRODUCTION

Over the last few years, the production of renewable fuels has increased dramatically. Rising oil prices, limited supplies of fossil fuel and increased concerns about global warming have created a growing demand for renewable energy sources. The future effect of renewable energy on agricultural markets has become an important topic in recent years, yet much uncertainty still remains. Uncertainties regarding new biofuel technologies as well as future fossil energy extraction conditions affect our ability to accurately predict the effects of biofuels on agricultural markets. These factors have a significant effect on the market prices for both fossil fuels and biofuels since they are close substitutes. The renewable fuels industry has the potential to reduce our dependency on foreign oil as well as lower toxic emissions. Ethanol production capacity in the U.S. has increased from under 2 billion gallons per year in 2000 to 7.6 billion gallons per year as of January 2008 (Aden et al. 2002, Renewable Fuels Association 2008). Currently, 137 plants are in operation and another 70 plants are currently under construction or expansion, leading to an increase in ethanol capacity by another 5.7 billion gallons in the next few years (Renewable Fuels Association 2008).

This dissertation follows the style of *American Journal of Agricultural Economics.*

U.S. biodiesel production capacity has increased from under 0.05 billion gallons per year in 2000 to 1.85 billion gallons per year as of September 2007, with another 1.4 billion gallons of capacity under construction (National Biodiesel Board 2008).

U.S. biofuel production is currently highly dependent on the availability of agricultural feedstocks. As the production of renewable energy continues to rise, producers of these feedstocks are experiencing an increased demand for their commodities, which leads to higher prices. The evolution of these new biofuel markets could have significant effects on future production levels, market prices, and world trade levels for various agricultural commodities. As ethanol production continues to increase in the U.S., the demand for corn will rise as well. According to USDA’s 2007 long-term projections, more than 30 percent of U.S. corn production will be used for ethanol production by 2009/10 compared to 14% in 2005/06 (Westcott 2007a). The U.S. and international corn markets will be directly affected as an increased demand for corn leads to higher prices and less corn available for export. The expanding U.S. ethanol industry has already created major shocks to the U.S. economy due to higher corn prices. The sector facing the largest setback is the livestock feeding sector as they use 50-60 % of U.S. corn (Westcott 2007b). Corn for livestock feeding is expected to drop by 10 to 20% over the next decade (Westcott 2007b). This trend will likely continue until alternative biofuel technologies are available to compete with corn-based ethanol production. Many of these alternative technologies, such as cellulosic ethanol production, are currently unavailable or extremely expensive.

Purpose and Objectives of This Research

Alternative scenarios involving new biofuel technologies and government policy may result in very different outcomes for the agricultural economy. The interactions of current and new biofuel technologies, including conventional ethanol production (from corn grain) and cellulosic ethanol production (from corn stover and switchgrass), and the current agricultural economy will be examined in a general equilibrium framework. The specific objectives of this study are as follows:

i. Quantify the economic outcomes of alternative scenarios relating to various levels of conventional and cellulosic ethanol production, with particular focus on:
    a. Trade offs among competing uses of agricultural commodities
        - The main trade off to consider is the use of corn grain for ethanol production, livestock feeding, and food. As more corn grain is used for ethanol production, less is available for human and livestock consumption and the price will typically be higher.
    b. Changes in the output of major agricultural producing countries competing with the United States
        - An expansion of the U.S. ethanol industry could result in lower exports of agricultural commodities from the U.S. to the rest of the world as well as increased imports from the rest of the world to the United States. This could also result in increased prices of world agricultural commodities which could benefit agricultural producers in the U.S. as well as the rest of the world. Some

  countries may also experience increased exports of agricultural commodities if U.S. exports decline.

c. Economic effects of increased biofuels production on the U.S. livestock industry

  - The livestock feeding industry has experienced major increases in costs in the past few years due to high corn prices. This trend could continue if ethanol production from corn grain increases. However, if cellulosic ethanol production becomes more profitable than conventional ethanol production, the livestock industry could experience some relief in corn prices. However, major expansions in switchgrass production could result in less available pastureland which would also affect the livestock industry.

d. Changes in U.S. land use patterns and land rents

  - The expansion of U.S. ethanol production from corn or switchgrass could have significant effects on agricultural land use patterns. An expansion of U.S. corn or switchgrass production would necessarily result in a contraction of land use in other agricultural sectors. Land rents may increase as more agricultural commodities compete for available land. Dedicated energy crops such as switchgrass must prove to be profitable before farmers will produce them. The prices of other agricultural commodities (not involved in ethanol production) may increase due to increased land competition.

Changes in U.S. conventional and cellulosic ethanol production may have profoundly different effects on many agents in the U.S. and world economy. The CGE approach allows us to simultaneously analyze the effects of conventional and cellulosic ethanol production on the entire economy. CGE models are very useful for analyzing economy-wide effects of a particular shock or policy change, as they allow for much greater detail than analytic general equilibrium models. In recent years, CGE models have become more widely used in energy studies and several studies have analyzed biofuel technologies in a CGE framework. However, most of these studies do not include both an explicit sector for agricultural biomass feedstocks and allow for joint products. The specific methods of this dissertation include:

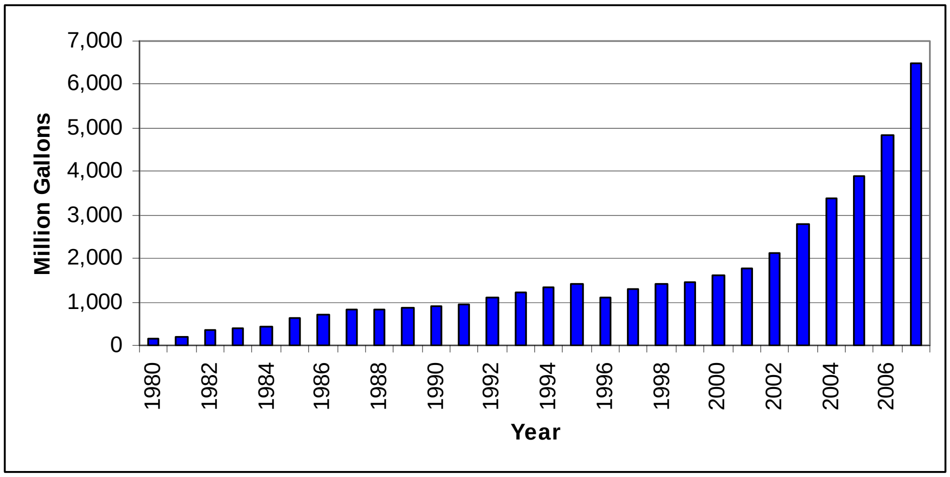
ii. Incorporate ethanol production from corn grain into a computable general equilibrium (CGE) model

iii. Incorporate new cellulosic ethanol technologies utilizing corn stover and switchgrass into a CGE model
    a. Include an explicit sector for switchgrass production
    b. Allow for joint products from corn production (i.e. corn stover)

CHAPTER II

BACKGROUND

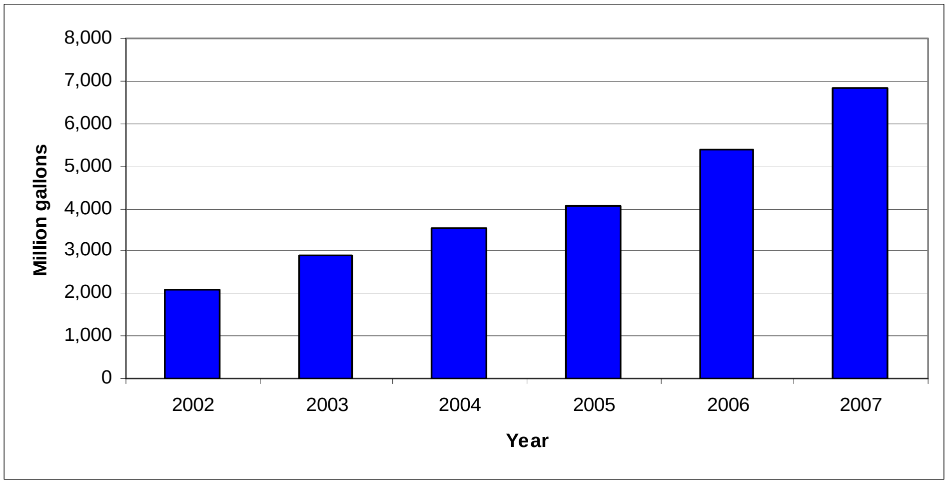
Renewable fuel production in the U.S. and world has expanded dramatically in the last few years. In the U.S., ethanol production has increased from 1.6 billion gallons in 2000 to 6.5 billion gallons in 2007 (Figure 1).



Source: Renewable Fuels Association (2008)

Figure 1. U.S. Ethanol Production

The quantity of U.S. ethanol demanded has increased from 2 billion gallons in 2002 to 6.8 billion gallons in 2007 (Figure 2). Various factors, such as rising oil prices, greenhouse gas emissions, fossil fuel depletion, environmental policy, and reduced MTBE use, have contributed to the surge in ethanol demand and are discussed briefly in this chapter. In addition, potential problems associated with increased ethanol production are discussed below. These problems are mostly attributed to the use of grains for both feed and fuel use. Many are concerned that traditional ethanol production has led to rising corn prices which has severely affected the world's poor population. Cellulosic ethanol production could alleviate some of these concerns if the particular feedstock used does not compete with food grains for land or use.

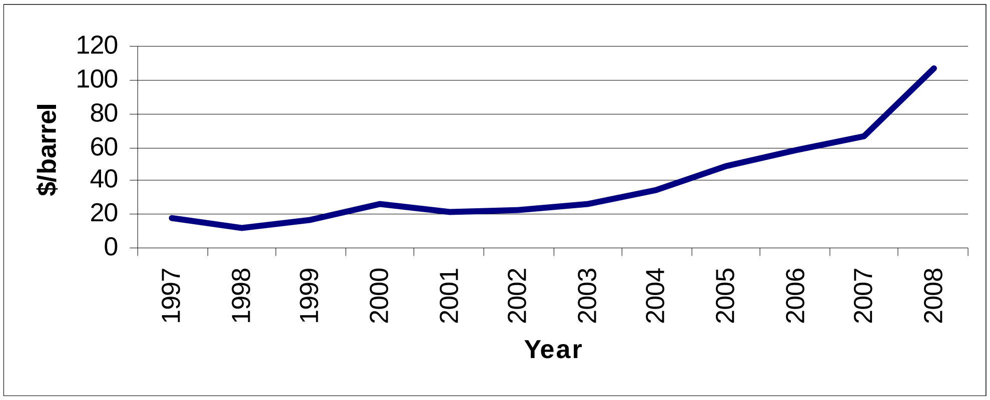


Source: Renewable Fuels Association (2008)

Figure 2. U.S. Ethanol Demand

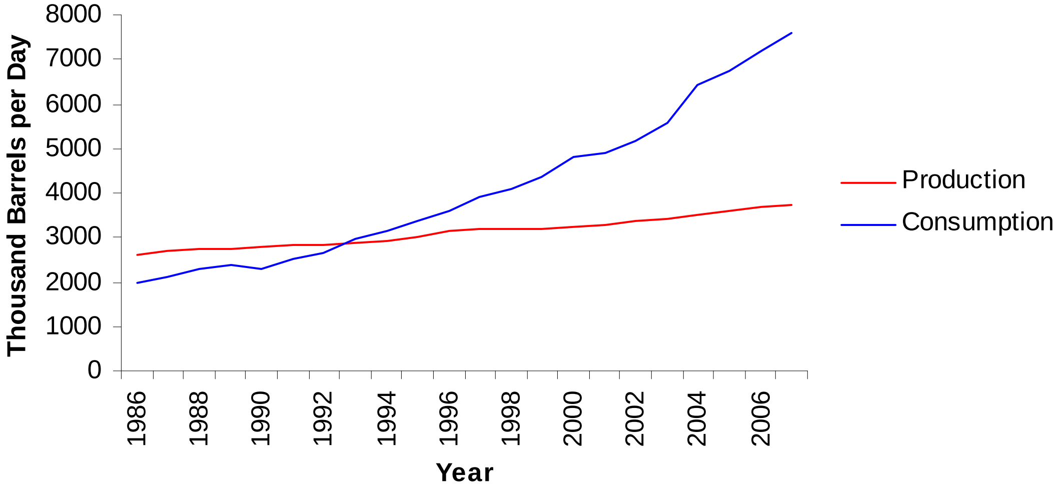
Rising Oil Prices

Oil prices have continued to hit record highs in the past few years (Figure 3). Several factors have contributed to this spike in oil prices. In the past few years, developing countries such as China and India have rapidly increased their consumption of oil (Figure 4).



Source: Energy Information Administration (2007)

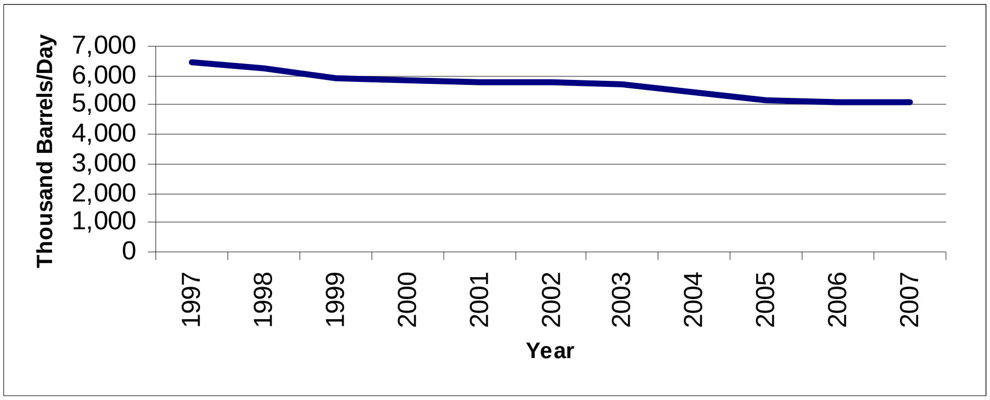
Figure 3. U.S. Crude Oil Prices



Source: Energy Information Administration (2007)

Figure 4. China Crude Oil Production and Consumption

In addition, excess refining capacity in oil producing nations may no longer exist at the levels that once occurred. Political instability has also contributed to higher oil prices along with a slight decline in world and U.S. oil production (Figure 5).



Source: Energy Information Administration (2007)

Figure 5. U.S. Crude Oil Production

Greenhouse Gas Emissions

The role of fossil fuel use on greenhouse gas emissions and global warming has become an increasingly discussed issue in the past few decades. Many are concerned that the level of emissions from fossil fuel burning is becoming dangerously high. This concern has prompted a wide range of studies analyzing potential reductions in greenhouse gas emissions from alternative or renewable energy sources. Some controversy does exist over the actual effect of fossil use on global warming and the subsequent reductions in greenhouse gas emissions from renewable energy sources. Yet, despite the controversy, increased concerns about global warming have been a contributing factor to the growing use of biofuels.

Fossil Fuel Depletion

It is widely known that fossil energy is a nonrenewable and finite resource. There are geological constraints that affect the rates at which fossil fuels can be extracted. Additionally, there are economic incentives that affect the fossil fuel extraction rate (as shown by Hotelling's model of optimal nonrenewable resource extraction). It is very likely that if world oil reaches the peak level and production starts to decline, the market for alternative biofuels will become more viable. However, it is very difficult to predict when this will actually occur due to the high level of uncertainty regarding reserve levels and the future path of crude oil extraction. Many other factors also contribute to this uncertainty. Political instability is a major factor since the Middle East holds the majority of the world's oil. World conventional oil production will eventually reach a maximum level, or peak, and then start to decline. Conventional oil includes crude oil extracted via the traditional oil well method. The majority of oil extracted in the world is conventional oil. Extraction of non-conventional oil (e.g. tar sands, heavy oil, and oil shale) is much more expensive than conventional oil extraction.

Environmental Policy

The Energy Independence and Security Act of 2007 seeks to jump start the development of economically feasible biofuel technologies. The renewable fuel standard requires the annual use of 36 billion gallons of renewable fuels by 2022, with 15 billion gallons from corn-based ethanol and 21 billion gallons from advanced biofuels. Advanced biofuels include any renewable fuels other than ethanol produced from corn starch that meets a 50 percent GHG emissions reductions requirement. Both cellulosic ethanol production and biomass-based diesel production are advanced biofuels. Within the advanced biofuel category, 16 of the 21 billion gallon requirement must come from cellulosic biofuels. The increase in both traditional (i.e. corn-based ethanol) and advanced biofuel production could have significant effects on world agricultural markets and trade. Since biofuels can be produced from various forms of biomass, different technological developments will have different implications. Of particular interest is the use of crop or forest residues to produce biofuels since this may be more economical in the initial stages than producing a dedicated biomass crop for biofuel production. However, there is still a high level of uncertainty regarding the probability of success of particular biofuel technologies and their associated biomass source. Therefore, the effects of alternative biofuel technologies on agriculture and the rest of the economy are still unknown.

Substitution of Ethanol for MTBE

Starting in mid-2006, most refiners replaced MTBE use in gasoline with ethanol. U.S. refiners began using MTBE at low levels in 1979 as a replacement for lead as an octane enhancer. However, in 1992, refiners began using MTBE at much higher levels to fill oxygenate requirements under the Clean Air Act Amendments of 1990. When evidence proved that MTBE was a carcinogenic groundwater pollutant, many states actually banned MTBE use and refiners increased their use of ethanol in gasoline blends. The oxygenate requirement in gasoline was eliminated in The Energy Policy Act of 2005 which resulted in further declines in MTBE use. Refiners now use ethanol in most gasoline blends even though an oxygenate requirement no longer exists since the use of oxygen in gasoline results in lower greenhouse gas emissions. Ethanol contains twice the oxygen content of MTBE and doesn't have the harmful effects of MTBE.

Potential Benefits of Biomass for Ethanol Production

Renewable fuels produced from biomass have the potential to benefit the environment by lowering greenhouse gas emissions. However, increased biomass production can also create environmental problems if not produced in a sustainable manner. A current issue of debate regarding biofuels is the balance of ethanol production. The net energy balance is the amount of energy required to grow and convert biomass into ethanol vs. the energy value present in the ethanol fuel. Many studies have analyzed the net energy value of conventional corn-based ethanol production (Durante and Miltenberger 2004, Graboski 2002, Ho 1999, Keeney and Deluca 1992, Lorenz and Morris 1995, Marland and Turhollow 1991, Pimental 1991, Pimental 2001, Shapouri, Duffield and Graboski 1995, Shapouri, Duffield and Wang 2002, Wang, Saricks and Santini 1999). These studies have provided a wide range of estimates due to variations in particular data and assumptions. Since the corn production process requires the use of fossil fuel, some are concerned that ethanol production provides a negative net energy balance (Ho 1999, Pimental 1991, Pimental 2001, Pimental and Patzek 2005, Pimental and Pimental 1996).

Shapouri, Duffield, and Wang (2002) note that many of the previous studies used older data which could lead to overestimation of energy use due to significant increases in corn ethanol production efficiency over time. Shapouri, Duffield, and Wang (2002) argue that the net energy value of conventional corn ethanol has been increasing over time as a result of advances in the technology of ethanol conversion and higher efficiency in farm production. They estimate that the entire corn ethanol production process yields 34 percent more energy than it requires to produce it. In a recent study, Pimental (2005) analyzed the energy intput:output ratio of ethanol produced from corn grain, switchgrass, and wood biomass. They found that ethanol production from corn grain uses 29% more energy than is produced, ethanol production from switchgrass uses 50% more fossil energy than is produced, and ethanol production from wood biomass uses 57% more energy than is produced. The net energy balance of biofuels is highly dependent on the particular biomass feedstock used to produce the biofuel. However, it is important to note that cellulosic ethanol is not currently produced on a large-scale basis and actual data on energy use may not be available. Biofuels produced from tropical plants tend to have a higher net energy balance than those grown in temperate regions (Rutz and Janssen 2007). Tropical plants are generally grown under more favorable climatic conditions and are manually cultivated which requires lower amounts of fossil energy, fertilizer, and pesticides (Rutz and Janssen 2007).

Biomass Sources/Supply

The expansion of the biofuel industry will largely depend on the amount of available biomass feedstock as well as biofuel policies. Biomass feedstocks can come from a variety of sources, such as agriculture, forestry, and municipal waste. In 2002, total land area in the U.S. was 2.3 billion acres (Lubowski et al. 2006). Agricultural land makes up 51.8% of the total U.S. land area. Agricultural land is broken down into cropland (26% or 442 million acres), grassland pasture and range (26% or 587 acres), grazed forest land (29% or 134 million acres), and farmsteads/farm roads (0.5% or 11 million acres). In the cropland category, 77% is used for crops (including alfalfa and other hay), 9% is idle (includes 34 million CRP acres), and 14% is used only for pasture (Lubowski et al. 2006).

Perlack et al. (2005) analyzed the potential U.S. biomass supply from dedicated energy crops and forest and agricultural residues. The study examined whether or not there is enough available land in the U.S. to produce biomass to displace 30 percent of U.S. petroleum consumption. They concluded that by 2030, 1.3 billion tons of biomass could be available each year in the U.S. for biofuel production and could displace more than 30 percent of petroleum use. Almost 1 billion tons of the annual requirement could be produced from agricultural lands while still meeting food, feed, and export demands. This amounts to 428 million tons of crop residues (corn, wheat, and soybeans), 377 million tons of perennial crops (switchgrass and hybrid poplars), 106 million tons of animal manures and miscellaneous feedstocks, and 87 million tons of grains used for biofuels. The agricultural land base required to meet this goal includes 342 million acres of active cropland, 39 million acres of idle cropland, and 67 million acres of cropland used as pasture. The study identified corn stover as the single largest source of biomass at a projected 75 million tons. In a recent study, Sims et al. (2006) analyzed the potential world production of dedicated energy crops and conversion technologies by exogenously specifying area dedicated to energy crop production. They found that by 2025, the realistically obtainable level of biofuel production should be between 2 and 21 quadrillion British thermal units.

Food vs. Fuel

The food versus fuel issue is now widely debated. Biofuels could increase the price of food either because food crops are used for fuel production or energy crops compete with food crops for agricultural lands. As more corn is being used for ethanol production, U.S. corn exports could decline significantly. Developing countries could benefit from lower U.S. corn exports by expanding their own production. However, food security for the world's poor may be threatened due to higher priced grains. An IFPRI study found that 160 million people live on less than 50 cents per day which is considered extreme poverty (Ahmed et al. 2007). From 1990 to 2004, the number of undernourished people in developing countries increased by 7 million (United Nations, Food and Agriculture Organization 2006). However, the increase in poverty has not been equal across countries (von Braun 2007). Since the early 1990's, the number of people suffering from food insecurity decreased by 18 percent in East Asia but increased by over 26 percent in Sub-Saharan Africa (von Braun 2007). The greatest percentage of hungry people live in South Asia which accounts for 36 percent of all undernourished people in developing countries (von Braun 2007). In developing countries, one of every three children is stunted and one of every four under five years old are underweight (von Braun 2007).

Food security in developing countries is threatened because cereal grains make up 80% of the world’s food supply (Pimental and Pimental 1996). Many are concerned that commodities are being diverted away from food and feed uses to biofuel production which has led to increased concerns about food security for the world’s poor. According to Regmi et al. (2001), a 1 percent increase in food prices causes a 0.75 percent decline in food consumption expenditure in developing countries. Basically when food prices increase, low-income people switch to less nutritious food (von Braun 2007).

CHAPTER III

REVIEW OF LITERATURE

This literature review is organized around several primary areas of research related to this dissertation:

- Recent work on the global impacts of increased biofuel production
- Conventional ethanol production technology
- Cellulosic ethanol production technology
- Ethanol feedstocks
- Conventional ethanol production costs
- Cellulosic ethanol production costs
- Potential ethanol production
- CGE analysis of energy issues
- CGE use in energy and agriculture analyses
- Incorporation of new biofuel technologies into CGE model

Recent Work on the Global Impacts of Increased Biofuel Production

The biofuels industry has attracted a huge amount of interest in recent years. An extensive amount of biofuels research has been conducted in the past few years. Much of the recent work in the biofuels industry focuses on the effects of biofuel production and use on climate and emissions (Botha and Blottnitz 2006, Nguyen, Gheewala and Garivait 2007, Dias de Oliveira, Vaughan and Rykiel 2005, Pimental 2003) with (Niven

2005) providing a survey of earlier work. Additional studies have examined the efficiency of renewable energy policies in achieving emissions reductions (Dittmer and Wassell 2006, Frondel and Peters 2007, Ryan, Convery and Ferreira 2006). Another area receiving considerable attention in recent years is the importance of biofuels in increasing energy supplies and security (Demirbas 2007, Goldemberg, Coelho and Lucon 2004, Mathews 2007).

In the past few years, the potential effects of increased biofuel production have also received considerable attention. Several recent studies have examined the effects of proposed energy policies and increased biofuel production on world agricultural markets and trade (Bryant 2007a, Bryant 2007b, Food and Agricultural Policy Research Institute 2005, Gallagher et al. 2003, Organisation for Economic Co-operation and Development 2006, Tyner and Quear 2006).

De La Torre Ugarte, English, and Jenson (2007b) used the POLYSYS and IMPLAN models to examine the economic and agricultural impacts of increased levels of ethanol and biodiesel production. They found that by the year 2030, 60 billion gallons of ethanol and 1.6 billion gallons of biodiesel could be produced on 35 million acres of dedicated energy cropland. In their model, corn grain is the main ethanol feedstock between 2007 and 2012. In 2012, cellulosic ethanol becomes economically viable and by 2014, dedicated energy crops are used as the primary feedstock for cellulosic ethanol production. Crop residues, such as corn stover and wheat straw, are used in significant amounts for cellulosic ethanol production after 2020. Their model predicts that by 2030, agricultural exports (mostly soybeans) will be lowered by $3 billion and ethanol will displace over 20 percent of U.S. gasoline consumption. According to the authors, this reduction in gasoline consumption could lower U.S. oil imports by $54 billion dollars.

In another study, De La Torre Ugarte et al. (2007a) developed a national industry expansion curve based on increased biofuel and bioproduct demand, feedstock supply, conversion technologies, and agricultural market dynamics. Starting in 2011, corn grain and cellulosic biomass will directly compete as feedstocks for ethanol production. They found that by 2014, cellulosic ethanol demand of 16.73 billion gallons would be met with 64.5 million dry tons of corn stover, 38.9 million dry tons of switchgrsss, and 2.8 million tons of wheat straw.

Wilson et al. (2007) used a special partial optimization model to analyze the effects of ethanol expansion in the U.S. on world cropping patterns and trade for corn, soybeans, and wheat. Their model indicated that increased ethanol production will have a significant impact on the quantity of corn available for export from the U.S. After 2010, they predict that U.S. corn exports will decline more than wheat or soybean exports. The authors do note that assumptions regarding yield growth and the feasibility of expanding corn acres significantly affect the model outcome.

Islas, Manzini, and Masera (2007) examined various scenarios of bioenergy use in Mexico based on moderate and high usage of bioenergy in the electricity and transportation sectors. The authors analyzed three scenarios from 2005 to 2030. Results of their model indicate that ethanol, biodiesel, and electricity produced from biomass could make up 16.17% of total energy consumption in the high usage case.

English et al. (2006) analyzed the agricultural and economic effects resulting from 25% renewable energy use in the U.S by 2025. They found that the 25% goal can be achieved through continuous crop yield increases, forestry sector utilization, and over 100 million acres of dedicated energy feedstocks, such as switchgrass. Additionally, they note that the U.S. agricultural industry would still be able to provide adequate food, feed, and fiber at reasonable prices. They do project an increase in U.S. corn acres in the near term, however; their model predicts significant increases in the production of dedicated energy crops after 2012. The model does predict higher corn prices, but the authors did not find a one-to-one correlation between increased feed crop prices and increased livestock feed expenses. By 2025, ethanol and biodiesel production could reach 86 billion and 1.2 billion gallons, respectively, which could lower gasoline consumption by 59 billion gallons.

Tokgov et al. (2007) used a multi-country partial equilibrium model to analyze the long-term and global tradeoffs between bio-energy, feed, and food. The authors analyzed various scenarios and the results of their model indicated that increased U.S. ethanol production causes an increase in long-run crop prices and livestock farmgate prices. If oil prices remain at a permanent level of $10/barrel over their baseline projections, they anticipate that U.S. ethanol production could significantly expand. However, they note that the actual level of ethanol expansion will depend on the future U.S. vehicle fleet and specifically the demand for flex-fuel vehicles. If a large ethanol mandate is in place and a severe drought occurs, their model predicts much higher crop prices, lower livestock production, and increased food prices. In all scenarios, Tokgov et al. (2007) found that cellulosic ethanol (from switchgrass) and biodiesel (from soybeans) was not economically feasible in the Corn Belt. They also found that cellulosic ethanol from corn stover was not feasible under any scenario due to high collection/transportation costs.

McDonald, Robinson, and Theirfelder (2006) analyzed the general equilibrium effects of substituting switchgrass for crude oil in U.S. petroleum production. They found that using switchgrass reduces production efficiency and U.S. GDP falls. As more switchgrass is produced, less cereals are produced leading to a slight increase in the world price of cereals. U.S. import demand for crude oil falls leading to a decrease in the world price of crude oil. Overall, economic welfare declines due to this change. However, a 30% increase in factor productivity in the petroleum industry or an increase in switchgrass production on “set-aside” land could offset the welfare losses in the U.S.

Msangi et al. (2007) used IFPRI’s IMPACT model to examine the implications of global biofuel production on food security and water use. They found that a “food-versus-fuel” tradeoff would occur if new technological innovations in crop production occur at a slow pace and biofuel production requirements are achieved primarily from conventional feedstock conversion methods. However, with improved crop productivity and increased investments in biofuel conversion technologies, the situation could be much different.

Smeets et al. (2007) analyzed global bio-energy potentials to 2050 using the Quickscan model. Results of their model indicated that the amount of land necessary to meet global food demand in 2050 could be reduced by up to 72% if more efficient agricultural systems are in place and land use patterns are geographically optimized. They estimate that potential global biofuel production in 2050 from agricultural residues, forestry residues, and wastes could be 76-96 EJ yr^{-1}.

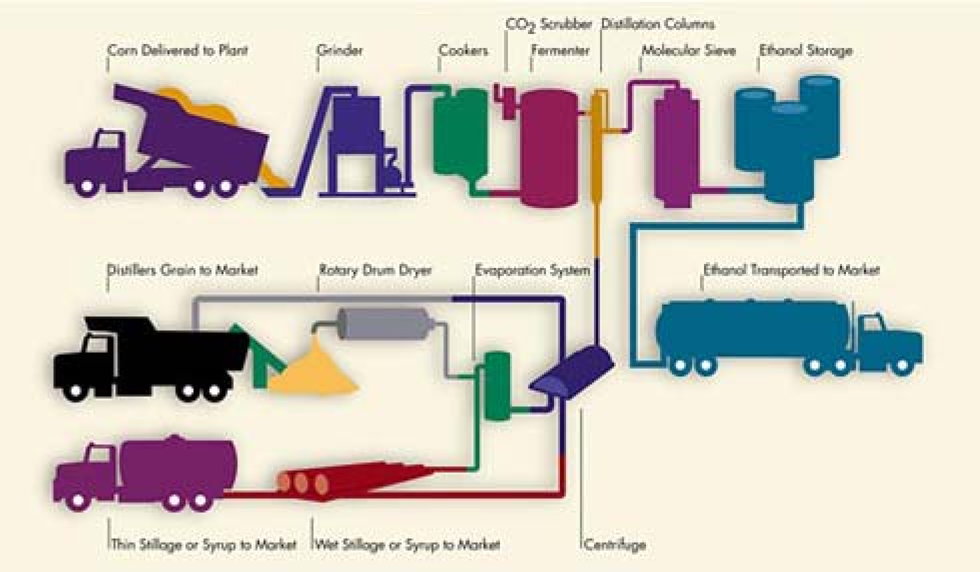
Elobeid et al. (2007) used a multi-country model to examine the long-run effects of ethanol production from corn on the livestock, grain, and oilseed sectors. They calculated the corn price that eliminates the incentive to expand ethanol production. At a corn price of $4.05, they predict that ethanol production will be 31.5 billion gallons per year and would require 95.6 million acres of corn (or 15.6 billion bushels). Their model predicts soybean acres will be reduced to meet the demand for more corn acres.

Conventional Ethanol Production Technology

Alcohol has been produced for thousands of years by various methods. It can be produced from many different feedstocks, including sugary, starchy, and cellulosic feedstocks. Denatured alcohol (or ethanol) is used for fuel purposes and is not drinkable. Sugarcane is an excellent feedstock source since it contains large amounts of sugar that can be easily fermented. However, sugarcane must be grown in a tropical or subtropical climate, which makes it an excellent biofuel feedstock for Brazil. Corn is a widely used biofuel feedstock in the United States. It contains starch in the kernels and the conversion process for transforming starch into sugar and then into ethanol is fairly easy and economical.

Both corn and sugarcane as well as many other feedstocks are considered first-generation feedstocks in which only a part of the plant is used for ethanol production.

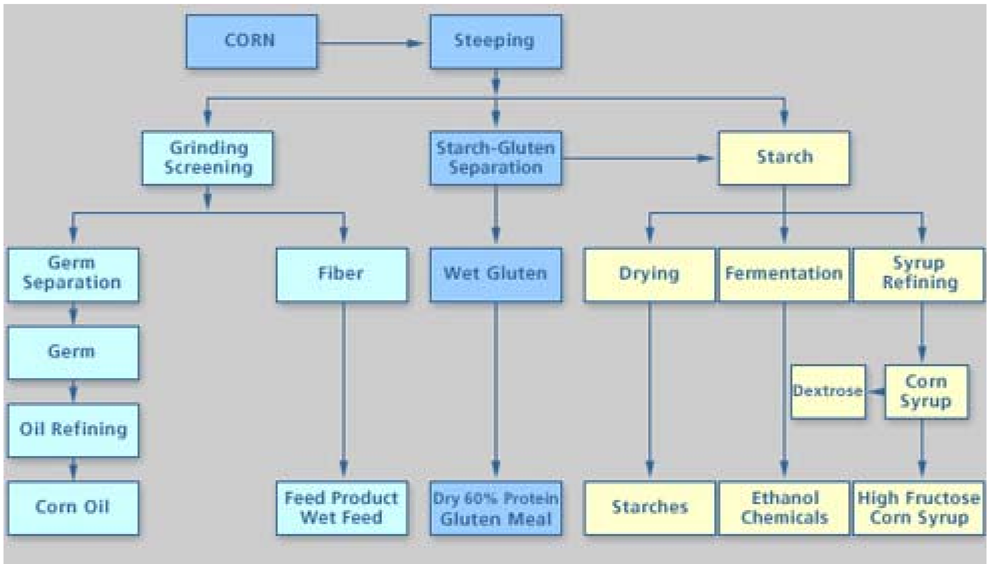
Two ethanol fermentation processes are used to convert starch or sugar-based feedstocks into fuel. These include wet milling and dry milling. The majority of ethanol plants are dry mill facilities. The main difference between wet and dry milling is the initial treatment of the grain and the feed co-products. In the dry mill process, the whole corn kernel is initially ground into flour before processing (Figure 6). Co-products of the dry mill process include dried distillers grains with solubles (DDGS) and carbon dioxide.



Source: Energy Information Administration (2007)

Figure 6. Dry Mill Ethanol Production Process

In the wet mill process, the corn is initially soaked or “steeped” to separate the grain into its various parts before processing (Figure 7). Co-products of the wet mill process include industrial starch, food starch, high fructose corn syrup, gluten feed (fed to livestock), gluten meal (fed to poultry), and corn oils.



Source: Energy Information Administration (2007)

Figure 7. Wet Mill Ethanol Production Process

Cellulosic Ethanol Production Technology

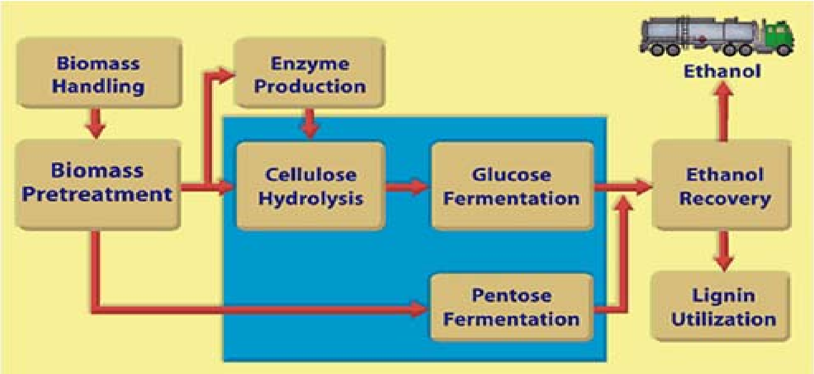
While traditional corn-based ethanol is produced from starch, cellulosic ethanol is produced from cellulose. The largest component of plant cell walls is cellulose and it is the most common organic compound on earth. However, cellulose is harder to break down and convert into sugars for ethanol production. Cellulosic ethanol can be produced from many agricultural and forestry products and residues, which greatly expands ethanol production ability in the United States. Second-generation feedstocks are used in cellulosic ethanol production. These feedstocks are made up of lignin, cellulose, and hemicellulose which must be converted to sugar by more advanced conversion technologies. Examples of feedstocks include crop residues (corn stover), dedicated energy crops (switchgrass), forest residues, and municipal solid wastes. Table 1 provides a summary of various feedstock types and their harvest methods, conversion processes, and co-products.

Table 1. Ethanol Production Process for Various Feedstocks

Feedstock Type	Feedstock	Harvest Technique	Feedstock Conversion to Sugar	Sugar Conversion to Alcohol	Co-Products
Sugar Crops	Sugarcane, sweet sorghum	Cane stalk cut, mostly taken from field	Sugars extracted through bagasse crushing, soaking, chemical treatment	Fermentation and distillation of alcohol	Heat, electricity, molasses
Starch Crops	Corn, wheat	Starchy parts of plants harvested, stalks mostly left in the field	Starch separation, milling, conversion to sugars via enzyme application	Fermentation and distillation of alcohol	Animal feed, sweetener
Cellulosic Crops	Grasses, Trees	Full plant harvested (trees), Grasses cut with regrowth	Cellulose conversion to sugar via saccarification (enzymatic hydroloysis)	Fermentation and distillation of alcohol	Heat, electricity, animal feed, bioplastics
Waste Biomass	Crop Residues, Forestry waste, municipal waste	Collected, separated, cleaned to extract material high in cellulose	Cellulose conversion to sugar via saccarafication (enzymatic & acid hydrolysis)	Fermentation and distillation of alcohol	Heat, electricity, animal feed, bioplastics

Source: Rutz and Jansen (2007)

Cellulosic ethanol can be produced by two different processes. The first process is cellulolysis which consists of hydrolysis on pretreated lignocellulosic materials (Figure 8). This is followed by fermentation and distillation. The other process consists of gasification that basically transforms the lignocellulosic material into gaseous carbon monoxide and hydrogen. These gases can be converted to ethanol by fermentation or chemical catalysis. The final step for both processes involves distillation to isolate the pure ethanol. Research on cellulosic ethanol production has been increasing in recent years, but actual cellulosic ethanol production does not currently exist in a large commercial facility (Rutz and Janssen 2007).



Source: Renewable Fuel Association (2008)

Figure 8. Cellulosic Ethanol Production

Ethanol Feedstocks

Both traditional and cellulosic ethanol production costs are highly dependent on the price of feedstocks. Ethanol can be produced from a large variety of biomass sources. However, only a few feedstocks will be considered in this dissertation. It is assumed that the primary feedstock for traditional ethanol production is corn grain. In the U.S. most ethanol plants use corn grain as the primary feedstock. For cellulosic ethanol production, the feedstocks considered include corn stover and switchgrass.

Corn

The composition of corn is shown in Table 2. The main component of corn grain is starch. On average, one acre of corn yields between 130 - 150 bushels (or 3 - 4 tons at 15% moisture). In FAPRI's January 2008 baseline projections (Food and Agricultural Policy Research Institute 2008), corn grain production is expected to reach 13.6 billion bushels by 2012 (Table 3). Corn yield per acre is projected to reach 159.9 bushels per acre in 2012 (Food and Agricultural Policy Research Institute 2008).

Table 2. Corn Composition

Component	% Dry Basis
Starch	72.0
Hemicellulose/Cellulose	10.5
Protein	9.5
Oil	4.5
Sugars	2.0
Ash	1.5
Total	100.0
% Moisture	15.0

Source: Wallace et al. (2005)

Corn stover is a byproduct of corn grain production and consists of the stalk, leaf, husk, and cob remaining in the field after the corn grain harvest. The main component of corn stover is cellulose. The composition of corn stover used in the cellulosic ethanol study by Aden et al. (2002) is shown in Table 4. Corn stover composition and moisture content varies due to several factors such as region, soil type, weather, corn variety, and harvesting methods (Aden et al. 2002). Half of the corn crop yield is corn stover, but it is generally left in the field after harvest. For every ton of corn that is produced, about 1 dry ton of stover remains on the field. A portion of the corn stover can be collected and used as a biomass source for cellulosic ethanol production. However, a certain percentage must be left on the ground so that soil erosion does not occur. Corn stover is potentially the most underutilized crop in the U.S. as less than 5% of corn stover production is generally used (Hettenhaus and Wooley 2000).

Table 3. Potential U.S. Corn Grain Production

	Sept-Aug Year				
	07/08	08/09	09/10	10/11	11/12
Harvested corn acres (mill)	86.5	84.2	84.7	86.9	85.4
Corn grain yield/acre (bu)	151.1	153.5	155.5	157.8	159.9
Total corn grain production (bill bu)	13.1	12.9	13.2	13.7	13.6

Source: Food and Agricultural Policy Research Institute (2008)

Table 4. Corn Stover Composition

Component	% Dry Basis
Cellulose	37.4
Galactan/Mannan	3.6
Xylan	21.1
Arabinan	2.9
Lignin	18.0
Ash	5.2
Acetate	.29
Extractives	4.7
Protein	4.2
Total	100.0
% Moisture	15.0

Source: Wallace et al. (2005)

Over 240 million dry tons of corn stover is produced each year in the U.S. (Atchison and Hettenhaus 2003) Removal of the excess corn stover after harvest can also reduce the need to till the field. However, corn stover will not become an economical feedstock for large ethanol plants without innovations in the collection, storage, and transportation of corn stover (Atchison and Hettenhaus 2003). Gallagher et al. (2003) found that crop residues are likely the lowest cost biomass source and they estimate that 12.5 percent of U.S. petroleum imports could be reduced by using reduced tillage and partial harvest of crop residues. If these practices are followed, Sheehan et al. (2004) found that corn stover from Iowa farms alone could produce 2.1 billion gallons of ethanol. In a recent study by the USDA, corn stover and forest and mill residues were found to be the most likely biomass sources during the initial stages of cellulosic ethanol production (United States Department of Agriculture 2007).

Cost Analysis

Many studies have examined the costs of corn stover collection and transportation. Researchers at the Oak Ridge National Laboratory estimate that the U.S. currently has 60 million tons of corn stover available at a cost of $30/ton. This estimate represents 30% of the total amount of corn stover produced in the U.S. as it takes into consideration the amount of corn stover that must remain in the field for erosion control and various harvesting/collection/transportation constraints. The cost per ton estimate includes harvesting costs and the cost to replace nutrients lost through corn stover removal but does not include a farmer premium or transportation costs. Researchers at the U.S. Department of Energy’s National Renewable Energy Laboratory (NREL) have estimated the delivered cost of corn stover to the ethanol plant to be $56/ton.

Brechbill and Tyner (2008) have provided a nice summary of current research relating to the corn stover collection process. Corn stover costs can be broken down into the following categories: nutrient replacement, harvesting/collecting, bale packaging, storage, dry matter loss, handling, and transportation (Brechbill and Tyner 2008). The total costs estimated by these studies differ based on the particular assumptions used, including yield, removal rates, seeding rates, nutrient replacement, herbicide application, and storage dry matter loss (Brechbill and Tyner 2008).

Yield

The amount of corn stover production is directly proportional to the amount of corn grain production and most studies use a stover to grain ratio of 1:1 (Brechbill and Tyner 2008). Lang (2002) adopted the 1:1 ratio and used a simple formula to determine the stover yield per acre. The formula is:

$$(1)\qquad \text{Stover yield}(\text{tons}/\text{acre}) = \frac{\text{Corn yield}(\text{bu}/\text{acre}) * 56\,(\text{lbs}/\text{bu})}{2000\,(\text{lbs}/\text{bu})}$$

Graham et al. 2007 also used a similar calculation to estimate corn stover yield. Basically, for every ton of corn that is produced, about 1 dry ton of stover remains on the field. Brechbill and Tyner (2008) used Lang’s formula and data from NASS’s September 2007 forecast for corn yield to calculate corn stover yield. Brechbill and Tyner’s (2008) estimates as well as others are shown in Table 5.

Table 5. Corn Grain and Stover Yield

Study	Corn Yield (bu/acre)	Stover Yield (tons/acre)
Brechbill and Tyner (2008)	160	4.48
Atchinson and Hettenhaus (2004)	170	4.00
Gallagher et al. (2003)	143	3.23
Perlack and Turhollow (2003)	130	3.20
Quick (2003)	150	4.20
Sokhansanj and Turhollow (2002)	150	3.60
Glassner, Hettenhaus, and Schechinger (1998)	150-200	4-5

Collection Efficiency

A portion of the corn stover can be collected and used as a biomass source for cellulosic ethanol production. However, a certain percentage must be left on the ground so that soil erosion does not occur. The amount that can be removed varies by region, soil conditions, and harvest activities. Corn stover is very important in preserving the organic matter and nutrients in the soil following corn grain harvesting (Brechbill and Tyner 2008). As a higher percentage of corn stover is removed, the risk of soil loss from wind erosion and runoff from water erosion increases (Brechbill and Tyner 2008). While it is difficult to establish a corn stover removal rate that is ideal for all regions due to variations in soil and weather conditions (Brechbill and Tyner 2008), various studies have provided estimates of possible corn stover removal rates (Table 6).

Corn stover collection is restricted by several constraints relating to equipment, soil moisture, and water and wind erosion (Graham et al. 2007). Different types of collection equipment result in different stover collection efficiencies. Soil moisture and water and wind erosion constraints affect the amount of corn stover that must be left in the field after harvest. Water and wind erosion issues can widely vary due to local climate conditions, cropping rotation, tillage, and agricultural soil types (Graham et al. 2007).

Nutrient Replacement

When corn stover is removed from the field, nutrients generally need to be replaced. These nutrients include nitrogen, phosphorus, and potassium. The replacement rate varies depending on the particular cropping rotation following corn production. (Brechbill and Tyner 2008) used average nutrient replacement levels from several studies (Table 7).

Table 6. Corn Stover Collection Efficiency

Study	Collection Efficiency	Collection Method
Graham et al. (2007)	28%	Current till practices
	33%	Universal Mulch till
	48%	Universal No-till
Petrolia (2006)	40%	Raking & baling
	30%	Baling
Wallace et al. (2005)	33%	NA
Schechinger and Hettenhaus (2004)	70%	Raking & baling
	40-50%	Baling
Sheehan et al. (2004)	70%	No-till
	40%	Continuous corn mulch tillage
Gallagher et al. (2003)	28%	NA
Montross et al. (2003)	64-75%	Shredding, raking, & baling
	50-55%	Raking & baling
	38%	Baling
Perlack and Turhollow (2003)	35%	NA
Shinners, Binversie, and Savoie (2003a)	56%	Baling
	33%	Allow stover to dry in field & bale
Lang (2002)	80%	Shredding, raking, & baling
	65%	Raking & baling
	50%	Baling
Hettenhaus and Wooley (2000)	50-60%	NA
Richey, Lechtenberg, and Liljedahl(1982)	29%	Raking & baling

Table 7. Corn Stover Nutrient Replacement

Study	Nitrogen (lbs)	Phosphorus (lbs)	Potassium (lbs)
Fixen (2007)	19.0	5.7	32.0
Petrolia (2006)	NA	6.2	33.0
Scheichinger and Hettenhaus (2004)	NA	7.0	35.0
Lang (2002)	15.0	5.9	25.0
Nielson (1995)	13.6	3.6	19.7

Source: Adapted from Brechbill and Tyner (2008)

Collection Costs

The corn stover collection process involves two main direct costs: baling and staging the stover at the edge of the field and transportation from the field to the ethanol plant (Aden et al. 2002). Gallagher et al. (2003) notes that the key factors affecting the difference between farmgate costs and delivered costs include residue density, processing plant capacity, and local truck-hauling rates. Transportation costs are very important since an area with low-cost crop residues may still not be economical if the hauling costs are expensive (Gallagher et al. 2003). Transportation costs also increase as the plant size increases since the plant needs to secure more corn stover from potentially greater distances (Gallagher et al. 2003). Very little actual published data on corn stover transportation costs exists since it is still not a common process. Biomass Ag Products in Harlan, Iowa is one of the few sources of actual data relating to corn stover transportation costs and Aden (2002) used this data in their cellulosic ethanol study.

Corn stover costs depend greatly on the stover yield per acre, which is related to the grain yield per acre, and the amount of stover that the producer chooses to remove. The per ton cost of corn stover is comprised of several components including nutrient replacement for each ton of stover removed from the field, harvesting or collecting, bale packaging, storage and an associated dry matter loss, handling, and transportation. Various studies have estimated the cost of corn stover collection and delivery to plant. The estimates for corn stover collection costs range from $13/ton to $63/ton (Gallagher et al. 2003, Graham et al. 2007, Sokhansanj and Turhollow 2002). The estimates for both collection and delivery range from $31/ton to $74/ton (Aden et al. 2002, Glassner et al. 1998, Perlack and Turhollow 2003, Petrolia 2008, Shinners, Binversie and Savoie 2003b, Sokhansanj, Turhollow and Perlack 2002, Tokgov et al. 2007).

Switchgrass

Switchgrass is a summer perennial grass that is native to North America and is a dominant species of the remnant tall grass prairies in the United States. Switchgrass is resistant to many pests and plant diseases and has the potential to produce high yields with low fertilizer application rates. Switchgrass can be grown on marginal land with fairly moderate inputs and can also protect the soil from erosion problems (Duffy and Nanhou 2001). Switchgrass can also be used to lower carbon emissions by sequestering carbon in the soil. The two main types of switchgrass are upland types (grow to 5 or 6 feet tall) and lowland types (grow to 12 feet tall). Switchgrass planting and harvesting is very similar to other hay crops and the same machinery can be used for harvesting. When switchgrass is produced for biomass, it can be cut once or twice a year. Switchgrass is currently grown as a forage crop on limited acreage in the Conservation

Reserve Program (CRP), and on various test plots throughout the United States (De La Torre Ugarte et al. 2003).

Cost Analysis

Duffy and Nanhou (2001) found that yields and land charges were the most significant factors affecting production costs. The costs of switchgrass production can vary widely depending on the assumptions used in each study, particularly yield and land charge assumptions (Duffy and Nanhou 2001). They found that costs decreased considerably when the yield increased from 1.5 to 6 tons/acre which shows the importance of yield in determining total production costs.

Yield

High switchgrass yields are possible and some research plots have produced yields up to 15 dry tons per acre per year (De La Torre Ugarte et al. 2003). However, high yields cannot always be expected when switchgrass is grown on marginal lands. Even though bioenergy crops can be grown in all areas of the U.S., high biomass yields are not feasible in all regions of the U.S. Switchgrass can be grown on some CRP acres but not the full 34 million acres due to geographic limitations as well as restrictions on environmentally sensitive areas (De La Torre Ugarte et al. 2003). In a study by Graham, Allison, and Becker (1996), switchgrass production regions and yields from the Oak Ridge Energy Crop County Level Database were utilized. The Oak Ridge database includes switchgrass yields ranging from an annual rate of 2 to 6.75 dry tons per acre. Table 8 provides a summary of switchgrass yield estimates from various studies.

Table 8. Switchgrass Yields

Study	Location	Yield (tons/acre)
Haque et al. (2008)	OK	3.7 – 6.2
Busby et al. (2007)	OK MS	6.85 – 7.08 12.5 – 14.87
Epplin et al. (2007)	OK	5.5
Kumar and Sokhansanj (2007)	ID	4.45
Vogel (2007)	NE, SD, ND	2.3 – 4.95
Tiffany et al. (2006)	Northern Great Plains	4
Fransen, Collins, and Boydston (2005)	WA	2.4 – 2.67
De La Torre Ugarte et al. (2003)	7 U.S. Regions	3.47 – 5.98
Duffy and Nanhou (2001)	IA	4
Kszos, McLaughlin and Walsh (2002)	7 U.S. Regions	3.47 – 5.98
Turhollow (2000)	DE	5

Existing Land Use

Existing land use prior to switchgrass planting was a very important factor as it affects land charges associated with switchgrass production. Duffy and Nanhou (2001) estimated switchgrass costs based on various land charges and found that land costs are the second most important factor in determining production costs. However, as yield increases, the effect on increased land costs is not as significant. The authors found that the type of land used for switchgrass production is very important. Switchgrass production is most economical when grown on marginal lands using the best management techniques available. Duffy and Nanhou (2001) found that switchgrass production costs were lowest when grown on land previously planted to pasture or hay.

Production and Transportation Costs

Several recent studies have examined the costs of switchgrass production and transportation. Costs vary widely due to the particular assumptions used in each study. Production cost estimates ranged from \$30/ton to \$90/ton (Duffy 2008, Duffy and Nanhou 200l, Khanna and Chapman 2007, Mapemba et al. 2007, Perrin et al. 2008, Perrin et al. 2003, Turhollow 2000, Vogel 2007, Walsh et al. 2003). De La Torre Ugarte et al. (2003) used a hybrid mathematical programming and equilibrium displacement model to examine the potential U.S. biomass supply from dedicated energy crops (switchgrass, willow, and poplar). The authors examined two possible scenarios with biomass prices around \$30 per dry ton and \$40 per dry ton. In both cases, the production of dedicated energy crops occurs on land that is diverted from traditional agricultural commodity production and CRP (Conservation Reserve Program) land. Results of the model indicated that the prices for traditional crops increase from three to nine percent in the \$30/ton scenario and from eight to fourteen percent in the \$40/ton scenario. Turhollow (1994) estimated the cost of production of hybrid poplar, sorghum, switchgrass, and energy cane for biomass and found that sorghum would be most profitable in the South and energy cane would be the lowest cost biomass crop in the Midwest.

Duffy and Nanhou (2001) analyzed the costs to produce switchgrass for biomass in Southern Iowa and found a wide range of production costs due to alternative management practices and varying soil types. The costs of production were estimated over four possible yield levels and seven scenarios based on alternative management practices. The authors used producer data as much as possible when estimating production costs. The alternative scenarios were based on various seeding practices. Switchgrass yields from actual fields ranged from 1 to over 4 tons/acre per year. Production costs (excluding land costs) ranged from $40/ton to $80/ton. The authors note that most producers who are currently producing switchgrass are not using the best management practices that could improve their yields and lower their production costs.

NREL has established a 2012 goal to produce switchgrass for $35/ton with a yield of 90 gallons per ton (Pacheco 2006). According to McLaughlin and De Le Torre Ugarte (2002), their agricultural sector model predicts that if the farmgate price of switchgrass is $40/ton, producers can earn greater profits growing switchgrass than conventional crops.

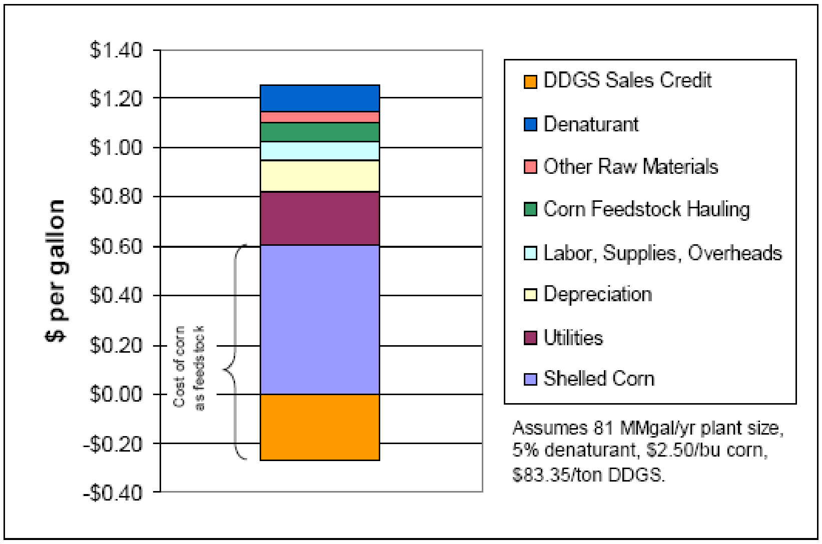
De La Torre Ugarte et al. (2003) evaluated biomass production on cropland, idle, and pasture acres and CRP acres under two management scenarios (high wildlife diversity and high biomass production). They analyzed two different cost scenarios as well. In the first scenario, they assume that switchgrass is $40/ton, willow is $42.32/ton, and poplar is $43.87/ton. In the second scenario, they assume that switchgrass is $30/ton, willow is $31.74/ton, and poplar is $32.90/ton. Results of their study indicated that energy crops have a higher potential profit than existing uses on 28.95 million acres and 132 million tons of biomass.

Kszos et al. (2002) evaluated acreage where switchgrass would compete with other major farm uses given a yield increase of 10% and/or a cost decrease of 10%. At a switchgrass production cost of $35/ton, both changes result in an increase of 14 million acres across the U.S. that could be economically competitive with alternative farm uses. They found that switchgrass production costs could be lowered by up to 17% (or $5/ton) if high yielding switchgrass varieties and better management techniques are used. Results of their study suggested an annual increase of over $6 billion in benefits values including increased farm revenues, improved soil quality, and decreased greenhouse gas emissions.

English et al. (2006) analyzed whether or not U.S. farms, forests and ranches could provide 25% of U.S. total energy needs by 2025 while continuing to produce a safe, abundant and affordable food, feed and fiber supply. They found that switchgrass production is suitable on 368 million of the total 424 million cropland acres in the U.S. However, they only limit geographic ranges where switchgrass production can occur to areas where it can be produced with high productivity under rain-fed moisture conditions. They assumed that switchgrass was not available in the first 2 years of simulation due to lag time before switchgrass can become a feedstock for ethanol production.

Grain Ethanol Production Costs

Various studies have examined the costs to produce ethanol from corn starch (i.e. grain ethanol production). Table 9 provides a summary of recent overall cost estimates for grain ethanol production. Ethanol costs are highly dependent on corn prices since corn is the main cost component. At high corn prices, ethanol plants have a much harder time making a profit. Figure 9 provides a breakdown by the EPA (Environmental Protection Agency) of costs typically associated with conventional ethanol production. Costs can be reduced by selling DDGS (dried distillers grains), which is a byproduct of conventional ethanol production.



Source: United States Environmental Protection Agency (2007)

Figure 9. Cost Breakdown of Corn Ethanol Production

Table 9. Conventional Ethanol Production Costs

Study	Corn Grain Ethanol ($/gal of ethanol)	Other Notes
Tiffany, Morey, and Kam (2008)	$2.25	$3.50 corn price, 50 MM gal/yr
	$1.83	$3.50 corn price, 100 MM gal/yr
United States Environmental Protection Agency (2007)	$1.26	40 MM gal/yr, 2012 RFS case
	$1.32	40 MM gal/yr 2012 EIA case
Eidman (2007)	$1.66	$3.00 corn price, 48 MM gal/yr
	$1.57	$3.00 corn price, 120 MM gal/yr
Tokgov et al. (2007)	$1.91	51 MM gal/yr
Burnes, Wichelns and Hagen (2005)	$1.604	151 million liter plant, CA corn
	$1.566	151 million liter plant, Midwest corn
Shapouri and Gallagher (2005)	$0.957	All plants
	$0.994	Small plants
	$0.921	Large plants
Wallace et al. (2005)	$1.023	25 MM gal/yr
	$0.955	50 MM gal/yr
Tiffany and Eidman (2003)	$1.92	$4.00 corn price, 60 mill gal/yr
	$1.83	$4.00 corn price, 120 mill gal/yr
McAloon, Taylor and Yee (2000)	$0.88	25 MM gal/yr

Cellulosic Ethanol Production Costs

While the conventional ethanol production process has been around for a long time, the cellulosic ethanol production process is just now getting started on a large scale. Only a few recent studies have analyzed the economics of cellulosic ethanol production. Costs vary based on the particular assumptions used in the study, such as feedstock costs and plant size. Estimates of total costs gallon range from $1.07 per gallon to $2.25 per gallon (Aden et al. 2002, McAloon et al. 2000, Tokgov et al. 2007, Wallace et al. 2005, Wooley et al. 1999).

Tokgov et al. (2007) analyzed potential ethanol production from corn stover. They used the best available information on production costs for corn-stover-based ethanol from the June 2002 technical report by Aden et al. of the National Renewable Energy Laboratory (NREL). For their study, they used the NREL estimates for a plant that used 2,000 tons per day and produced 51 million gallons per year. They did not use NREL's corn stover collection cost estimates since NREL arbitrarily assumes switchgrass production costs will be reduced to $33 per dry metric ton in the future through "improved collection." They compiled their own stover collection costs from Edwards and Smith (2006) for 1,265 pound bales as follows: baling, $10.10; staging, $2.25; and hauling, $15.00 ($0.30 per mile for 50 miles). According to Tokgov et al. (2007), farmers and agricultural equipment manufacturers have already squeezed costs from this system, and they do not anticipate that these costs will fall. Since some of the costs are transportation related, they would be higher under a higher oil price scenario. They used NREL estimates of the required premium to farmers of $5.50/bale and a lost fertilizer value of $4.00/bale. With an assumed conversion rate of 70 gallons/ton, they found that production and transportation costs were $73.70/ton. This is higher than NREL's estimate of $62/ton for corn stover production and transportation. The raw material cost is $1.05 per gallon.

Results of their study indicated that producers will choose to grow corn for ethanol instead of switchgrass for ethanol because an increase in the price of switchgrass will also mean an increase in the price of corn. However, they did not find cellulosic ethanol from switchgrass or corn stover to be economically viable in the Corn Belt under any of the scenarios. Cellulosic ethanol from corn stover does not enter into any scenario because of the high cost of collecting and transporting corn stover over the large distances that are required to supply a commercial-sized ethanol facility.

Cellulosic Ethanol Yields

An important variable in calculating cellulosic ethanol production costs is the number of gallons of ethanol that can be produced from a ton of feedstock. Ethanol yield varies across studies. Table 10 provides a summary of cellulosic ethanol yields used in recent studies.

Table 10. Cellulosic Ethanol Yields

Study	Ethanol Yield (gal/ton feedstock)
Tokgov et al. (2007)	70.0
Aden et al. (2002)	89.7
Wallace et al. (2005)	79.0
McAloon, Taylor, and Yee (2000)	72.0
Wooley et al. (1999)	68.0

Potential Ethanol Production

U.S. ethanol production from corn starch and corn stover was estimated based on FAPRI’s 2008 January Baseline. As shown in Table 11, if all U.S. corn grain production was used to produce ethanol, 39.2 billion gallons of ethanol could be produced in the

2011/2012 marketing year. Basically, 458 gallons of ethanol could be produced per acre of corn. About 92 million gallons of cellulosic ethanol could be produced from corn stover in the 2011/2012 marketing year (Table 12). The per acre ethanol yield for corn stover is less than corn grain. Only 358.2 gallons of ethanol could be produced per acre of corn stover. In total, almost 39.3 billion gallons of ethanol could be produced from all U.S. corn grain and corn stover production.

Table 11. Potential U.S. Corn Starch Ethanol Production

	Sept-Aug Year				
	07/08	08/09	09/10	10/11	11/12
Corn grain acres (mill)*	86.5	84.2	84.7	86.9	85.4
Corn grain yield/acre (bu)*	151.1	153.5	155.5	157.8	159.9
Corn grain ethanol total production/bu 2.87 gal/bu (bill gal)	37.5	37.1	37.8	39.3	39.2
Corn grain ethanol production/acre (gal/acre)	433.5	440.5	446.2	452.8	458.9

Source: FAPRI January 2008 baseline

Table 12. Potential U.S. Corn Stover Ethanol Production

	Sept-Aug Year				
	07/08	08/09	09/10	10/11	11/12
Corn stover yield (total mill tons available @ 25% collection efficiency)	94.5	90.5	92.2	95.9	95.6
Corn stover ethanol total production at 80 gal/ton (mill gal)	88	87	88	92	92
Corn stover ethanol production/acre (gal/acre)	338.4	343.8	348.3	353.4	358.2

CGE Analysis

Applied or computable general equilibrium (AGE or CGE) models have frequently been used to analyze a wide range of issues, including international trade, public finance, agriculture, income distribution, energy and environmental policy. The main objective of these studies is to examine the overall economic impact in an economy resulting from changes in a particular sector. Computable general equilibrium models allow for the inclusion of much more detail and complexity than simple analytical general equilibrium models. These models can be used to assess economy-wide, inter-industry responses to major structural change. In contrast to a partial equilibrium approach, a general equilibrium approach takes into account that a shock in one market may have a spillover effect in other markets as well. An applied or computable general equilibrium model numerically simulates the general equilibrium structure of an economy. CGE models represent the circular flow of goods in a closed economy, as shown in Figure 10. Basically, households own the primary factors of production (land, labor, capital, and natural resources) and consume the produced goods. Firms produce commodities by renting factors of production (i.e. capital and labor) from households. Households use payments received for capital and labor services to purchase goods produced by firms. The government collects taxes and makes transfer payments to households.

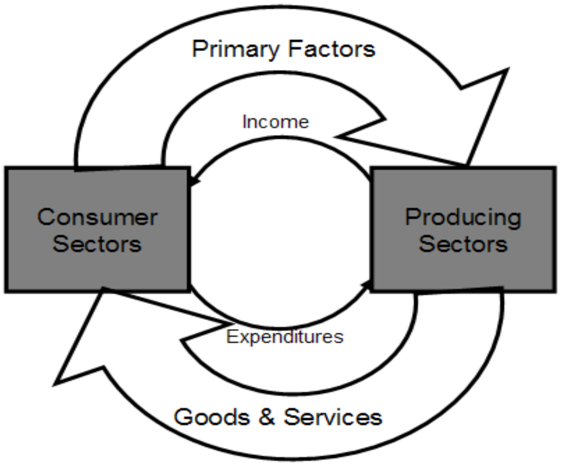


Figure 10. Circular Flow of the Economy

In a simple general equilibrium model, there are a specific number of consumers each with an initial endowment of N commodities and a set of preferences[1]. Market demands equal the sum of all consumer demands and are nonnegative, continuous, and homogenous of degree zero in prices. Market demands must satisfy Walras's law, such that consumer expenditures equal consumer incomes at all prices (or market excess demands equal zero at all prices). Production technology generally exhibits constant returns to scale or nonincreasing returns to scale and producers are assumed to maximize profit. At equilibrium, market demand equals market supply for all commodities. Each sector has a system of consumption, production, and trade equations. The Walrasian equilibrium leads to conservation of product and value (Wing 2004).

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[1] This discussion is adapted from Wing (2004).

Conservation of product requires that household factor endowments and produced commodities must be completely absorbed by firms or households within the economy. This is also referred to as market clearance (i.e. factor demands by firms must equal factor supply by households). Firms fully employ all household factor endowments and households consume all commodities produced by firms. Any commodities in excess supply must have a zero price. Conservation of value requires that total expenditures must equal total income for each activity in the economy. This condition reflects constant returns to scale in production and perfect competition in commodity markets which implies that producers make zero profit. Returns to household's for primary factors accrue to households as income used to purchase commodities from firms. This condition is known as income balance. The Walrasian equilibrium is defined by the three conditions of market clearance, zero profit, and income balance. If these conditions hold, the CGE model simultaneously solves for the set of prices and the allocation of commodities and factors that support general equilibrium.

CGE Use in Energy and Agriculture

The AGE framework was first applied to an energy issue by Hudson and Jorgenson (1974) following the first major oil shock in the 1970's. The model was used to forecast energy demand from 1975-2000 and evaluate how tax policies affect energy use in the United States. Manne (1977) also created a similar model to Hudson and Jorgenson, but included a more detailed treatment of energy technologies while aggregating the rest of the economy. These two early models provided the basic framework to apply AGE or CGE techniques to the energy sector. In the past three decades, many AGE or CGE models have been created to analyze the energy sector and its economic and environmental consequences (some recent examples are shown in Table 13). Many of these models specifically target global climate change, while others have a broader focus on energy related issues. Some energy models warrant further discussion in the present context, as they illustrate some of the model features that are planned for this dissertation project.

Table 13. Recent CGE Studies of Energy Use and Climate Change

Study
Fujino et al. (2006)
Kemfert et al. (2006)
Klepper and Peterson (2006)
Kurosawa (2006)
Reilly et al. (2006)
Viguier et al. (2006)
Nijkamp et al. (2005)
Babiker et al. (2004)
Manne and Richels (2004)
Bernard and Vielle (2003)
Bernstein et al. (2003)
Tol et al. (2003)
Kurosawa et al. (1999)

The Global Relationship Assessment to Protect the Environment (GRAPE) model (Kurosawa et al. 1999) is an example of a multi-region world trade CGE model that reflects competition for land use between agricultural and forestry, and incorporates biomass energy production potential into an energy-centric model. The authors predict that biomass energy will continue to make up a relatively small proportion of world energy use during this century. However, it is unclear to what extent fossil energy depletion is reflected in their model. The multi-region, multi-sector Global Trade Analysis Project model (GTAP) model is an international trade CGE model developed at Purdue University. The energy-intensive version of the GTAP model, GTAP-E, (Nijkamp et al. 2005) is a global trade model which incorporates more disaggregation of agricultural sectors than most other energy CGE models. However, biofuels are not directly represented in this model and agricultural issues have not been a main focus of the model applications.

The MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev, et al., 2005) is a 16-region, 25-sector world trade model. The model includes linkages to physical flows of fossil energy allowing fossil depletion effects to be examined and includes a three-sector representation of agriculture (crops, livestock, forestry). Reilly and Paltsev (2007) extend the model to include electricity and liquid fuel production from biomass. Land is employed directly in these production activities rather than using the output or coproduct from an agricultural sector as an intermediate input. They found that biofuel use in the U.S. could constitute 55% of liquid fuel use if significant restrictions on greenhouse gas emissions were established. In this case, the U.S. would become a significant importer of agricultural output.

Hertel (2002) provides a nice summary of CGE models targeted toward agricultural policy issues. While many of the models focus on a single region, several recent papers have examined the effects of climate change, water use and trade policy issues on world markets. Darwin et al. (1995) analyzed the effect of global climate change on world agriculture using the FARM CGE model, which links climate to available land and water resources. The model examines the extent that farmers respond to climate change and simulates the competition between agriculture and the rest of the economy for land and water use. The results of their study indicated that during the next century, climate change is unlikely to have a significant effect on world food production, but some regions will experience declining production.

Berrittella et al. (2007) used a 16-region, 17-sector CGE model to examine the effects of water resources and water scarcity on international agricultural trade. The authors found that under a restricted water scenario, total welfare is lowered due to constrained production. Francois et al. (2005) developed a 15-region, 18-sector world trade model with 7 agricultural sectors to analyze the possible economic effects of agricultural, trade, and tariff liberalization. Burfisher et al. (2002) used a 3-country, 26-sector CGE model to examine the economic effects of agricultural policies resulting from NAFTA. They found that multilateral trade liberalization was more beneficial than regional trade agreements.

Incorporation of New Biofuel Technologies into CGE Model

CGE models have also become more widely used to evaluate the effects of new biofuel technologies on the economy. Raneses, Hanson, and Shapouri (1998) used a

CGE model to analyze the economic effects of using cropland for fuel use instead of food use. They specifically analyzed the outcome of using switchgrass as a biomass source. In their study, the feedcrop sector was broken up into other hay and other feedcrops and switchgrass was treated as an alternative use of other hay. The CGE model was built using a 1993 base year SAM which does not include a switchgrass production sector. Therefore, other hay was could be used for livestock feed or fuel. Gan and Smith (2002) used a CGE model to analyze changes in energy prices as a result of alternative carbon tax scenarios on fossil fuels. They compared the production costs of fossil fuels generated by the CGE model to the costs of ethanol production from hybrid poplar, hybrid willow, switchgrass, and logging residues (which is a joint product). They estimated the joint and marginal costs to harvest both wood products and logging residues using an integrated harvesting system.

Kancs and Kremers (2002) used a CGE model to analyze the effects of renewable energy policies on the Polish bioenergy sector. The model allowed for multiple input and output technologies and could explicitly model the conversion of biomass into energy. Results of their study indicated that a fossil energy tax is more beneficial to the bioenergy sector than a subsidy. Sands and Schumacher (2003) incorporated advanced electric generating technologies into a CGE model of the German economy to analyze the cost of lowering carbon emissions. McDonald, Robinson, and Theirfelder (2006) employed a CGE model to examine the effect of using switchgrass as a bioenergy crop. They used the GTAP database version 5.4 for their study. In the GTAP database, switchgrass is included as an aggregate of cereals and other similar field crops. For their study, they added a separate switchgrass commodity/activity for only the USA since it is not a traded commodity and its use should not be altered in other countries (indirect effects may occur in other countries as other traded crops compete with switchgrass for land). They assumed that the primary input coefficients for switchgrass were equal to other U.S. cereal crops and the intermediate input coefficients were 70% of those for cereals in each region.

Dixon, Osbourne, and Rimmer (2007) used a dynamic CGE model to analyze the effect of a partial replacement of crude petroleum with biomass. Results indicated that biomass substitution will be likely and the world price of crude oil will decline. The authors assume that the biomass feedstock is mainly corn, however; this is not explicitly modeled. Gurgel, Reilly, and Paltsev (2007) used a CGE model to analyze the possible effects on land use resulting from a global biofuels industry. In their model, biomass production is parameterized using a “second generation” cellulosic biomass conversion technology and agro-engineering data on yields. The USAGE model is a CGE model of the U.S. economy that was created by Monash University and ERS (Economic Research Service). This model was recently extended to include ethanol production from both switchgrass and crop residues.

Top-Down and Bottom-Up Approaches

When incorporating advanced technologies into CGE models, it is somewhat of a challenge to do so in a manner that is consistent with engineering cost models (Sands and Schumacher 2003). CGE models are generally developed using a top-down approach or a bottom-up approach. The bottom-up method allows for a detailed representation of energy technologies using engineering data and can be used to find the least-cost combination of energy technologies to meet energy demands (McFarland, Reilly and Herzog 2004). The main advantage of this method is that new or future technologies can be included in the model. In the top-down approach, energy technologies are characterized by using aggregated production functions for each sector in the economy (McFarland et al. 2004). These models depict the supply of specific technological processes at an aggregated level by using substitutable production functions and abstract elasticities of substitution between factors of production (Steininger and Voraberger 2003). Basically, in the top-down approach, there is continuous substitution among inputs (e.g., between petroleum and agricultural feedstocks) used in energy production. The demand for energy inputs is derived from the demand for output produced by various sectors.

In the bottom-up approach, this is explicitly modeled as a shift between energy technologies (McFarland et al. 2004). Some developers integrate top-down representations of the economy and bottom-up energy technologies in a consistent modeling framework (Kemfert et al. 2006, Sands and Schumacher 2003). McFarland, Reilly, and Herzog (2004) discuss a method to incorporate bottom-up engineering data into the EPPA model, which is a top-down economic model. Reilly and Paltsev (2007) analyzed various greenhouse gas emissions by incorporating biofuels production and land competition into the EPPA model. Sands and Schumacher (2003) also followed this approach and constructed a fixed-coefficient production function for various electric generating technologies using engineering cost models. They used a nested logit structure to represent the electricity technologies and the technologies compete on levelized costs per kWh at each nest (Sands and Schumacher 2003).

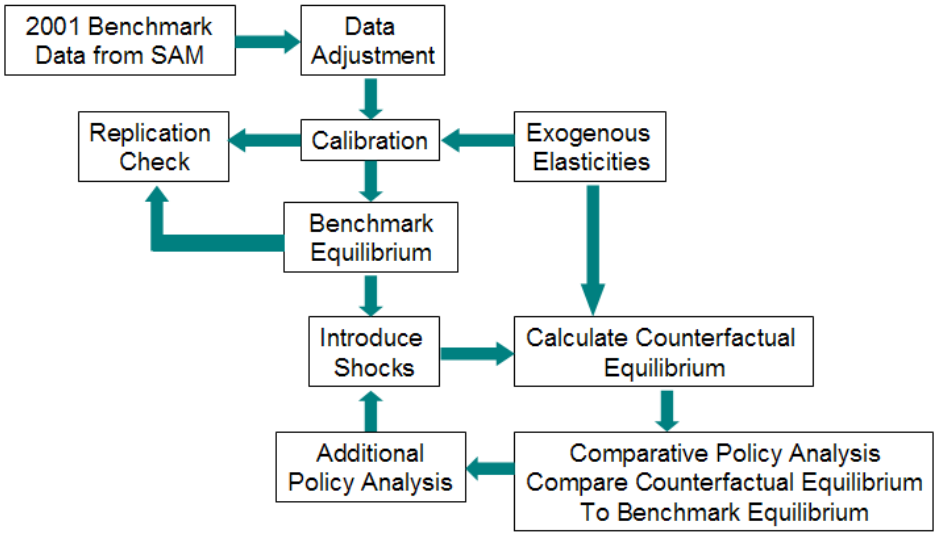
Another approach is to run bottom-up and top-down models independently of each other, in which case the results from one model feeds into the other model (Sands and Schumacher 2003). Rutherford et al. (1997) attempted to bridge the gap between top-down and bottom-up models by linking a detailed partial equilibrium model of the energy sector to a general equilibrium model. The MEGABARE model used the 'technology bundle' approach for energy substitution instead of using nested CES production functions (Fisher 1996). The model includes a bottom-up specification for the technology bundle, which includes a detailed representation of energy technologies, and a top-down specification for the rest of the model. The GREEN model uses a top-down approach but includes some bottom-up features in backstop technology (e.g. biomass or oil shale) specifications (Burniaux, Nicoletti and Oliveria-Martins 1992). In the GTAP-E model, energy substitution is represented by a top-down approach in which elasticities determine the degree of energy substitution (Burniaux and Truong 2002).

Steininger & Voraberger (2003) followed the top-down approach but also included a more detailed analysis of the various technologies in the biomass energy sector. They used a CGE model to examine the effect of various biomass energy technologies on the Austrian economy. They estimated the potential supply of 30 types of biomass by analyzing cost information. The model was constructed so that when the supply of energy with biomass technologies costs more than fossil fuel technologies, the government can either establish subsidies for biomass production or establish a CO_2 tax (which increases the relative price of fossil fuel technologies). While these studies do focus on new energy technologies, they do not incorporate both an explicit sector for agricultural biomass feedstocks and allow for joint products within a CGE framework.

CHAPTER IV

METHODOLOGY

A comparative static computable general equilibrium (CGE) model of the world economy was used for this dissertation. Figure 11 shows the basic components of CGE analysis. The benchmark data used for this analysis include a Social Accounting Matrix (SAM) representation of the Global Trade Analysis Project database version 6.0 (GTAP6) (see Hertel (1997) and McDonald and Thierfelder (2004), for a detailed description of the database and SAM derivation). To build the SAM, the GTAP database was converted from a series of multi-dimensional sub matrices to a single three dimensional SAM (McDonald and Theirfelder 2004). Basically, the SAM provides a detailed view of the major flows of income sources and expenditures in the world during 2001. All of the major economic transactions that occur among the agents in the world economy during 2001 are shown in the SAM. The rows of the SAM represent income flows and the columns represent expenditure flows. Since incomes and expenditures for each transaction must balance, the sum of each row must equal its corresponding column (Diao, Yeldan and Roe 1998). The SAM data portray the yearly outcome of the world economy in long-term equilibrium which allows the use of the SAM data as a benchmark to compare alternative policy scenarios.



Data Source: Adapted from Shoven and Whalley (1992)

Figure 11. CGE Model Flowchart

The GTAP6 database contains data on the circular flow of funds in the year 2001 among 57 economic sectors in each of 87 regions, as well as trade between regions, taxes and tariffs. The economic data found in GTAP are the National Income and Product Accounts (NIPAs) of countries. In the GTAP dataset, the quantity of inputs and outputs in the economy are measured by total expenditures or sales, which allows for greater aggregation (Paltsev et al. 2005). The basic economic theory behind this concept is that the commodity prices reflect their marginal value as inputs used in production or consumption.

The 2001 base year data were updated to a 2008 base year by updating capital, labor, and natural resource endowments for each region. Data on capital and population growth for each region for the 2001 – 2008 time period were obtained from the World

Bank database (World Bank 2008). Labor endowments were updated using population growth data.

The calibration procedure basically involves the selection of parameter values (Mansur and Whalley 1984). The first stage is to specify a functional form for demand and production functions (Shoven and Whalley 1992). The functional form should be chosen so that key parameters can easily be incorporated (Shoven and Whalley 1992). The calibration procedure uses the data in the SAM to assign values to the parameters and variables of the mathematical equations. The calibration procedure does not initially solve for a equilibrium, instead it uses the observed equilibrium to solve for model parameters. The chosen economy is assumed to be in equilibrium and the calibration procedure chooses parameters that will reproduce the benchmark data as an equilibrium solution (Shoven and Whalley 1992). This replication step serves as a valuable accuracy check of computer code because a failed replication check will point to possible programming errors (Shoven and Whalley 1992). The replication does not fail when the model reproduces a quantity value equal to its corresponding value in the SAM. The parameter values can then be used to solve for alternative equilibrium resulting from shocks, such as changes in factor endowments, changes in government policy, or technological advances. To analyze particular policy changes, a counterfactual equilibrium is computed for exogenous changes or policy evaluation questions. The counterfactual equilibrium from each shock is then compared to the benchmark equilibrium to evaluate the effects of these shocks economy.

Since the benchmark data from the SAM are estimated in value terms, the units for both goods and factors must be chosen so that separate price and quantity observations are obtained (Shoven and Whalley 1992). Following (Harberger 1962), the commonly used units convention was used which means that the units of all goods are chosen so they have a price of unity in the base year. The changes in prices from each shock are then analyzed as relative changes to the base year equilibrium.

Benchmark data only provide price and quantity observations for a single equilibrium solution (Shoven and Whalley 1992). For Cobb-Douglas production and demand functions, the parameters can be uniquely determined based on the single price and quantity observation (Shoven and Whalley 1992). However, for CES functions, the single price and quantity observation does not uniquely identify values for the parameters (Shoven and Whalley 1992). Therefore, particular values for the substitution and transformation elasticities must be specified exogenously (Shoven and Whalley 1992). The CGE model was formulated as a mixed-complimentary problem in GAMS.

As noted by Sanchez (2004), elasticity values are extremely important to CGE modeling and play a crucial role in how the model functions and responds to external shocks. On the production side, producers minimize costs by choosing the optimal mix of value-added and intermediate goods and maximize profit by selecting the optimal use of output for domestic sales and exports (Sanchez 2004). On the consumption side, consumers minimize costs by choosing the optimal mix of domestically produced and imported goods and services. The values of substitution and transformation elasticities affect the levels of quantity changes associated with relative price changes. Elasticity estimates are commonly borrowed from other studies when sufficient data are not available for estimation (Sanchez 2004). For this model, elasticity values for the sectors in the GTAP database were set at values similar to those used in the GTAP CGE model. For the new biofuel sectors, substitution elasticities were set at low values to allow little substitution between inputs.

A noteworthy feature of the calibration technique is that there are no statistical tests of the model specification since the parameter calculation is a deterministic procedure (Shoven and Whalley 1992). This calibration technique relies on the key assumption that the benchmark data represent an equilibrium for the particular economy being analyzed (Shoven and Whalley 1992). CGE models are often very complex and require the estimation of thousands of parameters which means that stochastic econometric estimation methods are generally not appropriate.

Model Description

The CGE model is similar to the MIT EPPA model (Paltsev et al. 2005), but provides a greater disaggregation of agricultural sectors, separates biofuel production from the production of biofuel feedstocks, does not include recursive dynamics, and includes less emphasis on issues relating to climate change, alternative forms of transportation, and alternative electricity generation technologies.

Regions

The CGE model includes 9 regions, which is an aggregation of the 87 regions in GTAP6. The basis for the aggregation includes importance in agricultural and other trade, consistent treatment under trade policy, and geographical proximity. Regional aggregation was also chosen to reduce computational difficulties. The regions are shown in Table 14.

Table 14. Regions Represented in the Model

Region Description	Code
United States	USA
Brazil	BRA
Rest of South America, Mexico, Central America and Caribbean	RSA
China and Hong	CHK
India	IND
Other High Income Far East, including Japan, Australia, New Zealand	OFE
EU-15, EFTA and Canada	EUF
Other Europe and Former Soviet Union	EUO
Rest of the World, including Africa and the Middle East	ROW

Sectors

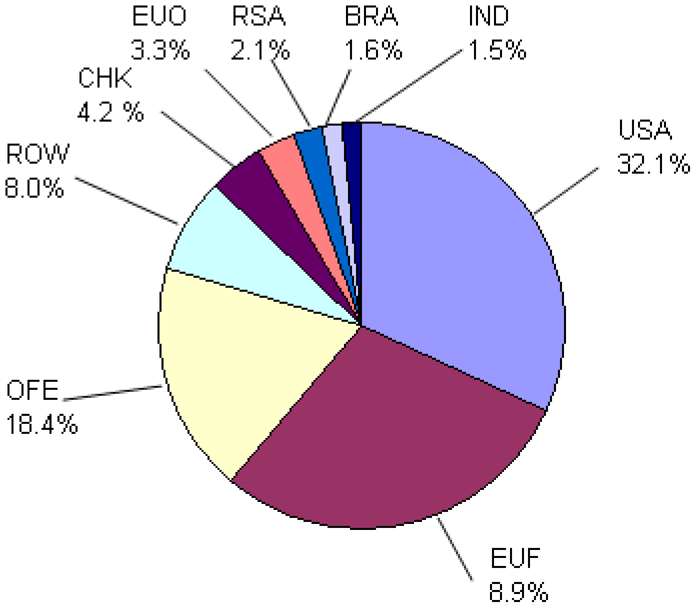
The CGE model consists of 32 sectors, which is an aggregation of the sectors found in the GTAP6 database (activities not central to this dissertation were aggregated). Additional sectors relating to renewable fuel production were incorporated into the model. These sectors include: ethanol from corn grain, ethanol from corn stover, switchgrass, and ethanol from switchgrass. These alternative biofuel technologies will only enter into the model if they become economically competitive with existing technologies. The top nest in the production technology of these commodities features primary feedstocks and value-added as fixed factors to allow calibration with engineering data and estimates of future conversion efficiency. The sectors represented in the model are listed in Table 15.

Table 15. Sectors Represented in the Model

GTAP6 Sectors	New sectors
Paddy rice	Switchgrass
Cereal grains	Ethanol from corn grain
Fruits/Vegetables	Ethanol from switchgrass
Oil seeds	Ethanol from corn stover
Plant-based fibers	
Livestock	
Raw milk	
Forestry	
Coal	
Natural gas	
Food Products	
Wood and paper products	
Chemicals, rubber, and plastics	
Gas distribution	
Services	
Wheat	
Vegetables, fruit, and nuts	
Sugar cane and beets	
Other crops	
Animal products	
Wool and silk	
Fishing	
Crude oil	
Minerals	
Clothing and textiles	
Manufactured goods	
Electricity	
Water	
Transportation	

Descriptive Statistics

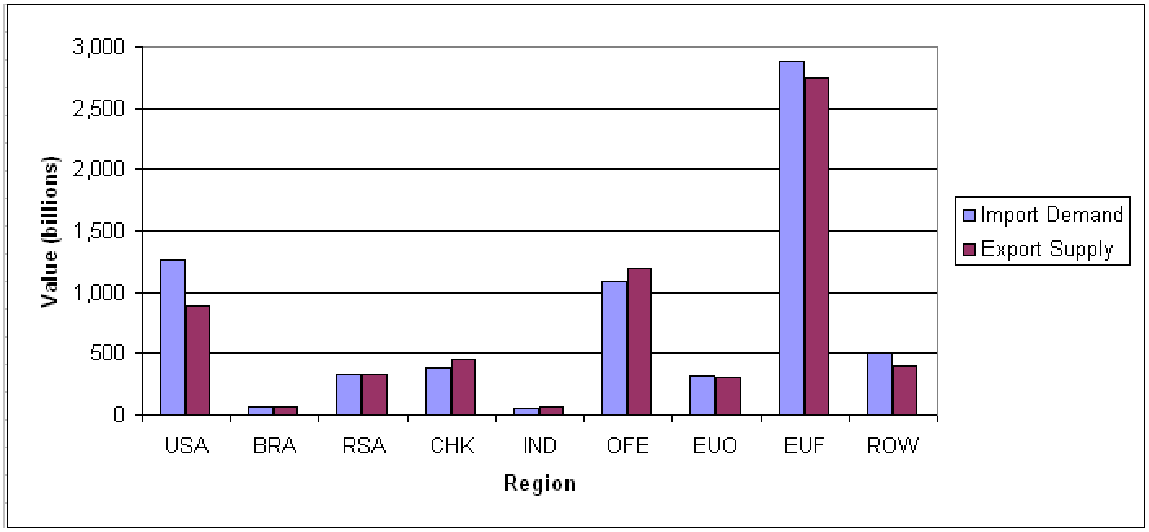
A general overview of the nine regions represented in the CGE model was assembled using the GTAP6 data. Figure 12 provides a comparison of the relative size of each region in the 2001 economy as measured by Gross Domestic Product (GDP). The US, EU, and OFE regions are the largest in terms of GDP. These three regions also dominate global imports and exports (Figure 13).



Source: Dimaranan (2006)

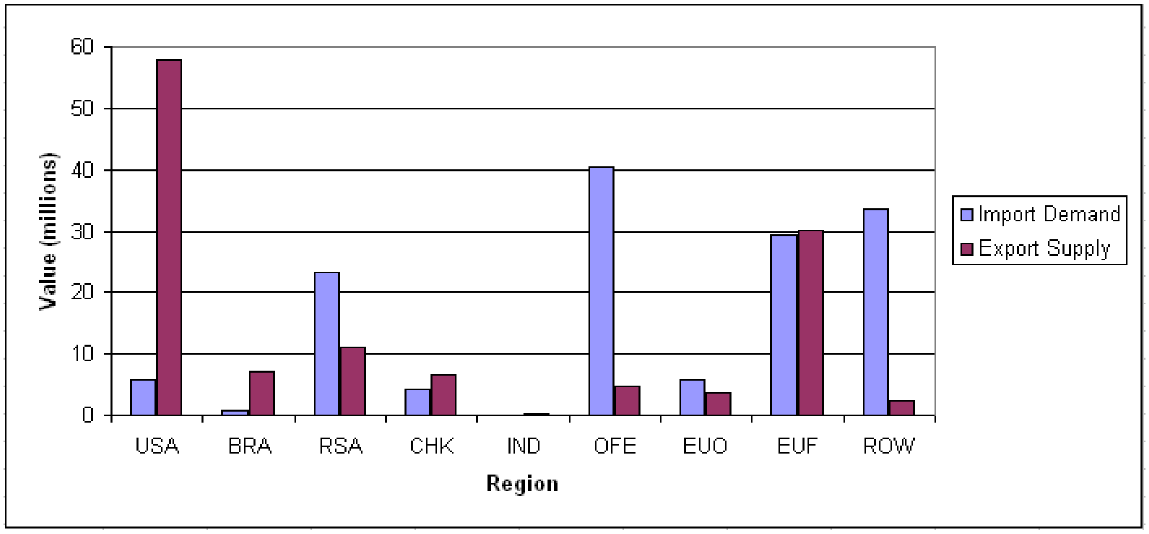
Figure 12. Gross Domestic Product (GDP) by Region (% Shares)
Note: See Table 14 for definitions.

The US and EUF regions dominate exports of cereal grains (Figure 14), while the OFE, EUF, and ROW import large amounts of cereal grains. As for wheat trade, the US and EUO regions export a large percentage of total wheat supply (Figure 15). The OFE, EU, and ROW regions dominate wheat imports.



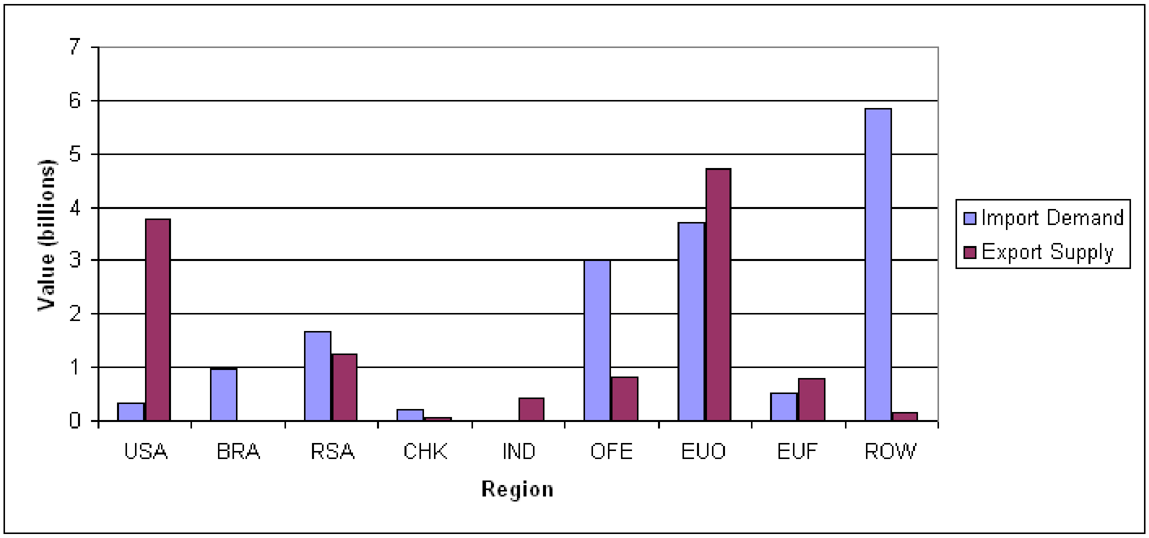
Source: Dimaranan (2006)

Figure 13. Total Import Demand and Export Supply by Region
Note: See Table 14 for definitions.



Source: Dimaranan (2006)

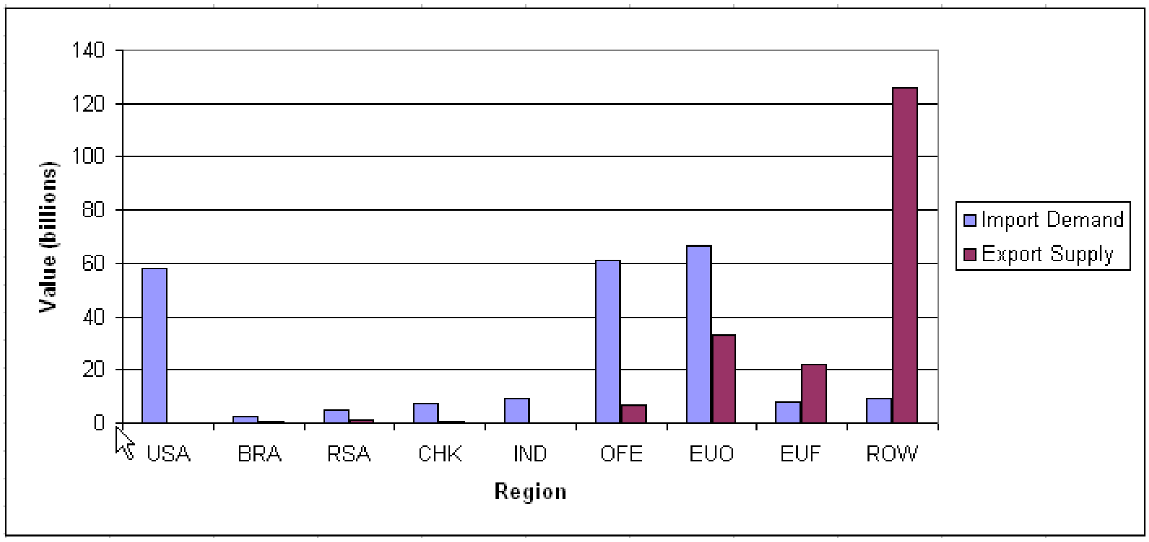
Figure 14. Cereal Grains Trade by Region
Note: See Table 14 for definitions.



Source: Dimaranan (2006)

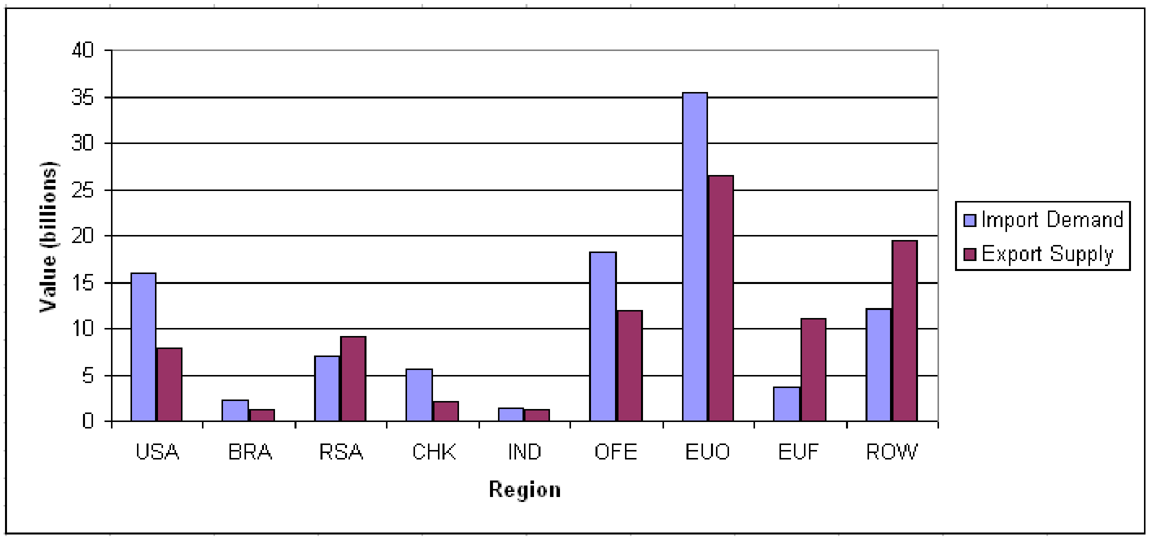
Figure 15. Wheat Trade by Region
Note: See Table 14 for definitions.

The USA, OFE, and EUO regions dominate world crude oil imports, while the ROW region provides the majority of crude oil exports (Figure 16). The EUO region imports the largest percentage of petroleum and coal products, followed by the OFE, USA, and ROW regions (Figure 17).



Source: Dimaranan (2006)

Figure 16. Crude Oil Trade by Region
Note: See Table 14 for definitions.



Source: Dimaranan (2006)

Figure 17. Petroleum and Coal Products Trade by Region
Note: See Table 14 for definitions.

Primary Factors

Each region is endowed with four primary factors: capital, labor, land, and natural resources. Capital, labor, land, and natural resources are assumed to be immobile across regions, but fully mobile across sectors. This implies that the model solves for a long-run equilibrium. Labor endowments in each region changed in proportion to exogenously specified population growth (which was projected based on observed population dynamics).

Both producers and consumers make input substitutions when making production and consumption decisions. Based on the technologies used in production, producers can substitute between labor, capital, land and natural resources. The tradeoffs made by producers and consumers are captured by the elasticities of substitution, which are key parameters in the CGE model.

Production

Nested CES production functions were used to represent constant returns to scale (CES) production technologies. The nested structure allowed for greater flexibility in setting elasticities of substitution for fuels. For each sector, the production functions represent the ways in which capital, labor, land, natural resources, and intermediate inputs can be used to produce output. For each region and each sector, a representative firm maximizes profits subject to its production technology constraints by choosing the optimal level of output, quantities of primary factors and intermediate inputs from other sectors. The CES production function can be written as:

$$(2) \qquad y = \left(\sum_i a_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad ,$$

where y is output, σ is the elasticity of substitution between factors of production, a_i is the share parameter (i.e. weighting parameter) for the ith commodity, and x_i is the quantity of the ith factor of production. The degree of substitutability between factors is represented by sigma (σ). As sigma approaches zero, goods become perfect compliments. As sigma approaches one, producers use fixed fractions of each factor. A value of sigma greater than one implies that the goods are partial substitutes. As sigma approaches infinity, goods become perfect substitutes. For constant returns to scale technology to hold, the following condition must hold:

$$(3) \qquad \sum_i a_i^{\frac{1}{\sigma}} = 1$$

The producer's profit maximization problem can be written as:

$$(4) \qquad \max = \varphi \left(\sum_i a_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad \text{s.t.} \quad \sum_i k_i w_i = y \quad ,$$

where y is the total cost, φ is the scale parameter (i.e. constant defining units of measurement), σ is the elasticity of substitution between factors of production, a_i is the share parameter for the ith commodity, x_i is the production input, k_i is the quantity of the ith factor of production, and w_i is the cost of ith input. Solving for the input quantities, we get the following equation:

$$(5) \qquad k_i{}^*(w, y) = y\left(\frac{1}{\varphi}\right)\left(\frac{a_i}{w_i{}^{\sigma}}\right)\left(\sum_j a_j w^{1-\sigma}\right)^{\frac{-\sigma}{\sigma-1}}$$

Solving for the output quantities, we get the following:

$$(6) \qquad x_i = k_i{}^* w_i{}^{\sigma}(1+t_i)^{\sigma}$$

The producer’s cost function can be written as:

$$C(w, y) = \sum_i w_i k_i{}^*(w, y)$$

$$(7) \qquad = y\left(\frac{1}{\varphi}\right)\left(\sum_j a_j w_j{}^{1-\sigma}\right)^{\frac{-\sigma}{\sigma-1}}\left(\sum_i a_i w_i{}^{1-\sigma}\right)$$

$$= y\left(\frac{1}{\varphi}\right)\left(\sum_j a_j w_j{}^{1-\sigma}\right)^{\frac{1}{1-\sigma}} ,$$

where y is the total cost, φ is the scale parameter (i.e. constant defining units of measurement), σ is the elasticity of substitution between factors of production, a_i is the share parameter for the j^{th} commodity, and w_i is the cost of j^{th} input. The unit cost function is derived by dividing the cost function by output:

$$(8) \qquad \frac{C(w, y)}{y} = C(w) = \left(\frac{1}{\varphi}\right)\left(\sum_j a_j w_j{}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

Domestic production is either sold to domestic consumers or exported based on the imperfect transformability assumption, which is represented by a constant elasticity of transformation (CET) function. The CET function determines the split of total domestic output into domestic supply and exports.

Calibrating the Production Function for Existing GTAP Sectors

The benchmark equilibrium observations of the use of each input in each sector were used to calibrate the CES production functions. For the value-added nest, the values of capital, land, labor, and natural resources along with tax rates were obtained from the benchmark equilibrium data. Units for factors were chosen so that all prices equal one at the benchmark equilibrium. Elasticity values were chosen and the share parameters were calibrated as follows:

$$(9)\qquad a_i = \frac{k_i w_i^{\sigma}}{\left(\sum_j k_j^{\frac{1}{\sigma}} w_j\right)^{\sigma}} \quad ,$$

where σ is the elasticity of substitution, a_i is the share parameter for the i^{th} input, k_i is the quantity of the i^{th} input, k_j is the quantity of the j^{th} input, w_i is the cost of the i^{th} input, and w_j is the cost of the j^{th} input. Assuming all w_i and w_j equal 1, a_i reduces to:

$$(10)\qquad a_i = \frac{k_i}{\left(\sum_j k_j^{\frac{1}{\sigma}}\right)^{\sigma}} \quad ,$$

which implies that k_i is equal to total expenditures on the i^{th} input.

Values for the scale parameter (phi), were derived from the zero-profit conditions for each industry. The zero-profit condition can be written as:

$$(11)\qquad p_j(1-t_y)y_j = y_j\left(\frac{1}{\varphi}\right)\left(\sum_i a_i\left(1+t_i\right)^{1-\sigma} w_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \quad ,$$

where p_j is the price of output, y is the total cost, φ is the scale parameter, σ is the elasticity of substitution between factors of production, a_i is the share parameter for the i^{th} input, w_i is the cost of the i^{th} input, t_i is the tax rate on the input, and t_j is the tax rate on the output. Solving for the scale parameter, ϕ, we get the following:

$$(12) \qquad \varphi = \frac{1}{p(1-t_y)}\left[\sum_{a_i} a_i(1+t_i)^{1-\sigma} w_i^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \quad ,$$

where p is the price of output, σ is the elasticity of substitution between factors of production, a_i is the share parameter for the i^{th} input, w_i is the cost of the i^{th} input, t_i is the tax rate on the input, and t_y is the tax rate on the output. Phi is a function of the quantity of inputs, price of inputs, tax on input use, price of output, and the elasticity of substitution.

Consumption

Each region includes a single representative household endowed with the primary factors and a nested CES utility function reflecting preferences over savings and all final goods. In each period, the representative household chooses a level of consumption to maximize utility subject to a budget constraint. The representative household saves a fixed proportion of income in each period. The household's utility maximization problem can be represented as:

$$(13) \qquad \max_{\{xi\}}\left\{\left(\sum_i a_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}\right\} \qquad \text{s.t. } \sum_j x_j p_j \le I \quad ,$$

where a_i is the share (or weighting) parameter for the i^{th} consumption good, σ is the elasticity of substitution between goods, x_i is the ith consumption good, x_j is the j^{th} consumption good, p_j is the price of j^{th} good, and I is income. Solving for the Marshallian demands, we get the following:

$$(14) \qquad x_i^*(p, I) = \frac{a_i I}{p_i^{\sigma} \sum_j a_j x_i p_j^{1-\sigma}} \quad ,$$

where a_i is the share parameter for i^{th} consumption good, x_i is the ith consumption good, x_j is the j^{th} consumption good, p_j is the price of j^{th} good, and I is income. Similar to the producer case, sigma represents the degree of substitutability between consumption commodities. The parameters of the CES demand functions are calibrated from the benchmark equilibrium observations on commodity purchases by households.

In each period, a Walrasian equilibrium is found that satisfies the three conditions of zero profit, market clearance, and income balance. The Armington assumption was used for this model (Armington 1969), since calibration is otherwise difficult. The homogeneity assumption implies perfect substitutability between domestic and imported goods within the same category. However, since goods within the same category can be both exported and imported, the homogeneity assumption can lead to problems. The Armington assumption differentiates domestic goods and imported goods within the same category (i.e. they are imperfect substitutes).

Model Features

The main features of the CGE model include:

- Calibration for an arbitrary number of households, producing sectors, and primary factors
- Replication of the base year equilibrium
- A simple government that pays out fixed proportions of revenue to households and for commodities
- Taxes on households’ income
- Taxes on factor use
- Taxes on intermediate use of commodities
- Taxes on final use of commodities
- Nested CES production function: inputs into the top nest are a value-added bundle and an intermediate bundle (Figure 18).
- CES final demand

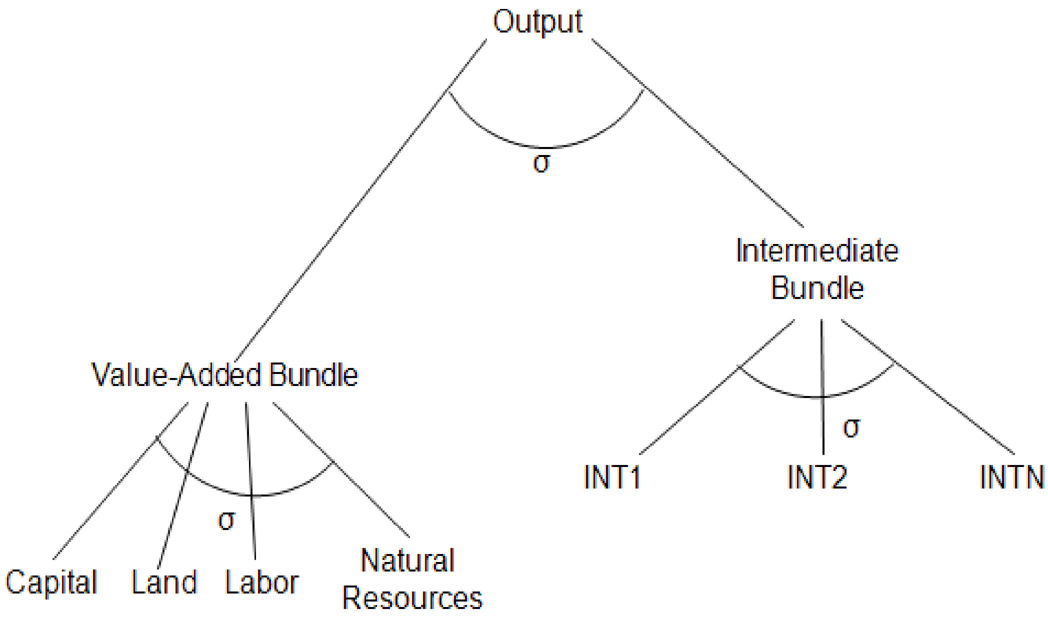


Figure 18. Commodity Production

Basic Model Relationships

The CGE model includes the following basic relationships for factor markets, commodity markets, households, government, and trade (Figure 19):

1. Factor Market Balance
    - Total market demand for factors equals total market supply of factors by households
2. Commodity Market Balance

   - Total use of each commodity must equal government purchases of the commodity + intermediate use of the commodity by each sector + household use of the commodity + investment purchases of the commodity
   - Total demand for each commodity including consumer purchases, intermediate use, and government purchases must be less than or equal to total production of the commodity

3. Firm Zero Profit Conditions
   - Prices are set so that total firm revenues equal total firm costs (zero profits)
   - All rents are allocated to factors
4. Household Income
   - Household income is comprised of factor sales adjusted for taxes plus government transfer payments
   - Total household income equals total household expenditures
5. Household Commodity Demand
   - Households have a CES utility function
   - Commodity demand is subject to a budget constraint
6. Producer Factor Demand
   - CES production functions
   - Factor demand is a function of production quantity and factor prices
7. Government Tax Income
   - Total government transfer payments plus government consumption equal total government tax revenue

- Government uses tax revenues to purchase goods and make transfer payments to households

8. Trade

- Total exports of each commodity must equal the corresponding import quantity for the relevant trade partner

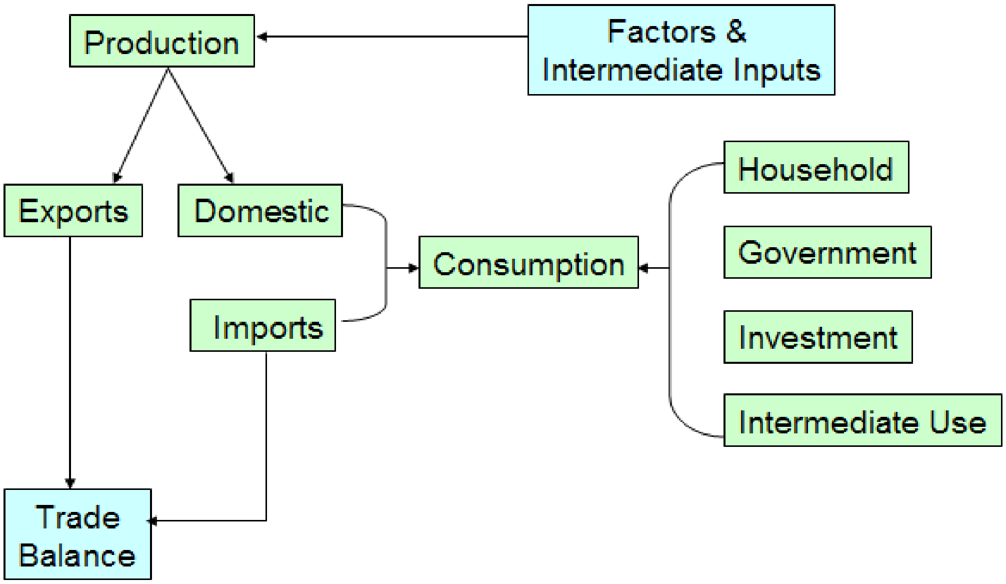


Figure 19. Commodity Flow

Addition of New Biofuel Sectors

To incorporate biofuel sectors into the CGE model, new agricultural commodity sectors were added to the model that are not currently produced or utilized, but may enter into production under favorable market conditions or technologies. This refers to the production of switchgrass as a dedicated biomass feedstock and the collection of corn stover as a biomass feedstock. Agronomic and engineering data for cellulosic ethanol production from switchgrass were used to calibrate the model parameters. Corn stover collection for biomass was specified as a fixed-proportions joint product of the sector producing other primary commodities (i.e. corn and corn stover). Agronomic data were used to determine the quantities of the joint products produced per unit of primary output. The incorporation of joint products into the CGE model allows for a more realistic depiction of the most likely feedstocks that would be initially employed in cellulosic ethanol production. At this point in time, it may not be practical to assume that cellulosic ethanol production will be fueled by dedicated biomass feedstocks. This approach ensures that dedicated biomass feedstocks do not displace other agricultural commodities to a disproportionate and unrealistic extent.

The GTAP database does not include a separate commodity/activity account for switchgrass, corn stover, corn, or ethanol. Corn is included in the cereal grains sector and switchgrass is included in an aggregated cereals and field crops sector. McDonald, Robinson, and Theirfelder (2006) used the GTAP database to analyze switchgrass production and added a separate switchgrass commodity and activity accounts to the SAM for the U.S. They assumed that switchgrass would not be traded and that switchgrass production would not change in other regions. They assumed that the only inter-regional linkages will be indirect – an increase in switchgrass production in the U.S. takes land from other agricultural sectors leading to production changes and trade effects. We have also adopted this assumption and have only added new commodity and activity accounts to the SAM for the United States.

To parameterize the CES production function for the switchgrass sector, McDonald, Robinson, and Theirfelder (2006) assumed that switchgrass production costs were the same as production costs for the other cereals and field crops sector that already exists in the GTAP database. For this dissertation, we used actual switchgrass production data to determine total production costs for switchgrass. To parameterize the production function, we followed a similar approach to McDonald, Robinson, and Theirfelder (2006) and assigned parameters similar to other cereal crops. A separate commodity/activity account was not created for corn as corn is the primary commodity in the cereal grains sector. We did introduce a separate nest into the cereal grains sector to allow for joint products (i.e. corn stover). These new technologies will not generally be competitive with conventional technologies until changes in input prices increase the costs of the conventional technologies.

As discussed in the previous chapter, various methods have been used to incorporate new technologies into a CGE model. The main idea behind the approach for this dissertation is similar to the method used in various applications of the EPPA model by McFarland, Reilly, and Herzog (2004), McFarland and Herzog (2006), and Reilly and Paltsev (2007). However, some of the methods used to incorporate new technologies into this CGE model differed from those used in the EPPA model.

The GTAP database contains a petroleum sector that consists of petroleum and coal products (includes gasoline). In this model, a new petroleum sector was introduced into the SAM for the United States (Figure 20). In this new sector, substitution exists between gasoline (old petroleum sector) and ethanol. Within the ethanol sub-sector, substitution exists between corn grain, switchgrass, and corn stover ethanol. The final ethanol product produced from each of these feedstocks is assumed to be the same (i.e. same energy content).

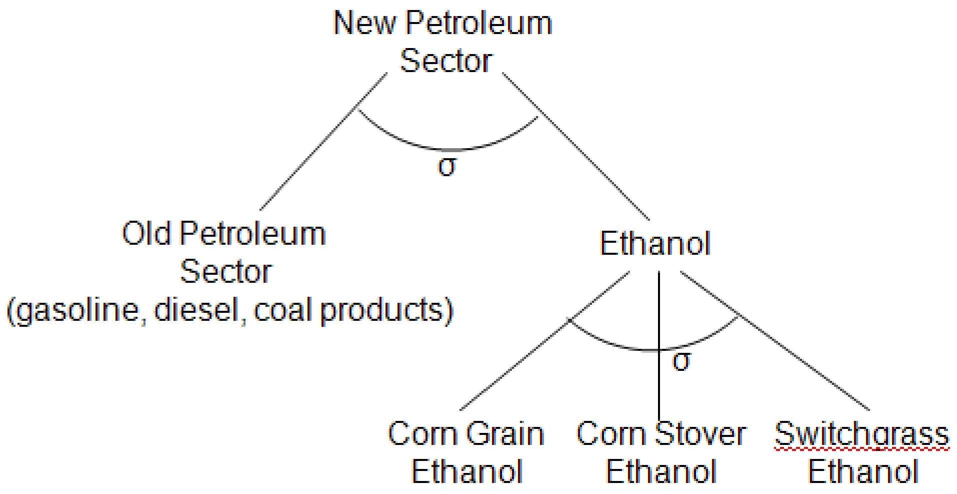


Figure 20. New Biofuels Sectors

Calibrating the Production Function for New Biofuel Sectors

To parameterize the CES production functions for each of these new biofuel technologies, a slightly different approach was used since there are no benchmark equilibrium observations for these new sectors. Instead, engineering data relating to the production of switchgrass, ethanol from corn grain, ethanol from corn stover, and ethanol from switchgrass were used to parameterize the production functions. The engineering data were used to develop appropriate economic representations of current cost structures for conventional ethanol production (from corn grain) and possible cost structures that may exist for cellulosic ethanol production (from corn stover and switchgrass). These costs were then grouped into categories consistent with the CGE modeling framework. The engineering data provided a bottom-up representation of these biofuel technologies. The bottom-up information was translated into a top-down representation by translating the cost categories into factors of production (i.e. capital, land, labor, natural resources) and intermediate goods (i.e. feedstock, electricity, natural gas, fuel, chemicals) found in the CGE model. A separate calibration was required for the new petroleum, composite ethanol, grain ethanol, corn stover ethanol, switchgrass ethanol, switchgrass, and corn stover production sectors.

New Petroleum Sector

Input-output data for 2001 were used to calibrate the production function for the new petroleum sector. The old petroleum sector (found in the GTAP database) contains both petroleum products and coal products. Total expenditures for petroleum and coal products for 2001 were obtained from the SAM. The sum of expenditures on petroleum and coal products was assumed to represent total expenditures for the old petroleum or "fossil" sector. Ethanol production data from 2001 were obtained from the Renewable Fuel Association (2008). The ethanol price was set equal to the grain ethanol cost for

2001 as determined by a review of the literature. This data were used to represent total expenditures for the ethanol sector. The CES production function for the top nest of the new petroleum sector can be written as:

$$(15) \qquad y = \phi\left(a_{ethanol}^{\frac{1}{\sigma}} x_{ethanol}^{\frac{\sigma-1}{\sigma}} + a_{fossil}^{\frac{1}{\sigma}} x_{fossil}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad ,$$

where $a_{ethanol}$ is equal to total ethanol expenditures in 2001 and x_{fossil} is equal to total fossil expenditures in 2001. The x values were calculated as follows:

$$(16) \qquad x_{ethanol} = k_{ethanol} * w_{ethanol}^{\sigma} (1 + t_{ethanol})^{\sigma}$$

$$(17) \qquad x_{fossil} = k_{fossil} * w_{fossil}^{\sigma} \quad ,$$

where $k_{ethanol}$ is the quantity of ethanol produced in 2001, $w_{ethanol}$ is the cost of ethanol in 2001, k_{fossil} is the benchmark equilibrium quantity of petroleum/coal in 2001, w_{fossil} is the price of petroleum/coal products in the 2001 benchmark equilibrium, and $t_{ethanol}$ is the ethanol subsidy. The price for the fossil sector was set equal to 1 and the price for the ethanol sector was the 2001 average U.S. ethanol cost, which is \$1.08. The elasticity of substitution was set equal to 2.0 to allow a moderate amount of substitution between fossil fuel and ethanol. To calculate the share parameters, the following formulas were used:

$$(18) \qquad a_{ethanol} = x_{ethanol} \left(x_{ethanol}^{\frac{1}{\sigma}} + x_{fossil}^{\frac{1}{\sigma}} \right)^{-\sigma}$$

$$(19) \qquad a_{fossil} = x_{f\ ossil} \left(x_{ethanol}^{\frac{1}{\sigma}} + x_{fossil}^{\frac{1}{\sigma}} \right)^{-\sigma}$$

To calibrate phi, the following formula was used:

(20) $$\varphi = \frac{1}{p}\left[\begin{matrix}\left(a_{\text{ethanol}}(1+t_{\text{ethanol}})^{1-\sigma} w_{\text{ethanol}}{}^{1-\sigma}\right)+ \\ \left(a_{\text{fossil}}(1+t_{\text{fossil}})^{1-\sigma} w_{\text{fossil}}{}^{1-\sigma}\right)\end{matrix}\right]^{\frac{1}{1-\sigma}},$$

where p is the price of output from the new petroleum sector. In this case, we assume that p equals 1.

Composite Ethanol Sector

For the ethanol sector, a large elasticity of substitution (i.e. sigma) was used to allow for a high level of substitution between grain ethanol, switchgrass ethanol, and corn stover ethanol. The production function for the composite sector can be written as:

(21) $$y = \left(a_{\text{grain}}{}^{\frac{1}{\sigma}} x_{\text{grain}}{}^{\frac{\sigma-1}{\sigma}} + a_{\text{switch}}{}^{\frac{1}{\sigma}} x_{\text{switch}}{}^{\frac{\sigma-1}{\sigma}} + a_{\text{stover}}{}^{\frac{1}{\sigma}} x_{\text{stover}}{}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

The share parameters were calculated by the following equations:

(22) $$a_{\text{grain}} = x_{\text{grain}}\left(x_{\text{grain}}{}^{\frac{1}{\sigma}} + x_{\text{switch}}{}^{\frac{1}{\sigma}} + x_{\text{stover}}{}^{\frac{1}{\sigma}}\right)^{-\sigma}$$

(23) $$a_{\text{switch}} = x_{\text{switch}}\left(x_{\text{grain}}{}^{\frac{1}{\sigma}} + x_{\text{switch}}{}^{\frac{1}{\sigma}} + x_{\text{stover}}{}^{\frac{1}{\sigma}}\right)^{-\sigma}$$

(24) $$a_{\text{stover}} = x_{\text{stover}}\left(x_{\text{grain}}{}^{\frac{1}{\sigma}} + x_{\text{switch}}{}^{\frac{1}{\sigma}} + x_{\text{stover}}{}^{\frac{1}{\sigma}}\right)^{-\sigma}$$

Since no actual expenditure data exists for cellulosic ethanol, the k values were set equal to 0.3333 (i.e. one divided by the number of ethanol types). The x values were calculated as follows:

(25) $x_{grain} = k_{grain} * w_{grain}^{\sigma}$

(26) $x_{switch} = k_{switch} * w_{switch}^{\sigma}$

(27) $x_{stover} = k_{stover} * w_{stover}^{\sigma}$

where w is the price of each ethanol type. The w values were set equal to one. The scale parameter was calibrated as follows:

(28) $$\varphi = \frac{1}{p}\left[a_{grain} w_{grain}^{1-\sigma} + a_{switch} w_{switch}^{1-\sigma} + a_{stover} w_{stover}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

where p is the price of output. All prices were set equal to 1.

Individual Ethanol Sectors

For the new sectors, the share parameters were calculated using cost share information from agronomic engineering data. Grain ethanol cost data were obtained from previous studies (Burnes et al. 2005, McAloon et al. 2000, Shapouri and Gallagher 2005, Tiffany and Eidman 2003, Wallace et al. 2005). The estimates from each of these studies were adjusted to reflect a 2001 corn price. To develop a reasonable cost structure for conventional ethanol, an average estimate based on previous studies was used. The average cost plus transportation was \$1.08. Table 16 includes a breakdown of the grain ethanol production costs into primary and intermediate inputs.

Table 16. Grain Ethanol Production Costs ($/gal)

Value-Added Bundle	
Capital	0.12
Land	0.00
Natural Resources	0.00
Labor	0.14
Total Value-Added	0.26
Intermediate Bundle	
Feed	0.42
Water	0.01
Chemicals	0.07
Fuel	0.12
Electricity	0.03
Natural gas	0.04
Transportation	0.13
Total Intermediate	0.82
Total	1.08

Cellulosic ethanol cost data were also obtained from previous studies (Aden et al. 2002, McAloon et al. 2000, Wallace et al. 2005, Wooley et al. 1999). These studies estimated the cost of cellulosic ethanol from corn stover. To develop a reasonable cost structure for the two cellulosic ethanol technologies, these estimates were used to calculate an average cost of cellulosic ethanol production excluding the feedstock. Cellulosic ethanol is currently not produced on a large scale basis, so these production costs are hypothetical and only a few studies have estimated these costs. To my knowledge, there are currently no published studies estimating cellulosic ethanol production costs from switchgrass. Therefore, the same production costs for cellulosic ethanol production from corn stover was assumed for cellulosic ethanol production from switchgrass. Additional transportation costs were added to the average cost to produce a gallon of cellulosic ethanol. The transportation costs included transport of switchgrass or stover to the ethanol plant and transportation of the final ethanol product to the terminal. The transportation costs were estimated from previous studies (Energy Information Administration 2002, Schlatter 2006). Table 17 includes a breakdown of the cellulosic ethanol production costs into primary and intermediate inputs.

Table 17. Cellulosic Ethanol Production Costs ($/gal)

Value-Added Bundle	
Capital	0.47
Land	0.00
Natural Resources	0.00
Labor	0.16
Total Value-Added	0.63
Intermediate Bundle	
Feed	0.67
Water	0.01
Chemicals	0.45
Fuel	0.03
Electricity	0.11
Natural gas	0.00
Transportation	0.18
Total Intermediate	1.16
Total	2.08

Calibration of Ethanol Sectors

Assuming S_i is the cost share of the i^{th} input, C is the total cost of all inputs, and the cost of the i^{th} input equals 1, the following relationship holds:

(29) $k_i = S_i$,

where k_i is the quantity of the i^{th} input. Substituting k_i into to the share calibration equation yields the following equation:

$$(30) \qquad a_i = \frac{S_i C}{\left(C^{\frac{1}{\sigma}} \sum_j S_j^{\frac{1}{\sigma}} \right)^{\sigma}} = \frac{S_i}{\left(\sum_j S_j^{\frac{1}{\sigma}} \right)^{\sigma}} \quad ,$$

where S_j is the quantity of the j^{th} input.

Each ethanol sector (i.e. grain, stover, and switchgrass) and the switchgrass sector has a top nest which is made up of a value-added bundle and an intermediate bundle. Therefore, it was necessary to calibrate three sets of parameters for each of these sectors. The same methodology was used to calculate the parameters for the top nest, value-added nest, and intermediate nest. The elasticities of substitution are set at 0.1 for all three nests to allow for little substitution between inputs.

Agronomic engineering data were used to develop cost shares for inputs into each nest. The top nest consists of the value-added and intermediate bundles. The production function can be written as:

$$(31) \qquad y = \left(a_{VAD}^{\frac{1}{\sigma}} x_{VAD}^{\frac{\sigma-1}{\sigma}} + a_{INT}^{\frac{1}{\sigma}} x_{INT}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

The share parameters for the top nest were calculated with the following formulas:

$$(32) \qquad a_{VAD} = \frac{S_{VAD}}{\left(S_{VAD}^{\frac{1}{\sigma}} + S_{INT}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

(33) $$a_{INT} = \frac{S_{INT}}{\left(S_{VAD}^{\frac{1}{\sigma}} + S_{INT}^{\frac{1}{\sigma}} \right)^{\sigma}} \quad ,$$

where, S_{VAD} is the cost share for the value-added bundle and S_{INT} is the cost share for the intermediate bundle. All input prices are assumed to equal 1. The scale parameter was calculated as follows:

(34) $$\varphi = \frac{1}{p}\left(a_{VAD} * w_{VAD}^{1-\sigma} + a_{INT} * w_{INT}^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \quad ,$$

where p is equal to the cost per gallon of ethanol.

For the value-added nest, the production function can be written as:

(35) $$y = \begin{pmatrix} a_{Capital}^{\frac{1}{\sigma}} x_{Capital}^{\frac{\sigma-1}{\sigma}} + a_{Land}^{\frac{1}{\sigma}} x_{Land}^{\frac{\sigma-1}{\sigma}} + a_{Labor}^{\frac{1}{\sigma}} x_{Labor}^{\frac{\sigma-1}{\sigma}} \\ + a_{NatRes}^{\frac{1}{\sigma}} x_{NatRes}^{\frac{\sigma-1}{\sigma}} \end{pmatrix}^{\frac{\sigma}{\sigma-1}}$$

The share parameters were calibrated as follows:

(36) $$a_{Capital} = \frac{S_{Capital}}{\left(S_{Capital}^{\frac{1}{\sigma}} + S_{Land}^{\frac{1}{\sigma}} + S_{Labor}^{\frac{1}{\sigma}} + S_{NatRes}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

(37) $$a_{Land} = \frac{S_{Land}}{\left(S_{Capital}^{\frac{1}{\sigma}} + S_{Land}^{\frac{1}{\sigma}} + S_{Labor}^{\frac{1}{\sigma}} + S_{NatRes}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

$$(38)\qquad a_{\text{Labor}} = \frac{S_{\text{Labor}}}{\left(S_{\text{Capital}}^{\frac{1}{\sigma}} + S_{\text{Land}}^{\frac{1}{\sigma}} + S_{\text{Labor}}^{\frac{1}{\sigma}} + S_{\text{NatRes}}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

$$(39)\qquad a_{\text{NatRes}} = \frac{S_{\text{NatRes}}}{\left(S_{\text{Capital}}^{\frac{1}{\sigma}} + S_{\text{Land}}^{\frac{1}{\sigma}} + S_{\text{Labor}}^{\frac{1}{\sigma}} + S_{\text{NatRes}}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

The scale parameter was calibrated using the following formula:

$$(40)\qquad \varphi = \begin{pmatrix} a_{\text{Capital}} * w_{\text{Capital}}^{1-\sigma} + a_{\text{Land}} * w_{\text{Land}}^{1-\sigma} \\ + a_{\text{Labor}} * w_{\text{Labor}}^{1-\sigma} + a_{\text{NatRes}} * w_{\text{NatRes}}^{1-\sigma} \end{pmatrix}^{\frac{1}{1-\sigma}}$$

The production function for the intermediate nest can be written as:

$$(41)\qquad y = \begin{pmatrix} a_{\text{Feedstock}}^{\frac{1}{\sigma}} x_{\text{Feedstock}}^{\frac{\sigma-1}{\sigma}} + a_{\text{Water}}^{\frac{1}{\sigma}} x_{\text{Water}}^{\frac{\sigma-1}{\sigma}} + \\ a_{\text{Chemicals}}^{\frac{1}{\sigma}} x_{\text{Chemicals}}^{\frac{\sigma-1}{\sigma}} + a_{\text{Fuel}}^{\frac{1}{\sigma}} x_{\text{Fuels}}^{\frac{\sigma-1}{\sigma}} + \\ a_{\text{NatGas}}^{\frac{1}{\sigma}} x_{\text{NatGas}}^{\frac{\sigma-1}{\sigma}} + a_{\text{Electr}}^{\frac{1}{\sigma}} x_{\text{Electr}}^{\frac{\sigma-1}{\sigma}} \end{pmatrix}^{\frac{\sigma}{\sigma-1}}$$

The share parameters were calibrated as follows:

$$(42)\qquad a_{\text{Feedstock}} = \frac{S_{\text{Feedstock}}}{\left(S_{\text{Feedstock}}^{\frac{1}{\sigma}} + S_{\text{Water}}^{\frac{1}{\sigma}} + S_{\text{Chemicals}}^{\frac{1}{\sigma}} + S_{\text{Fuel}}^{\frac{1}{\sigma}} + S_{\text{NatGas}}^{\frac{1}{\sigma}} + S_{\text{Electr}}^{\frac{1}{\sigma}} \right)^{\sigma}}$$

$$(43)\qquad a_{Water} = \frac{S_{Water}}{\left(S_{Feedstock}^{\frac{1}{\sigma}} + S_{Water}^{\frac{1}{\sigma}} + S_{Chemicals}^{\frac{1}{\sigma}} + S_{Fuel}^{\frac{1}{\sigma}} + S_{NatGas}^{\frac{1}{\sigma}} + S_{Electr}^{\frac{1}{\sigma}}\right)^{\sigma}}$$

$$(44)\qquad a_{Chemicals} = \frac{S_{Chemicals}}{\left(S_{Feedstock}^{\frac{1}{\sigma}} + S_{Water}^{\frac{1}{\sigma}} + S_{Chemicals}^{\frac{1}{\sigma}} + S_{Fuel}^{\frac{1}{\sigma}} + S_{NatGas}^{\frac{1}{\sigma}} + S_{Electr}^{\frac{1}{\sigma}}\right)^{\sigma}}$$

$$(45)\qquad a_{Fuel} = \frac{S_{Fuel}}{\left(S_{Feedstock}^{\frac{1}{\sigma}} + S_{Water}^{\frac{1}{\sigma}} + S_{Chemicals}^{\frac{1}{\sigma}} + S_{Fuel}^{\frac{1}{\sigma}} + S_{NatGas}^{\frac{1}{\sigma}} + S_{Electr}^{\frac{1}{\sigma}}\right)^{\sigma}}$$

$$(46)\qquad a_{NatGas} = \frac{S_{NatGas}}{\left(S_{Feedstock}^{\frac{1}{\sigma}} + S_{Water}^{\frac{1}{\sigma}} + S_{Chemicals}^{\frac{1}{\sigma}} + S_{Fuel}^{\frac{1}{\sigma}} + S_{NatGas}^{\frac{1}{\sigma}} + S_{Electr}^{\frac{1}{\sigma}}\right)^{\sigma}}$$

$$(47)\qquad a_{Electr} = \frac{S_{Electr}}{\left(S_{Feedstock}^{\frac{1}{\sigma}} + S_{Water}^{\frac{1}{\sigma}} + S_{Chemicals}^{\frac{1}{\sigma}} + S_{Fuel}^{\frac{1}{\sigma}} + S_{NatGas}^{\frac{1}{\sigma}} + S_{Electr}^{\frac{1}{\sigma}}\right)^{\sigma}}$$

The scale parameter for the intermediate nest was calibrated as follows:

$$(48)\qquad \varphi = \frac{1}{p}\left(\begin{array}{l} a_{Feedstock} * w_{Feedstock}^{1-\sigma} + a_{Water} * w_{Water}^{1-\sigma} + \\ a_{Chemicals} * w_{Chemicals}^{1-\sigma} + a_{Fuel} * w_{Fuel}^{1-\sigma} + \\ a_{NatGas} * w_{NatGas}^{1-\sigma} + a_{Electr} * w_{Electr}^{1-\sigma} \end{array}\right)^{\frac{1}{1-\sigma}},$$

where p is set equal to 1.

Switchgrass Sector

Calibration for the switchgrass sector was completed using the same methods as in the individual ethanol sectors. Cost shares for switchgrass were assigned similar values to other crops in the GTAP database. Agronomic engineering data were used to determine average switchgrass production costs. An average of these estimates was used for this dissertation. The average estimate for switchgrass production costs is $63/ton.

The formulas for the switchgrass production functions, share parameters, and scale parameters for the three nests are calibrated the same as the ethanol sectors. In the top nest, the price of output was set equal to the cost per ton of switchgrass.

Corn Stover Sector

Corn stover production was modeled as a joint product of corn grain production. Corn stover was produced as a fixed proportion of corn grain production. Based on a review of the literature, a one-to-one ratio of corn stover to corn grain production was assumed (i.e. one ton of corn grain produces one dry ton of corn stover). A wide range of corn stover collection efficiencies have been reported in the literature. For the base scenario, a collection efficiency of 30% was assumed. Corn stover cost data were not incorporated into the model. There is not a separate production function for corn stover, so the model assumes the same costs for corn stover and corn production/collection. Since there is not an actual market price for corn stover, the price of corn stover is determined by market interactions in the model solution.

CHAPTER V

RESULTS

The effects of changes in U.S. ethanol production on both the U.S. and world economy were examined. The results are presented as percent changes from a base equilibrium and are representative of long-run adjustments to the base equilibrium. The base equilibrium consists of a 2008 equilibrium with only grain ethanol production. Cellulosic ethanol technologies are not available in the base equilibrium. The actual dollar value and shares of commodity production, exports, and imports in the 2008 base equilibrium for each region are presented in APPENDIX A, APPENDIX B, and APPENDIX C, respectively. The results will primarily focus changes in prices, production, and trade for agricultural commodities and crude oil/petroleum products.

Alternative scenarios relating to conventional and cellulosic ethanol production were analyzed. The scenarios included:

- Technological advances in cellulosic ethanol production
- Removal of the current ethanol subsidy

The scenarios were analyzed without imposing the current renewable fuel standards for grain ethanol or cellulosic ethanol production.

Increases in Cellulosic Ethanol Production Technology

In this model, changes in technology occur in the form of input-intensive technical change. The most likely source of technical change in the cellulosic ethanol industry is enzyme technology. Four scenarios relating to different enzyme costs were analyzed and compared to the 2008 base with no cellulosic ethanol production. The scenarios include:

- Scenario 1: Full cost of enzymes - $0.45/gal
- Scenario 2: 25% reduction in enzyme costs - $0.3375/gal
- Scenario 3: 45% reduction in enzyme costs - $0.2475/gal
- Scenario 4: 65% reduction in enzyme costs - $0.1575/gal

U.S. Summary

Table 18 shows the change in total ethanol production from the 2008 base equilibrium. With the addition of full cost cellulosic ethanol production into the base equilibrium, total ethanol production increased by 6.58%. Total ethanol production continued to increase as new technological advances led to lower enzyme costs. An increase in total ethanol production was expected. As ethanol costs become cheaper relative to petroleum products, factors will be shifted out of petroleum production and into ethanol production.

Table 18. U.S. Total Ethanol Production (% Change from Base*)

	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Ethanol	6.58%	14.27%	26.07%	63.67%

*2008 base with no cellulosic ethanol production

To examine changes in cellulosic ethanol production, the results of reducing enzyme costs were compared to the new base equilibrium that includes both grain ethanol and full cost cellulosic ethanol production.

Table 19 shows the change in grain and cellulosic ethanol production resulting from cheaper enzyme costs. If enzyme costs were reduced by 25%, the production of grain ethanol declined by 13.74%, while the production of stover ethanol increased by 249.64%. At a reduction of 45%, grain ethanol declined by 53.26% and stover ethanol increased by 1093.43%. If enzyme costs were lowered by 65%, producers completely switched to stover ethanol production. As cellulosic ethanol became cheaper relative to grain ethanol, the production of stover ethanol increased.

Even as cellulosic ethanol became cheaper, switchgrass ethanol did not become economically viable under any scenario. This result is consistent with McDonald, Robinson, and Theirfelder (2006). In McDonald, Robinson, and Theirfelder's (2006) model, switchgrass was used in the production of biofuels. However, results of their study indicated that substituting switchgrass for crude oil led to a general decline in economic welfare. The results of this study do not follow the findings of Tokgov et al. (2007). In their study, cellulosic ethanol from corn stover was not feasible under any scenario due to high collection/transportation costs.

The results of this model will likely change once the renewable fuel standards for cellulosic ethanol become binding. To increase corn stover production by large amounts requires an increase in the collection efficiency of corn stover or an increase in corn grain production. Further increases in corn grain production will require either increases in yield technologies or increases in corn acreage. Additional increases in corn acreage will drive up the price of land as well as other agricultural commodities. If switchgrass can be grown successfully on land that is not directly competing with major crops, it may become more of an economically viable option.

Table 19. U.S. Ethanol Production (% Change from Base*)

Feedstock	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Corn Grain	-13.74%	-53.26%	-100.00%
Corn Stover	249.64%	1093.43%	2461.31%

*2008 base full cost cellulosic ethanol production

The effects on U.S. commodity production were also very similar across scenarios. Table 20 shows change in production of agricultural commodities, crude oil, and petroleum/coal products. The production of cereal grains decreased slightly as cellulosic ethanol became cheaper. Production increased for most agricultural commodities. Livestock and raw milk production increased across all scenarios as cellulosic ethanol became cheaper. As less grain ethanol is produced, more corn is available to livestock producers. The production of crude oil and petroleum/coal products decreased by a slightly larger amount as cellulosic ethanol became cheaper. Since cheaper cellulosic ethanol leads to increased ethanol production, the demand for crude oil and petroleum products in the U.S. declines.

Table 20. U.S. Commodity Production (% Change from Base*)

Production	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Wheat	-0.03%	0.02%	0.18%	0.35%
Cereal Grains	0.22%	-0.28%	-1.70%	-3.38%
Fruits/Veg	-0.02%	0.01%	0.12%	0.24%
Oil Seeds	-0.03%	0.02%	0.15%	0.29%
Sugar Cane	-0.02%	0.02%	0.11%	0.22%
Plant Fibers	-0.02%	0.01%	0.10%	0.20%
Other Crops	-0.02%	0.02%	0.15%	0.30%
Livestock	-0.01%	0.01%	0.07%	0.14%
Animal Products	-0.01%	0.01%	0.04%	0.08%
Raw Milk	-0.01%	0.01%	0.06%	0.12%
Crude Oil	-0.18%	-0.23%	-0.41%	-0.75%
Petroleum/Coal	-0.01%	-0.02%	-0.08%	-0.14%

*2008 base with no cellulosic ethanol production

The effects on U.S. commodity prices were very similar for all scenarios. The changes were small but this result does represent a long-run adjustment to changes in cellulosic ethanol costs assuming no renewable fuel standards are in place. Table 21 shows the change in commodity prices for agricultural commodities, crude oil, and petroleum products. With the addition of full-cost cellulosic ethanol to the model, U.S. commodity prices increased slightly. As enzyme costs were reduced, commodity prices decreased from the 2008 base. This could be explained by the slight increase in production for most agricultural commodities. As grain ethanol production declines, less corn grain is needed, resulting in more available land for other crops.

Table 21. U.S. Commodity Prices (% Change from Base*)

Price	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Wheat	0.02%	-0.02%	-0.14%	-0.28%
Cereal Grains	0.02%	-0.03%	-0.17%	-0.34%
Fruits/Veg	0.01%	-0.02%	-0.10%	-0.21%
Oil Seeds	0.02%	-0.02%	-0.14%	-0.28%
Sugar Cane	0.02%	-0.03%	-0.15%	-0.31%
Plant Fibers	0.02%	-0.02%	-0.12%	-0.23%
Other Crops	0.02%	-0.03%	-0.15%	-0.30%
Livestock	0.01%	-0.02%	-0.09%	-0.18%
Animal Products	0.01%	-0.01%	-0.06%	-0.11%
Raw Milk	0.01%	-0.01%	-0.09%	-0.17%
Crude Oil	-0.05%	-0.07%	-0.11%	-0.21%
Petroleum/Coal	-0.00%	-0.01%	-0.02%	-0.04%

*2008 base with no cellulosic ethanol production

The largest changes in land use occurred in the cereal grains sector (Table 22). Initially, more grain ethanol and stover ethanol was produced, resulting in more corn grain production. As more cereal grains were produced, the production of other agricultural commodities declined. However, as cellulosic ethanol became cheaper, land used for corn declined and land use in other agricultural sectors increased slightly from the base. The only sector experiencing a decrease in land use as cellulosic ethanol become cheaper was the cereal grains sector. This is intuitive since lower cellulosic ethanol costs lead to lower demand for corn grain for ethanol. In the livestock sector, land use increases by a higher percentage as cellulosic ethanol becomes cheaper.

Table 22. Land Use Changes in the U.S. (% Change from Base*)

	Full Cost Cellulosic	25% Reduction Cellulosic	45% Reduction Cellulosic	65% Reduction Cellulosic
Wheat	-0.06%	0.07%	0.44%	0.87%
Cereal Grains	0.19%	-0.23%	-1.43%	-2.85%
Fruits/Vegetables	-0.05%	0.06%	0.39%	0.78%
Oil Seeds	-0.06%	0.07%	0.41%	0.82%
Plant Based Fibers	-0.05%	0.06%	0.36%	0.75%
Other Crops	-0.05%	0.07%	0.40%	0.79%
Livestock	-0.04%	0.06%	0.36%	0.72%

*2008 base with no cellulosic ethanol production

With the exception of cereal grains, exports of U.S. agricultural commodities increased by a small amount from the base (Table 23). For most commodities, the change across scenarios was very minimal. Livestock exports also increased as cellulosic ethanol became cheaper. As more cereal grains are available for livestock production, more livestock and animal products are available for export.

Table 23. U.S. Exports (% Change from Base*)

Exports	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Wheat	-0.04%	0.02%	0.23%	0.45%
Cereal Grains	-0.01%	-0.01%	-0.04%	-0.06%
Fruits/Veg	-0.03%	0.02%	0.18%	0.36%
Oil Seeds	-0.04%	0.03%	0.22%	0.43%
Plant-based Fibers	-0.03%	0.02%	0.15%	0.33%
Other Crops	-0.04%	0.04%	0.26%	0.52%
Livestock	-0.03%	0.02%	0.13%	0.26%
Animal Products	-0.02%	0.01%	0.07%	0.14%
Crude Oil	-0.05%	-0.06%	-0.12%	-0.23%
Petroleum/Coal	-0.01%	-0.02%	-0.04%	-0.07%

*2008 base with no cellulosic ethanol production

Table 24 shows changes in imports of agricultural commodities to the United States. Many agricultural commodities are imported in limited quantities by the U.S. and therefore are not shown in the table. Imports initially increased slightly from the base, but declined as cellulosic ethanol became cheaper. The largest changes occurred in the cereal grains sector. Cereal grain imports declined by a larger amount as cellulosic ethanol became cheaper. Lower grain ethanol production may have resulted in less demand for corn imports. However, it is important to note that U.S. cereal grain imports make up a very small portion of total U.S. imports. Imports of crude oil and petroleum/coal products also declined by slightly larger amounts as cellulosic ethanol became cheaper. As U.S. consumers substitute more ethanol for gasoline, less crude oil and petroleum imports are demanded.

Table 24. U.S. Imports (% Change from Base*)

Imports	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Wheat	0.02%	-0.01%	-0.11%	-0.22%
Cereal Grains	0.19%	-0.22%	-1.40%	-2.80%
Fruits/Vegetables	0.02%	-0.01%	-0.10%	-0.19%
Other Crops	0.02%	-0.02%	-0.13%	-0.26%
Livestock	0.02%	-0.01%	-0.06%	-0.12%
Animal Products	0.01%	-0.00%	-0.04%	-0.07%
Crude Oil	-0.14%	-0.18%	-0.30%	-0.54%
Petroleum/Coal	0.01%	-0.01%	-0.04%	-0.08%

*2008 base with no cellulosic ethanol production

Land prices decreased slightly from the 2008 base and continued to increase as cellulosic ethanol became less expensive (Table 25). As cellulosic ethanol became cheaper, more corn stover ethanol was produced instead of grain ethanol. This may have resulted in less competition for agricultural lands. Natural resource prices also decreased slightly from the 2008 as cellulosic ethanol became cheaper. This could be attributed to a declining demand for crude oil as more ethanol is available for consumption. Capital and labor prices increased slightly and labor prices decreased slightly from the 2008 base.

Table 25. U.S. Factor Prices (% Change from Base*)

	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
Land	0.08%	-0.11%	-0.64%	-1.27%
Natural Resources	-0.15%	-0.18%	-0.31%	-0.56%
Capital	0.00%	0.01%	0.02%	0.04%
Labor	-0.00%	-0.00%	-0.00%	-0.01%

*2008 base with no cellulosic ethanol production

World Summary

For the exchange rate comparisons, the world reference currency is the U.S. dollar. The exchange rate for each region is the number of the local currency units per unit of the world reference currency. The exchange rate increased slightly for all regions as cellulosic ethanol became cheaper. Basically, this means that these regions can buy fewer U.S. dollars per unit of their local currency (Table 26).

Table 26. Exchange Rates by Region (% Change from Base*)

	Full Cost Cellulosic Ethanol	25% Reduction Cellulosic Ethanol	45% Reduction Cellulosic Ethanol	65% Reduction Cellulosic Ethanol
BRA	0.00%	0.01%	0.01%	0.03%
CHK	0.01%	0.01%	0.02%	0.03%
RSA	0.01%	0.01%	0.01%	0.04%
IND	0.01%	0.01%	0.01%	0.03%
OFE	0.01%	0.01%	0.01%	0.03%
EUF	0.01%	0.01%	0.01%	0.03%
EUO	0.01%	0.01%	0.01%	0.03%
ROW	0.01%	0.01%	0.02%	0.05%

*2008 base with no cellulosic ethanol production

For regions other than the U.S., the effects of lower cellulosic ethanol costs did not change much across scenarios after the incorporation of full cost cellulosic ethanol to the model. Therefore, only the changes resulting in the production of full cost cellulosic ethanol are presented here for these regions. Overall, the effects on commodity prices and production in all regions other than the US were quite minimal for all scenarios.

Cellulosic ethanol production in the U.S. had a very minimal effect on exports and imports. Changes in crude oil and petroleum exports were quite small for all regions. The changes in U.S. ethanol production were not large enough to have much of an effect on world crude oil and petroleum exports. Changes in cereal grains and wheat imports were also quite small for all regions. Table 27 shows changes in cereal grain exports from all regions to the United States. The most significant changes in exports occurred in the cereal grains sector. However, it is important to note that the U.S. is not a large importer of cereal grains, so these changes in total volumes of cereal grains exports are small.

Table 27. Exports of Cereal Grains by Region (% Change from Base*)

	65% Reduction Cellulosic Ethanol
	Cereal Grains
BRA	-2.80%
RSA	-2.77%
CHK	-2.84%
IND	-2.75%
OFE	-2.76%
EUF	-2.82%
EUO	-2.81%
ROW	-2.71%

*2008 base with no cellulosic ethanol production

Changes in crude oil and petroleum exports were quite small for all regions. The changes in U.S. ethanol production were not large enough to have much of an effect on world crude oil and petroleum exports. Changes in cereal grains and wheat imports were also quite small for all regions. The effect on the major crude oil and petroleum importers was quite minimal. This result was expected since ethanol is only produced and consumed in the United States. In addition, the quantity of ethanol production was not large enough to displace large quantities of crude oil and thus affect the world price for crude oil.

Removal of the U.S. Ethanol Subsidy

Ethanol blenders currently receive a subsidy of $0.51 per gallon to blend ethanol with gasoline, which basically makes the cost of ethanol cheaper. The ethanol subsidy was converted from a direct subsidy to an ad valorem subsidy so that it could be incorporated into the model. The effects of removing the subsidy were analyzed. The effects of removing an ad valorem subsidy are considered to provide a somewhat comparable analysis to the effects of removing a volumetric subsidy. However, the effects of increasing or decreasing an ad valorem subsidy would not be as comparable to increasing or decreasing a volumetric subsidy and therefore was not included in the analysis.

U.S. Summary

The 2008 base contains no cellulosic ethanol production. If the ethanol subsidy is removed from the 2008 base, ethanol production from corn grain decreases by 84.88% (Table 28). These results were expected since removal of the subsidy leads to higher ethanol production costs.

Table 28. U.S. Ethanol Production – Removal of Subsidy (% Change)

Feedstock	2008 Base No Cellulosic Ethanol
Corn Grain	-84.88%

Table 29 shows changes to U.S. commodity prices and production with the removal of the ethanol. The largest changes occurred in the cereal grains sector. The production of cereal grains declined by 2.84% when the ethanol subsidy was removed and the production of other agricultural commodities increased slightly. The removal of the subsidy resulted in less ethanol production and less demand for corn. The prices of all agricultural commodities declined slightly. The production of crude oil also increased slightly, which was expected due to decreased ethanol production.

Table 29. U.S. Commodity Prices and Production – Removal of Subsidy

	2008 Base No Cellulosic Ethanol	
	% Change in Price	% Change in Production
Wheat	-0.24%	0.37%
Cereal Grains	-0.28%	-2.84%
Fruits/Veg	-0.16%	0.24%
Oil Seeds	-0.23%	0.29%
Plant Fibers	-0.20%	0.19%
Other Crops	-0.23%	0.27%
Livestock	-0.14%	0.14%
Animal Products	-0.10%	0.09%
Crude Oil	0.30%	1.01%
Petroleum/Coal	-0.17%	0.13%

Land use changes resulting in the removal of the ethanol subsidy from the 2008 base are shown in Table 30. Land use in the cereal grains sector declined when the subsidy was removed, which was expected since ethanol production declined. Land use for all other agricultural commodities increased when the subsidy was removed. Producers respond to the decreasing corn demand by shifting acreage into other crops and/or livestock.

Table 30. Land Use Changes (% Change from Base)

	2008 Base No Cellulosic Ethanol
Wheat	0.78%
Cereal Grains	-2.42%
Fruits/Vegetables	0.67%
Oil Seeds	0.71%
Sugar Cane/Beets	0.59%
Plant Based Fibers	0.65%
Other Crops	0.66%
Livestock	0.59%

The effects of removing the ethanol subsidy on U.S. exports and imports are shown in Table 31. The changes were very minimal for most commodities. For most agricultural commodities, exports increased and imports decreased when the ethanol subsidy was removed. The domestic production of these commodities increased, leading less demand for imports and more available for export. The largest changes occurred in the cereal grains and crude oil sectors. Imports of cereal grains declined by about 2.4%. Lower ethanol production results in a lower demand for corn imports. Crude oil imports increased with the removal of the subsidy. This was expected since lower ethanol production leads to an increased demand for petroleum.

Table 31. U.S. Exports and Imports – Removal of Subsidy

	2008 Base No Cellulosic Ethanol	
	% Change in Exports	% Change in Imports
Wheat	0.47%	-0.23%
Cereal Grains	0.03%	-2.41%
Fruits/Vegetables	0.36%	-0.20%
Oil Seeds	0.43%	-0.25%
Plant-based Fibers	0.29%	-0.24%
Other Crops	0.49%	-0.26%
Livestock	0.27%	-0.15%
Animal Products	0.19%	-0.11%
Raw Milk	0.26%	-0.15%
Crude Oil	0.22%	0.80%
Petroleum/Coal	0.32%	-0.23%

Land prices decreased, while natural resource prices increased (Table 32). As less ethanol is produced, corn demand should decline, resulting in less competition for land and lower land prices. The price of natural resources went up as more petroleum products were demanded. Capital and labor prices changed slightly from the base equilibrium.

Table 32. U.S. Factor Prices - Removal of Subsidy (% Change)

	2008 Base No Cellulosic Ethanol
Land	-1.01%
Natural Resources	0.85%
Capital	0.01%
Labor	0.01%

World Summary

The effects of removing the subsidy on regions other than the U.S. were very similar to the previous scenarios. Commodity prices in most regions decreased slightly. The production of most agricultural commodities increased in the U.S. region and decreased in most other regions. The production of cereal grains decreased in most regions, which was expected due to lower ethanol production. The effect on exports and imports in regions other than the United States was quite minimal. Exports of most agricultural commodities from regions other than the U.S. declined slightly. Imports of non-agricultural commodities were mostly not affected by the removal of the subsidy.

CHAPTER VI

CONCLUSIONS

The effects of changes in cellulosic ethanol production technology and government policy on world agricultural markets and trade were examined. As projected, advances in cellulosic ethanol technology led to less grain ethanol production and more stover ethanol production in the United States. The production of switchgrass ethanol was not economically feasible under any scenario, which was expected due to the availability of lower priced corn stover. The effects of changes in U.S. ethanol production on the world economy were smaller than expected. Overall, it was expected that a decrease in the costs of cellulosic ethanol production would lead to a higher increase in total U.S. ethanol production than actually occurred. A higher increase in total ethanol production would then lead to a decrease in crude oil imports. Increased ethanol production should then lead to an increase in the demand for corn for domestic use and a decrease in corn available for export. The resulting changes in U.S. corn exports and crude oil imports would then have significant effects on world trade. However, since total U.S. ethanol production only increased slightly from the base, the effects on the world economy were minimal.

Research Limitations

The Renewable Fuel Standard (RFS) mandates were not incorporated into the model. This will be useful to analyze the economy-wide effects of large amounts of cellulosic ethanol production. It is likely that larger amounts of cellulosic ethanol production will lead to much larger effects on the world economy. It is also quite likely that switchgrass ethanol will be produced when the RFS mandates are binding.

Additional limitations relate to the incorporation of corn stover and switchgrass into the model. Corn stover is modeled as a joint product of corn grain production. Therefore, the costs of corn stover production/collection are assumed to be the same as corn grain. However, it is important to note that this assumption may not be completely realistic as corn stover costs may differ from corn grain production costs. Also, the model assumes that switchgrass can be substituted for other U.S. crops when it is economical to do so. Yet, it may only be economical to grow switchgrass if high yields can be expected. It is also likely that switchgrass will only be grown in specific areas of the United States. The model does not account for the effects of land productivity or region on switchgrass production.

Topics for Further Research

Additional natural resource constraints will be incorporated into the model to provide a more realistic depiction of the 2008 world economy. Additional data will be added to the model to provide a more realistic picture of the world economy. Ethanol production in regions other than the U.S. will be incorporated into the model.

Further research on transformation and substitution elasticities will be conducted. A common method employed by CGE modelers is to “borrow” elasticities from previous research. However, previous literature on these elasticities is somewhat scarce since we are modeling the production of commodities that are currently produced in limited quantities.

As the renewable fuels industry continues to expand at a rapid pace, more and more businesses and individuals will become involved in this industry. The industry has tremendous implications for world agriculture and trade and the potential for new biofuel technologies could open up many new opportunities for agricultural producers.

Alternative scenarios regarding new biofuel technologies will have very different implications regarding bioenergy production, and very different effects on agricultural markets, and the broader economy. If the production of conventional oil increases significantly, market prices could remain at a stable level even as the world economy continues to grow and consume more fossil energy. However, if the economy must rely on unconventional sources of crude oil (e.g., deep offshore, tar stands, oil shale, etc.) that are more costly to extract, petroleum prices may increase considerably. If this occurs, the market values for biofuels would also increase substantially and the agricultural sector would face increasing competition for biofuel feedstocks. As the demand for agricultural feedstocks increases, more agricultural commodities could be pulled away from food uses and instead used for fuel. This could lead to a decline in agricultural exports from wealthy countries, which could threaten food security for the world's poor. A thorough understanding of these issues is essential for policy makers to make informed decisions regarding agriculture, food security, and the biofuels industry.

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APPENDIX A

VALUE OF COMMODITY PRODUCTION BY REGION

Table 33. USA Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	962
Wheat	6,606
Cereal Grains	24,973
Fruits/Veg	29,115
Oil Seeds	13,930
Sugar Cane	2,590
Plant Fibers	7,904
Other Crops	33,662
Livestock	36,886
Animal Products	40,979
Raw Milk	28,619
Wool/Silk	141
Forestry	20,285
Fishing	4,075
Coal	33,636
Crude Oil	40,022
Natural Gas	7,100
Minerals	36,889
Food Products	877,237
Textiles	305,682
Wood/Paper	704,336
Petroleum/Coal	164,092
Chemicals/Plastics	805,220
Manuf Products	2,701,930
Electricity	307,213
Gas Manuf/Distrib	49,778
Water	101,132
Services	13,204,440
Transportation	737,782
Grain Ethanol	5,000
Corn Stover	10

*2008 base with no cellulosic ethanol production

Table 34. BRA Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	1,359
Wheat	280
Cereal Grains	2,869
Fruits/Veg	2,194
Oil Seeds	7,803
Sugar Cane	3,764
Plant Fibers	909
Other Crops	9,066
Livestock	6,564
Animal Products	6,225
Raw Milk	3,206
Wool/Silk	45
Forestry	1,478
Fishing	259
Coal	128
Crude Oil	9,413
Natural Gas	634
Minerals	7,364
Food Products	80,993
Textiles	26,822
Wood/Paper	27,411
Petroleum/Coal	19,968
Chemicals/Plastics	50,769
Manuf Products	154,216
Electricity	23,071
Gas Manuf/Distrib	643
Water	5,136
Services	507,929
Transportation	30,565
Paddy Rice	1,359
Wheat	280

*2008 base with no cellulosic ethanol production

Table 35. RSA Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	2,337
Wheat	6,631
Cereal Grains	11,960
Fruits/Veg	35,825
Oil Seeds	7,620
Sugar Cane	3,466
Plant Fibers	1,991
Other Crops	20,996
Livestock	18,931
Animal Products	17,184
Raw Milk	12,686
Wool/Silk	1,229
Forestry	8,658
Fishing	10,415
Coal	2,301
Crude Oil	57,968
Natural Gas	9,246
Minerals	22,622
Food Products	298,594
Textiles	126,392
Wood/Paper	95,178
Petroleum/Coal	44,426
Chemicals/Plastics	145,817
Manuf Products	419,730
Electricity	41,234
Gas Manuf/Distrib	6,789
Water	6,692
Services	1,263,804
Transportation	247,964
Paddy Rice	2,337
Wheat	6,631

*2008 base with no cellulosic ethanol production

Table 36. CHK Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	29,585
Wheat	15,743
Cereal Grains	14,906
Fruits/Veg	208,620
Oil Seeds	11,515
Sugar Cane	1,776
Plant Fibers	10,810
Other Crops	2,680
Livestock	10,157
Animal Products	137,305
Raw Milk	3,558
Wool/Silk	4,911
Forestry	15,326
Fishing	46,490
Coal	17,469
Crude Oil	30,680
Natural Gas	1,245
Minerals	64,860
Food Products	341,669
Textiles	557,677
Wood/Paper	136,717
Petroleum/Coal	105,915
Chemicals/Plastics	361,639
Manuf Products	1,111,705
Electricity	112,330
Gas Manuf/Distrib	2,539
Water	11,106
Services	805,344
Transportation	335,638
Paddy Rice	29,585
Wheat	15,743

*2008 base with no cellulosic ethanol production

Table 37. IND Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	10,266
Wheat	18,652
Cereal Grains	5,133
Fruits/Veg	29,756
Oil Seeds	20,686
Sugar Cane	9,021
Plant Fibers	5,898
Other Crops	19,720
Livestock	4,954
Animal Products	11,532
Raw Milk	26,814
Wool/Silk	3,021
Forestry	8,782
Fishing	6,411
Coal	4,693
Crude Oil	5,132
Natural Gas	3,453
Minerals	4,971
Food Products	68,075
Textiles	56,177
Wood/Paper	18,881
Petroleum/Coal	27,092
Chemicals/Plastics	85,166
Manuf Products	206,948
Electricity	59,819
Gas Manuf/Distrib	109
Water	2,462
Services	446,133
Transportation	95,807
Paddy Rice	10,266
Wheat	18,652

*2008 base with no cellulosic ethanol production

Table 38. OFE Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	39,060
Wheat	4,873
Cereal Grains	4,848
Fruits/Veg	59,786
Oil Seeds	2,542
Sugar Cane	4,096
Plant Fibers	2,373
Other Crops	29,834
Livestock	15,185
Animal Products	33,680
Raw Milk	12,158
Wool/Silk	3,492
Forestry	18,830
Fishing	36,486
Coal	14,139
Crude Oil	20,562
Natural Gas	14,847
Minerals	37,257
Food Products	559,681
Textiles	247,301
Wood/Paper	301,587
Petroleum/Coal	154,541
Chemicals/Plastics	543,615
Manuf Products	2,474,057
Electricity	280,565
Gas Manuf/Distrib	4,546
Water	36,041
Services	6,107,172
Transportation	621,857
Paddy Rice	39,060
Wheat	4,873

*2008 base with no cellulosic ethanol production

Table 39. EUF Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	772
Wheat	14,770
Cereal Grains	14,428
Fruits/Veg	50,816
Oil Seeds	8,038
Sugar Cane	4,247
Plant Fibers	1,297
Other Crops	53,228
Livestock	30,335
Animal Products	53,634
Raw Milk	44,720
Wool/Silk	375
Forestry	31,658
Fishing	38,948
Coal	9,629
Crude Oil	53,393
Natural Gas	29,589
Minerals	27,640
Food Products	863,396
Textiles	298,993
Wood/Paper	588,796
Petroleum/Coal	162,024
Chemicals/Plastics	879,807
Manuf Products	3,144,561
Electricity	277,712
Gas Manuf/Distrib	18,453
Water	43,195
Services	9,434,057
Transportation	914,651
Paddy Rice	772
Wheat	14,770

*2008 base with no cellulosic ethanol production

Table 40. EUO Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	3,246
Wheat	25,306
Cereal Grains	24,307
Fruits/Veg	38,082
Oil Seeds	4,409
Sugar Cane	3,595
Plant Fibers	4,359
Other Crops	31,360
Livestock	15,468
Animal Products	39,856
Raw Milk	38,103
Wool/Silk	2,143
Forestry	14,550
Fishing	5,021
Coal	16,707
Crude Oil	59,027
Natural Gas	50,052
Minerals	38,219
Food Products	269,805
Textiles	98,259
Wood/Paper	94,648
Petroleum/Coal	68,295
Chemicals/Plastics	142,822
Manuf Products	536,913
Electricity	142,947
Gas Manuf/Distrib	21,777
Water	15,928
Services	873,004
Transportation	178,391
Paddy Rice	3,246
Wheat	25,306

*2008 base with no cellulosic ethanol production

Table 41. ROW Commodity Production in Base*

Commodity	Value (millions $)
Paddy Rice	27,636
Wheat	19,069
Cereal Grains	16,320
Fruits/Veg	96,571
Oil Seeds	7,432
Sugar Cane	7,008
Plant Fibers	11,295
Other Crops	30,938
Livestock	28,329
Animal Products	31,630
Raw Milk	19,164
Wool/Silk	5,968
Forestry	22,822
Fishing	23,921
Coal	11,691
Crude Oil	193,845
Natural Gas	28,812
Minerals	29,214
Food Products	221,713
Textiles	151,965
Wood/Paper	82,940
Petroleum/Coal	98,848
Chemicals/Plastics	113,302
Manuf Products	335,441
Electricity	91,820
Gas Manuf/Distrib	17,788
Water	12,565
Services	1,359,862
Transportation	222,675
Paddy Rice	27,636
Wheat	19,069

*2008 base with no cellulosic ethanol production

Table 42. Commodity Production by Region in Base* (% of Total)

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
Paddy Rice	0.01	0.01	0.02	0.26	0.09	0.34	0.01	0.03	0.24
Wheat	0.06	0.00	0.06	0.14	0.17	0.04	0.13	0.23	0.17
Cereal Grains	0.21	0.02	0.10	0.12	0.04	0.04	0.12	0.20	0.14
Fruits/Veg	0.05	0.00	0.07	0.38	0.05	0.11	0.09	0.07	0.18
Oil Seeds	0.17	0.09	0.09	0.14	0.25	0.03	0.10	0.05	0.09
Sugar Cane	0.07	0.10	0.09	0.04	0.23	0.10	0.11	0.09	0.18
Plant-based Fibers	0.17	0.02	0.04	0.23	0.13	0.05	0.03	0.09	0.24
Other Crops	0.15	0.04	0.09	0.01	0.09	0.13	0.23	0.14	0.13
Livestock	0.22	0.04	0.11	0.06	0.03	0.09	0.18	0.09	0.17
Animal Products	0.11	0.02	0.05	0.37	0.03	0.09	0.14	0.11	0.09
Raw Milk	0.15	0.02	0.07	0.02	0.14	0.06	0.24	0.20	0.10
Wool/Silk	0.01	0.00	0.06	0.23	0.14	0.16	0.02	0.10	0.28
Forestry	0.14	0.01	0.06	0.11	0.06	0.13	0.22	0.10	0.16
Fishing	0.02	0.00	0.06	0.27	0.04	0.21	0.23	0.03	0.14
Coal	0.30	0.00	0.02	0.16	0.04	0.13	0.09	0.15	0.11
Crude Oil	0.09	0.02	0.12	0.07	0.01	0.04	0.11	0.13	0.41
Natural Gas	0.05	0.00	0.06	0.01	0.02	0.10	0.20	0.35	0.20
Minerals	0.14	0.03	0.08	0.24	0.02	0.14	0.10	0.14	0.11
Food Products	0.24	0.02	0.08	0.10	0.02	0.16	0.24	0.08	0.06
Textiles	0.16	0.01	0.07	0.30	0.03	0.13	0.16	0.05	0.08
Wood/Paper	0.34	0.01	0.05	0.07	0.01	0.15	0.29	0.05	0.04
Petroleum/Coal	0.19	0.02	0.05	0.13	0.03	0.18	0.19	0.08	0.12
Chemicals/Plastics	0.26	0.02	0.05	0.12	0.03	0.17	0.28	0.05	0.04
Manuf Products	0.24	0.01	0.04	0.10	0.02	0.22	0.28	0.05	0.03
Electricity	0.23	0.02	0.03	0.08	0.04	0.21	0.21	0.11	0.07
Gas Manuf/Distrib	0.41	0.01	0.06	0.02	0.00	0.04	0.15	0.18	0.15
Water	0.43	0.02	0.03	0.05	0.01	0.15	0.18	0.07	0.05
Services	0.39	0.01	0.04	0.02	0.01	0.18	0.28	0.03	0.04
Transportation	0.22	0.01	0.07	0.10	0.03	0.18	0.27	0.05	0.07

*2008 base with no cellulosic ethanol production

Note: See Table 14 for definitions.

APPENDIX B

VALUE OF EXPORTS BY REGION

Table 43. Commodity Abbreviations

Name	Abbreviation
Paddy Rice	pdr
Wheat	wht
Cereal Grains	gro
Fruits/Veg	v_f
Oil Seeds	osd
Sugar Cane	c_b
Plant Fibers	pfb
Other Crops	ocr
Livestock	ctl
Animal Products	oap
Raw Milk	rmk
Wool/Silk	wol
Forestry	frs
Fishing	fsh
Coal	coa
Crude Oil	oil
Natural Gas	gas
Minerals	omn
Food Products	ofb
Textiles	clt
Wood/Paper	wdp
Petroleum/Coal	p_c
Chemicals/Plastics	crp
Manuf Products	mfg
Electricity	ely
Gas Manuf/Distrib	gdt
Water	wtr
Services	srv
Transportation	trn

Table 44. USA Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	-	0.1	190.7	0.1	-	39.4	46.9	1.8	16.3
wht	-	13.5	810.6	65.0	-	1,280.2	270.6	9.4	1,241.6
gro	-	1.2	2,046.8	11.4	0.5	2,346.1	375.8	29.4	1,014.7
v_f	-	9.3	628.7	517.7	83.8	1,234.7	2,385.5	42.8	195.3
osd	-	0.5	1,075.2	1,585.5	1.1	1,782.7	1,302.8	56.4	267.4
c_b	-	0.1	1.1	-	-	0.6	0.2	-	-
pfb	-	3.4	692.5	154.0	202.6	689.7	141.6	6.0	358.9
ocr	-	19.4	376.6	72.6	10.4	865.7	1,233.4	111.8	176.0
ctl	-	0.6	144.7	6.0	0.0	86.8	340.7	0.3	99.1
oap	-	29.7	528.0	1,137.9	8.7	1,253.3	478.5	35.4	65.9
rmk	-	-	-	-	-	0.1	0.2	-	-
wol	-	-	1.1	0.6	0.5	0.7	5.4	0.5	0.7
frs	-	0.9	30.3	30.6	3.4	621.1	499.4	4.6	14.7
fsh	-	0.1	3.8	4.9	0.0	44.3	150.7	0.4	1.2
coa	-	177.8	64.2	9.1	1.8	127.2	1,016.4	64.2	83.5
oil	-	1.3	2.0	1.8	5.5	10.6	24.5	1.9	3.5
gas	-	0.0	228.5	-	-	250.7	91.5	0.2	0.5
omn	-	11.0	202.5	48.6	7.9	269.6	837.2	25.2	42.5
ofb	-	124.9	6,076.6	2,013.6	136.4	9,796.9	7,820.6	1,365.3	2,493.8
clt	-	110.8	10,043.8	1,075.8	47.7	1,436.8	4,842.0	238.4	603.2
wdp	-	264.7	6,526.4	1,001.3	170.9	4,284.6	13,368.9	230.8	1,030.1
p_c	-	146.3	3,513.6	164.0	119.1	1,377.4	1,991.3	71.3	474.4
crp	-	3,199.7	20,641.7	4,005.9	736.1	17,040.5	44,354.1	1,374.0	3,271.0
mfg	-	10,136.3	74,058.7	11,446.1	2,453.4	91,202.5	189,713.3	5,029.3	21,968.0
ely	-	75.8	9.1	5.6	3.9	7.5	659.0	32.9	26.3
gdt	-	7.7	4.4	33.4	0.1	79.8	92.0	13.1	38.7
wtr	-	3.0	16.9	13.9	2.0	53.8	176.4	19.3	25.3
srv	-	1,958.4	6,546.0	2,592.2	1,484.6	25,961.9	86,397.2	8,379.5	20,413.2
trn	-	291.1	2,201.4	1,670.3	521.8	8,245.1	23,840.7	1,917.9	3,432.3

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 45. BRA Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	-	-	2.8	-	-	0.2			
wht	-	-	0.4	-	-	-	-	-	0.7
gro	0.7	-	16.6	-	-	254.2	121.3	60.5	439.1
v_f	186.8	-	54.6	1.1	-	5.8	298.3	10.9	11.7
osd	2.6	-	134.3	1,084.4	327.6	2,083.7	34.1	124.0	
c_b	-	-	-	-	-	-	-	-	-
pfb	9.1	-	36.1	6.2	48.8	36.2	52.9	4.2	32.1
ocr	541.8	-	207.5	182.5	1.4	360.6	1,519.6	190.0	242.4
ctl	5.8	-	0.6	-	0.0	0.0	0.8	-	0.2
oap	76.9	-	34.3	7.1	0.2	22.7	73.6	1.6	4.2
rmk	0.3	-	0.1	0.1	0.0	0.2	0.6	0.1	0.1
wol	0.1	-	7.1	-	2.1	21.6	9.1	-	1.5
frs	5.8	-	1.0	0.3	0.9	1.5	29.3	0.6	8.2
fsh	37.5	-	0.3	0.6	-	5.4	8.1	-	0.3
coa	-	-	-	-	-	-	-	-	-
oil	103.6	-	242.5	23.2	9.6	8.1	111.7	7.0	48.8
gas	-	-	-	-	-	-	-	-	-
omn	218.7	-	304.5	471.4	24.7	946.4	1,470.8	116.6	435.5
ofb	760.8	-	1,157.1	477.9	177.5	981.0	3,912.2	1,591.9	2,053.2
clt	1,681.5	-	1,147.4	237.3	6.5	132.5	939.5	27.7	70.3
wdp	1,743.2	-	1,155.4	227.8	6.7	457.4	1,643.5	30.2	192.3
p_c	1,143.7	-	212.0	4.6	2.0	31.4	53.5	4.4	117.7
crp	948.4	-	2,804.9	80.8	34.0	326.5	846.1	59.3	238.3
mfg	10,388.7	-	9,616.0	411.7	110.0	1,634.2	5,808.5	283.0	1,234.4
ely	-	-	-	-	-	-	0.2	-	-
gdt	-	-	-	-	-	-	-	-	-
wtr	2.0	-	0.5	0.4	0.1	1.7	4.7	0.5	1.0
srv	1,434.4	-	247.0	107.7	114.0	1,265.8	3,643.3	318.2	836.5
trn	188.2	-	64.7	36.3	28.9	389.8	793.2	62.4	165.1

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 46. RSA Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	0.2	88.2	38.6	-	-	0.4	33.5	0.1	4.6
wht	4.3	1,043.8	205.0	0.6	-	16.7	81.6	1.2	634.0
gro	137.2	85.4	359.8	8.2	0.3	335.4	229.0	15.6	450.4
v_f	5,386.0	280.9	728.9	168.4	3.6	263.3	2,959.1	367.2	161.3
osd	59.7	157.6	410.6	1,451.4	0.1	232.7	433.1	17.0	101.4
c_b	0.6	-	1.0	0.1	-	0.4	1.3	0.1	0.2
pfb	9.5	43.0	72.1	10.6	48.1	54.6	29.1	3.3	25.7
ocr	2,146.6	28.4	294.1	9.9	1.2	409.3	1,698.2	85.0	158.2
ctl	488.5	5.2	55.3	0.2	-	1.4	16.0	0.2	8.0
oap	85.6	5.9	124.6	28.5	0.9	36.8	109.5	5.5	8.3
rmk	2.6	0.1	0.5	0.6	0.1	1.7	5.7	0.6	0.7
wol	1.4	0.3	12.1	27.0	5.3	1.4	47.4	1.3	1.7
frs	18.7	5.8	18.5	7.6	18.6	28.5	157.1	1.8	10.0
fsh	324.8	31.1	35.7	3.6	0.1	15.9	54.0	1.0	1.9
coa	448.5	45.1	75.6	0.5	1.8	4.5	1,015.9	30.3	92.4
oil	20,865.5	645.7	3,848.1	50.0	6,236.8	467.0	1,959.8	11.4	28.5
gas	170.5	302.8	684.6	-	-	63.1	37.9	0.4	0.3
omn	681.4	373.2	341.3	472.5	270.2	1,897.4	1,681.2	167.2	149.3
ofb	8,004.0	845.5	6,397.3	1,222.5	614.8	3,057.2	6,994.2	1,253.1	2,217.2
clt	25,602.5	427.8	3,187.8	550.7	32.3	525.2	1,960.1	119.7	193.9
wdp	7,480.8	305.3	3,202.7	386.5	10.3	888.4	1,236.7	43.0	187.5
p_c	6,026.1	745.8	3,210.0	31.3	9.3	141.5	716.6	19.1	138.9
crp	7,221.6	1,939.1	9,057.8	261.8	39.3	1,134.7	3,286.9	151.1	542.6
mfg	127,352.0	4,372.7	14,300.6	1,296.4	160.3	5,612.5	22,448.6	889.4	1,580.3
ely	47.6	930.5	405.5	12.5	14.5	16.5	903.2	74.8	63.1
gdt	7.5	4.6	4.1	22.7	0.1	37.8	84.9	14.2	21.7
wtr	22.0	0.9	4.7	4.1	0.6	15.1	50.8	5.5	6.5
srv	4,620.0	291.1	1,085.2	493.0	198.0	3,607.9	11,890.2	1,189.7	2,271.8
trn	4,455.0	262.9	907.1	660.3	205.7	3,620.1	10,204.3	968.2	1,491.0

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 47. CHK Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	2.9	0.1	0.6	0.2	0.1	21.4	7.0	2.5	16.1
wht	0.7	-	0.2	0.1	-	60.6	1.8	1.1	6.0
gro	1.1	0.1	0.2	6.1	0.5	728.1	8.6	1.2	87.0
v_f	188.6	15.7	89.9	285.7	29.8	964.2	431.3	93.1	244.5
osd	3.9	0.1	17.2	4.6	0.1	206.5	135.9	52.4	75.1
c_b	0.8	-	0.2	1.0	-	0.9	1.8	0.2	0.3
pfb	0.5	0.2	0.1	2.2	2.2	97.9	20.5	1.1	3.3
ocr	111.1	2.0	28.6	90.0	11.4	649.2	158.3	59.2	213.6
ctl	1.3	-	0.3	18.1	-	1.0	2.9	0.3	2.6
oap	346.8	6.4	32.4	362.2	11.4	359.8	439.8	88.9	85.3
rmk	0.7	-	0.2	-	0.0	0.5	1.6	0.2	0.2
wol	0.2	-	0.8	2.8	151.9	70.0	38.7	2.7	17.4
frs	8.6	0.3	2.0	0.8	1.2	97.8	23.5	2.0	3.4
fsh	39.5	1.3	7.6	106.0	0.9	369.5	81.8	8.6	17.6
coa	38.4	95.9	22.5	164.2	172.6	3,274.3	259.7	44.6	45.9
oil	312.9	3.4	10.7	-	154.1	674.8	140.1	19.4	174.6
gas	-	-	-	1.1	-	-	-	-	-
omn	292.2	6.4	23.3	66.3	187.3	773.8	303.5	44.0	67.4
ofb	1,545.8	19.5	281.6	2,407.1	27.0	7,909.8	1,844.7	351.3	1,459.9
clt	45,396.9	372.2	6,362.6	39,787.7	299.6	44,474.7	29,315.9	6,205.5	12,790.1
wdp	16,499.5	27.4	536.7	2,552.9	47.4	6,579.1	5,230.1	284.3	961.5
p_c	535.7	74.7	155.9	208.8	517.7	2,079.7	608.7	139.3	2,316.8
crp	13,310.0	519.0	2,322.4	4,959.4	1,377.6	13,120.5	12,217.4	1,052.1	5,168.7
mfg	155,552.4	1,871.1	12,645.2	26,453.8	2,262.2	107,450.8	98,162.9	7,771.4	22,472.4
ely	21.8	67.8	3.9	637.3	5.9	10.1	155.2	32.1	31.5
gdt	-	-	-	-	-	0.5	0.4	0.0	0.1
wtr	46.9	1.8	10.6	3.4	1.3	31.9	108.8	11.9	14.1
srv	28,255.5	1,226.0	4,372.0	14,490.3	1,815.0	26,536.3	50,849.6	3,580.6	8,740.6
trn	14,754.4	573.4	2,371.6	672.7	450.1	8,002.0	22,795.6	2,040.5	3,231.7

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 48. IND Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	14.2	-	0.5	0.3	-	3.4	87.3	0.3	21.9
wht	4.4	0.2	0.9	0.9	-	160.3	8.4	0.9	294.1
gro	1.6	0.1	0.4	0.3	-	7.7	3.0	0.4	12.6
v_f	278.4	0.8	5.0	7.1	-	73.3	144.0	5.6	214.7
osd	22.9	0.7	10.7	3.4	-	78.1	42.1	15.5	60.7
c_b	1.1	-	0.2	0.3	-	0.8	2.4	0.3	0.4
pfb	1.4	-	0.3	0.8	-	10.4	5.5	0.7	26.1
ocr	246.7	4.7	37.0	21.8	-	127.1	312.6	213.1	259.4
ctl	0.1	-	-	-	-	0.1	0.1	-	0.2
oap	3.9	0.4	1.2	5.6	-	35.1	20.9	1.7	26.4
rmk	5.0	0.2	1.1	1.1	-	3.7	11.2	1.2	1.9
wol	2.9	0.3	0.7	2.4	-	2.4	8.7	0.7	1.4
frs	9.1	0.3	2.0	1.2	-	7.5	33.4	2.1	4.6
fsh	2.6	0.1	0.8	3.8	-	9.8	5.6	0.4	9.2
coa	3.0	0.2	0.4	1.0	-	3.1	8.4	3.8	39.2
oil	-	-	-	-	-	-	0.1	-	-
gas	-	-	-	-	-	-	-	-	-
omn	68.8	0.1	29.9	631.6	-	581.6	367.5	74.0	173.2
ofb	536.4	3.4	32.2	274.3	-	1,451.8	632.9	134.8	1,558.7
clt	3,592.8	39.7	411.5	560.2	-	1,263.9	6,338.2	648.8	2,777.7
wdp	277.4	0.8	20.0	18.3	-	74.9	334.7	20.6	303.0
p_c	394.7	430.1	14.0	79.1	-	231.8	226.2	10.1	133.4
crp	1,899.2	412.2	765.4	1,036.4	-	1,731.7	2,625.8	667.5	3,255.0
mfg	9,687.7	150.4	576.2	1,059.4	-	5,158.3	7,327.5	580.7	7,784.5
ely	1.4	6.4	0.2	0.5	-	0.9	11.2	2.7	3.7
gdt	-	-	-	-	-	-	-	-	-
wtr	0.4	-	0.1	0.1	-	0.3	0.9	0.1	0.1
srv	2,379.7	283.1	485.8	355.7	-	2,991.1	8,341.1	671.4	1,613.3
trn	611.2	39.1	143.8	90.0	-	547.3	1,416.6	142.0	270.3

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 49. OFE Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	2.4	0.1	1.0	1.2	0.1	17.8	34.0	1.8	1,046.7
wht	0.1	-	4.0	4.0	0.1	859.0	58.4	-	945.1
gro	2.3	0.3	15.2	315.2	0.1	253.1	5.7	0.5	139.7
v_f	264.2	3.0	19.1	924.0	184.7	1,572.9	644.0	28.0	383.2
osd	52.8	0.4	1.1	99.5	1.0	212.8	71.6	0.4	94.3
c_b	1.8	0.1	0.4	0.4	0.0	2.7	3.9	0.4	0.5
pfb	6.6	2.3	1.8	62.6	105.7	883.6	77.4	1.6	132.7
ocr	1,295.3	145.2	154.6	862.5	102.2	2,419.0	1,396.2	185.1	443.9
ctl	50.3	0.1	36.1	46.1	0.7	197.0	29.0	1.3	425.3
oap	156.6	6.8	23.7	805.4	10.1	753.6	305.4	24.5	135.6
rmk	0.1	-	-	-	-	0.1	0.2	-	-
wol	41.0	-	14.1	1,056.0	216.0	348.5	714.3	80.3	84.5
frs	11.4	0.2	1.2	300.4	303.1	978.4	42.7	1.2	46.2
fsh	145.0	1.0	7.2	160.3	0.7	924.6	101.7	7.4	60.8
coa	55.8	206.9	162.7	214.4	627.0	6,349.9	1,432.4	32.3	278.7
oil	647.5	2.6	27.7	412.3	2,471.5	4,488.2	91.5	17.3	164.5
gas	0.3	0.1	0.2	1.3	-	6,390.6	2.1	0.3	1.8
omn	192.7	14.0	24.8	997.7	479.0	4,818.1	1,927.4	222.4	265.7
ofb	8,507.6	74.1	1,180.5	5,907.3	1,378.4	18,894.3	7,396.4	626.0	6,906.8
clt	20,207.5	487.8	3,158.8	23,069.8	729.4	10,933.9	11,512.4	1,050.2	10,324.6
wdp	6,648.3	38.8	443.6	4,230.7	339.6	12,938.4	4,646.4	205.7	2,836.8
p_c	1,530.6	123.1	109.1	4,432.5	185.1	6,557.2	473.3	42.0	1,381.9
crp	21,479.3	958.4	3,133.9	26,900.5	1,916.2	40,150.3	17,269.3	1,470.9	9,437.3
mfg	247,128.3	5,483.1	34,007.9	62,564.1	6,340.7	273,378.1	155,838.9	11,321.2	51,313.9
ely	1.3	4.1	0.2	0.5	0.3	0.0	10.5	2.4	1.9
gdt	0.8	0.5	1.9	11.2	0.0	39.6	14.5	2.1	7.1
wtr	47.6	1.9	10.6	8.5	1.4	30.0	105.2	11.5	15.2
srv	18,290.1	1,404.4	3,880.7	2,483.8	1,667.3	15,854.5	56,088.7	5,268.1	9,645.2
trn	9,489.8	599.9	2,090.7	1,152.2	509.0	6,149.1	18,490.1	1,540.7	3,178.1

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 50. EUF Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	0.5	0.3	0.4	0.1	0.0	0.3	139.2	1.4	9.8
wht	353.4	6.1	840.3	231.1	0.0	706.7	2,987.6	92.9	2,388.8
gro	509.5	8.4	122.3	261.0	0.0	85.0	2,098.3	264.1	805.1
v_f	1,095.2	40.3	231.6	105.2	219.3	147.3	14,794.1	1,229.8	650.1
osd	141.5	0.5	205.1	424.7	7.3	566.4	959.3	27.9	156.8
c_b	0.3	-	0.1	0.1	-	0.2	9.3	0.1	1.8
pfb	25.5	3.7	7.2	114.6	34.8	48.4	378.0	124.3	231.6
ocr	1,402.3	42.5	214.7	134.4	18.3	717.3	7,655.4	881.3	598.6
ctl	1,678.9	1.5	49.2	21.9	0.2	40.4	1,617.2	15.8	219.3
oap	852.3	34.2	68.8	783.6	27.1	387.9	4,188.2	355.5	418.8
rmk	7.6	0.3	1.7	1.6	0.2	5.0	15.6	1.9	2.1
wol	6.6	0.2	0.5	14.2	16.9	18.9	127.4	19.8	8.4
frs	285.0	3.0	24.2	134.1	8.4	167.0	1,369.6	44.1	69.9
fsh	671.5	4.2	31.3	134.2	2.6	309.7	3,214.1	88.8	61.9
coa	115.4	57.6	50.4	1.9	1.9	542.0	230.5	22.3	61.7
oil	10,887.2	10.2	132.7	247.6	144.8	171.2	22,290.8	61.9	87.7
gas	11,488.7	5.3	99.0	39.4	0.1	113.2	9,118.1	444.4	43.5
omn	821.7	53.5	244.2	223.4	81.3	844.8	4,409.5	358.5	559.0
ofb	19,257.7	606.2	3,777.3	2,978.1	116.9	10,092.9	101,770.4	8,607.9	11,834.1
clt	12,893.5	292.2	1,869.4	3,895.9	294.8	6,456.8	70,597.7	13,996.0	10,387.2
wdp	41,278.8	631.3	3,038.8	1,779.7	494.2	7,772.6	89,260.4	8,897.9	7,328.9
p_c	5,310.6	98.6	295.6	161.7	140.1	672.9	19,788.3	1,342.0	3,127.8
crp	66,726.3	4,455.7	10,392.9	6,509.6	1,674.3	25,490.4	239,208.1	26,155.4	25,459.4
mfg	277,043.0	12,397.3	35,940.6	24,461.2	10,759.8	84,900.0	793,172.2	91,529.6	107,936.0
ely	1,612.5	665.3	58.9	54.5	40.4	73.2	10,569.0	687.3	621.5
gdt	8.6	13.2	47.0	110.5	0.3	250.8	384.4	72.0	111.8
wtr	122.9	4.8	27.7	22.4	3.3	82.3	261.3	31.0	35.7
srv	70,545.1	5,403.0	17,082.9	8,246.0	4,675.1	64,770.5	202,889.2	20,773.9	32,622.8
trn	36,628.0	1,974.4	6,841.2	3,753.4	1,574.0	24,445.6	57,630.3	5,326.2	9,258.1

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 51. EUO Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	1.1	-	0.3	0.3	-	0.7	2.4	10.8	1.8
wht	4.9	0.1	1.1	0.6	0.1	32.4	350.2	439.1	404.2
gro	6.1	0.1	2.4	0.4	0.1	4.3	114.4	261.1	391.6
v_f	28.0	0.7	4.4	66.0	4.7	12.1	466.2	464.5	36.5
osd	6.5	-	21.9	34.5	1.4	0.5	485.6	109.6	74.2
c_b	0.2	-	-	-	0.0	0.1	0.4	0.7	0.5
pfb	4.6	5.0	0.8	17.2	18.2	139.4	314.4	691.8	186.1
ocr	40.7	0.3	4.4	1.4	1.1	10.6	187.4	373.8	48.9
ctl	8.4	0.4	1.7	1.7	0.2	5.0	270.1	39.5	109.8
oap	24.9	0.5	3.2	115.9	2.5	61.9	491.0	273.3	65.2
rmk	8.8	0.3	1.9	1.9	0.2	5.8	19.4	1.6	2.5
wol	0.4	0.0	0.1	7.9	3.2	0.5	6.5	40.8	4.7
frs	9.8	0.3	2.6	488.5	0.9	469.8	1,223.4	176.1	74.1
fsh	4.9	0.1	0.9	3.5	0.1	7.8	96.9	21.0	4.6
coa	22.2	0.3	4.7	5.2	3.8	196.8	1,190.6	1,418.8	282.4
oil	70.9	3.1	1,195.7	468.3	52.6	195.4	14,681.8	9,210.6	1,342.3
gas	1.2	1.1	2.7	7.1	0.0	23.6	6,926.7	12,109.5	1,847.9
omn	38.9	5.8	20.1	54.0	23.4	47.3	484.0	1,372.0	207.4
ofb	939.8	28.1	182.1	442.1	7.3	1,648.7	4,224.6	5,935.7	1,462.8
clt	1,251.0	8.7	91.0	78.9	24.4	248.7	17,105.3	3,266.1	558.9
wdp	717.1	4.8	58.8	640.4	121.7	444.5	13,368.3	4,995.8	1,762.7
p_c	1,407.9	16.3	74.8	601.5	16.0	130.1	8,007.1	2,691.0	807.7
crp	3,392.5	640.1	727.4	2,295.8	358.3	879.7	10,473.9	10,168.3	2,342.7
mfg	10,423.6	433.6	2,030.5	4,230.6	1,022.9	7,440.7	82,622.1	30,137.8	12,625.7
ely	83.5	312.2	16.3	28.8	21.1	38.7	1,761.5	3,329.7	914.1
gdt	1.3	1.1	3.2	8.6	-	25.2	41.5	8.6	17.8
wtr	23.3	0.9	5.2	4.2	0.6	15.3	53.8	5.2	6.5
srv	5,550.1	337.0	1,142.2	551.7	294.1	4,619.1	15,469.0	1,352.7	2,365.7
trn	4,525.9	216.5	779.5	476.1	174.7	2,782.1	7,707.3	585.1	1,081.1

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 52. ROW Exports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	17.4	0.4	2.3	1.9	0.3	10.1	57.9	22.0	158.1
wht	22.7	0.9	7.3	5.3	0.8	44.1	83.7	20.8	305.9
gro	23.0	0.9	9.2	8.4	0.8	149.9	73.9	11.9	246.3
v_f	340.9	24.7	58.2	433.6	750.8	408.3	4,411.4	592.2	1,752.7
osd	24.8	0.3	6.7	39.0	2.3	163.4	174.3	24.6	212.3
c_b	2.2	0.1	0.5	8.1	0.1	1.4	4.6	0.5	1.4
pfb	52.3	50.9	65.6	85.6	252.0	618.2	656.4	80.8	571.6
ocr	1,311.3	50.5	197.4	317.8	101.4	1,003.9	4,612.7	919.5	1,963.5
ctl	26.0	1.0	5.1	5.4	1.0	41.0	193.7	5.4	330.1
oap	75.4	3.1	12.7	180.3	41.2	133.4	576.8	62.6	225.4
rmk	17.4	0.7	3.6	3.5	0.5	10.8	35.5	3.9	4.2
wol	15.9	0.6	3.1	16.0	19.3	13.5	80.2	5.4	18.4
frs	46.8	1.7	11.9	509.0	317.2	343.2	776.3	25.3	168.3
fsh	105.3	0.8	4.7	23.8	6.8	210.5	547.7	6.4	105.4
coa	18.2	40.7	13.3	8.0	85.6	246.9	1,918.4	37.2	365.4
oil	35,072.3	2,121.2	568.1	7,328.2	2,441.0	59,002.9	30,005.2	218.7	7,836.7
gas	768.9	34.4	23.6	20.6	0.6	4,612.0	6,832.8	111.2	161.9
omn	465.5	71.8	121.0	889.8	575.9	1,407.7	2,447.7	364.9	717.6
ofb	1,681.2	18.4	245.5	755.6	191.3	2,776.6	7,267.1	821.3	7,034.0
clt	17,855.4	106.3	784.3	1,616.4	207.0	3,170.7	31,360.0	1,575.9	4,766.8
wdp	612.9	20.7	110.4	176.1	109.8	1,133.4	3,664.5	367.9	2,575.4
p_c	2,908.2	1,028.6	397.1	1,034.9	847.6	8,792.8	5,432.3	317.2	5,294.6
crp	3,942.4	502.3	575.8	2,262.8	2,189.6	3,753.5	7,728.3	1,411.7	7,893.1
mfg	19,840.1	743.8	2,184.7	1,849.5	3,573.5	12,904.9	41,082.6	4,070.6	20,365.5
ely	36.0	141.7	5.7	11.2	16.1	23.9	313.2	100.3	978.2
gdt	1.8	42.3	21.9	37.2	0.4	115.5	642.7	34.8	236.9
wtr	25.7	1.0	5.4	4.4	0.8	16.3	51.5	5.6	6.4
srv	11,989.8	719.1	2,288.5	1,098.0	696.2	8,682.9	24,893.1	2,395.2	4,476.7
trn	9,784.3	358.3	1,498.6	972.6	295.0	4,946.3	13,373.6	1,262.5	1,834.5

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 53. Commodity Exports by Region in Base* (% of Total)

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
Paddy Rice	0.13	0.00	0.08	0.02	0.06	0.51	0.07	0.01	0.12
Wheat	0.21	0.00	0.11	0.00	0.03	0.11	0.44	0.07	0.03
Cereal Grains	0.38	0.06	0.11	0.05	0.00	0.05	0.27	0.05	0.03
Fruits/Veg	0.10	0.01	0.20	0.05	0.01	0.08	0.36	0.02	0.17
Oil Seeds	0.34	0.21	0.16	0.03	0.01	0.03	0.14	0.04	0.04
Sugar Cane	0.03	0.00	0.06	0.09	0.09	0.17	0.20	0.03	0.32
Plant-based Fibers	0.25	0.03	0.03	0.01	0.01	0.14	0.11	0.15	0.27
Other Crops	0.07	0.07	0.11	0.03	0.03	0.16	0.27	0.02	0.24
Livestock	0.10	0.00	0.09	0.00	0.00	0.12	0.54	0.06	0.09
Animal Products	0.20	0.01	0.02	0.10	0.01	0.13	0.40	0.06	0.07
Raw Milk	0.00	0.01	0.06	0.02	0.13	0.00	0.18	0.21	0.40
Wool/Silk	0.00	0.01	0.03	0.08	0.01	0.74	0.06	0.02	0.05
Forestry	0.12	0.00	0.03	0.01	0.01	0.17	0.21	0.24	0.22
Fishing	0.02	0.01	0.06	0.07	0.00	0.17	0.53	0.02	0.12
Coal	0.07	0.00	0.07	0.17	0.00	0.39	0.05	0.13	0.12
Crude Oil	0.00	0.00	0.14	0.01	0.00	0.03	0.14	0.11	0.58
Natural Gas	0.01	0.00	0.02	0.00	0.00	0.10	0.34	0.33	0.20
Minerals	0.04	0.10	0.15	0.04	0.05	0.22	0.19	0.05	0.17
Food Products	0.09	0.03	0.09	0.05	0.01	0.15	0.47	0.04	0.06
Textiles	0.03	0.01	0.06	0.34	0.03	0.15	0.22	0.04	0.11
Wood/Paper	0.09	0.02	0.05	0.11	0.00	0.11	0.53	0.07	0.03
Petroleum/Coal	0.07	0.01	0.10	0.06	0.01	0.13	0.27	0.12	0.23
Chemicals/Plastics	0.12	0.01	0.03	0.07	0.02	0.16	0.52	0.04	0.04
Manuf Products	0.11	0.01	0.05	0.12	0.01	0.23	0.40	0.04	0.03
Electricity	0.03	0.00	0.09	0.04	0.00	0.00	0.54	0.24	0.06
Gas Manuf/Distrib	0.10	0.00	0.07	0.00	0.00	0.03	0.36	0.04	0.41
Water	0.18	0.01	0.06	0.13	0.00	0.13	0.34	0.07	0.07
Services	0.16	0.01	0.03	0.14	0.02	0.12	0.44	0.03	0.06
Transportation	0.11	0.00	0.04	0.15	0.01	0.15	0.39	0.06	0.08

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

APPENDIX C

VALUE OF IMPORTS BY REGION

Table 54. USA Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	-	-	0.2	2.9	14.2	2.4	0.5	1.1	17.4
wht	-	-	4.3	0.7	4.4	0.1	353.4	4.9	22.7
gro	-	0.7	137.2	1.1	1.6	2.3	509.5	6.1	23.0
v_f	-	186.8	5,386.0	188.6	278.4	264.2	1,095.2	28.0	340.9
osd	-	2.6	59.7	3.9	22.9	52.8	141.5	6.5	24.8
c_b	-	-	0.6	0.8	1.1	1.8	0.3	0.2	2.2
pfb	-	9.1	9.5	0.5	1.4	6.6	25.5	4.6	52.3
ocr	-	541.8	2,146.6	111.1	246.7	1,295.3	1,402.3	40.7	1,311.3
ctl	-	5.8	488.5	1.3	0.1	50.3	1,678.9	8.4	26.0
oap	-	76.9	85.6	346.8	3.9	156.6	852.3	24.9	75.4
rmk	-	0.3	2.6	0.7	5.0	0.1	7.6	8.8	17.4
wol	-	0.1	1.4	0.2	2.9	41.0	6.6	0.4	15.9
frs	-	5.8	18.7	8.6	9.1	11.4	285.0	9.8	46.8
fsh	-	37.5	324.8	39.5	2.6	145.0	671.5	4.9	105.3
coa	-	0.0	448.5	38.4	3.0	55.8	115.4	22.2	18.2
oil	-	103.6	20,865.5	312.9	0.0	647.5	10,887.2	70.9	35,072.3
gas	-	0.0	170.5	0.0	0.0	0.3	11,488.7	1.2	768.9
omn	-	218.7	681.4	292.2	68.8	192.7	821.7	38.9	465.5
ofb	-	760.8	8,004.0	1,545.8	536.4	8,507.6	19,257.7	939.8	1,681.2
clt	-	1,681.5	25,602.5	45,396.9	3,592.8	20,207.5	12,893.5	1,251.0	17,855.4
wdp	-	1,743.2	7,480.8	16,499.5	277.4	6,648.3	41,278.8	717.1	612.9
p_c	-	1,143.7	6,026.1	535.7	394.7	1,530.6	5,310.6	1,407.9	2,908.2
crp	-	948.4	7,221.6	13,310.0	1,899.2	21,479.3	66,726.3	3,392.5	3,942.4
mfg	-	10,388.7	127,352.0	155,552.4	9,687.7	247,128.3	277,043.0	10,423.6	19,840.1
ely	-	-	47.6	21.8	1.4	1.3	1,612.5	83.5	36.0
gdt	-	-	7.5	-	-	0.8	8.6	1.3	1.8
wtr	-	2.0	22.0	46.9	0.4	47.6	122.9	23.3	25.7
srv	-	1,434.4	4,620.0	28,255.5	2,379.7	18,290.1	70,545.1	5,550.1	11,989.8
trn	-	188.2	4,455.0	14,754.4	611.2	9,489.8	36,628.0	4,525.9	9,784.3

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 55. BRA Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	0.1	-	88.2	0.1	-	0.1	0.3	-	0.4
wht	13.5	-	1,043.8	-	0.2	-	6.1	0.1	0.9
gro	1.2	-	85.4	0.1	0.1	0.3	8.4	0.1	0.9
v_f	9.3	-	280.9	15.7	0.8	3.0	40.3	0.7	24.7
osd	0.5	-	157.6	0.1	0.7	0.4	0.5	-	0.3
c_b	0.1	-	-	-	-	0.1	-	-	0.1
pfb	3.4	-	43.0	0.2	0.0	2.3	3.7	5.0	50.9
ocr	19.4	-	28.4	2.0	4.7	145.2	42.5	0.3	50.5
ctl	0.6	-	5.2	-	-	0.1	1.5	0.4	1.0
oap	29.7	-	5.9	6.4	0.4	6.8	34.2	0.5	3.1
rmk	0.0	-	0.1	-	0.2	-	0.3	0.3	0.7
wol	0.0	-	0.3	-	0.3	-	0.2	-	0.6
frs	0.9	-	5.8	0.3	0.3	0.2	3.0	0.3	1.7
fsh	0.1	-	31.1	1.3	0.1	1.0	4.2	0.1	0.8
coa	177.8	-	45.1	95.9	0.2	206.9	57.6	0.3	40.7
oil	1.3	-	645.7	3.4	-	2.6	10.2	3.1	2,121.2
gas	0.0	-	302.8	-	-	0.1	5.3	1.1	34.4
omn	11.0	-	373.2	6.4	0.1	14.0	53.5	5.8	71.8
ofb	124.9	-	845.5	19.5	3.4	74.1	606.2	28.1	18.4
clt	110.8	-	427.8	372.2	39.7	487.8	292.2	8.7	106.3
wdp	264.7	-	305.3	27.4	0.8	38.8	631.3	4.8	20.7
p_c	146.3	-	745.8	74.7	430.1	123.1	98.6	16.3	1,028.6
crp	3,199.7	-	1,939.1	519.0	412.2	958.4	4,455.7	640.1	502.3
mfg	10,136.3	-	4,372.7	1,871.1	150.4	5,483.1	12,397.3	433.6	743.8
ely	75.8	-	930.5	67.8	6.4	4.1	665.3	312.2	141.7
gdt	7.7	-	4.6	-	-	0.5	13.2	1.1	42.3
wtr	3.0	-	0.9	1.8	-	1.9	4.8	0.9	1.0
srv	1,958.4	-	291.1	1,226.0	283.1	1,404.4	5,403.0	337.0	719.1
trn	291.1	-	262.9	573.4	39.1	599.9	1,974.4	216.5	358.3

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 56. RSA Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	190.7	2.8	38.6	0.6	0.5	1.0	0.4	0.3	2.3
wht	810.6	0.4	205.0	0.2	0.9	4.0	840.3	1.1	7.3
gro	2,046.8	16.6	359.8	0.2	0.4	15.2	122.3	2.4	9.2
v_f	628.7	54.6	728.9	89.9	5.0	19.1	231.6	4.4	58.2
osd	1,075.2	134.3	410.6	17.2	10.7	1.1	205.1	21.9	6.7
c_b	1.1	0.0	1.0	0.2	0.2	0.4	0.1	0.0	0.5
pfb	692.5	36.1	72.1	0.1	0.3	1.8	7.2	0.8	65.6
ocr	376.6	207.5	294.1	28.6	37.0	154.6	214.7	4.4	197.4
ctl	144.7	0.6	55.3	0.3	-	36.1	49.2	1.7	5.1
oap	528.0	34.3	124.6	32.4	1.2	23.7	68.8	3.2	12.7
rmk	-	0.1	0.5	0.2	1.1	0.0	1.7	1.9	3.6
wol	1.1	7.1	12.1	0.8	0.7	14.1	0.5	0.1	3.1
frs	30.3	1.0	18.5	2.0	2.0	1.2	24.2	2.6	11.9
fsh	3.8	0.3	35.7	7.6	0.8	7.2	31.3	0.9	4.7
coa	64.2	0.0	75.6	22.5	0.4	162.7	50.4	4.7	13.3
oil	2.0	242.5	3,848.1	10.7	-	27.7	132.7	1,195.7	568.1
gas	228.5	0.0	684.6	-	-	0.2	99.0	2.7	23.6
omn	202.5	304.5	341.3	23.3	29.9	24.8	244.2	20.1	121.0
ofb	6,076.6	1,157.1	6,397.3	281.6	32.2	1,180.5	3,777.3	182.1	245.5
clt	10,043.8	1,147.4	3,187.8	6,362.6	411.5	3,158.8	1,869.4	91.0	784.3
wdp	6,526.4	1,155.4	3,202.7	536.7	20.0	443.6	3,038.8	58.8	110.4
p_c	3,513.6	212.0	3,210.0	155.9	14.0	109.1	295.6	74.8	397.1
crp	20,641.7	2,804.9	9,057.8	2,322.4	765.4	3,133.9	10,392.9	727.4	575.8
mfg	74,058.7	9,616.0	14,300.6	12,645.2	576.2	34,007.9	35,940.6	2,030.5	2,184.7
ely	9.1	-	405.5	3.9	0.2	0.2	58.9	16.3	5.7
gdt	4.4	-	4.1	-	-	1.9	47.0	3.2	21.9
wtr	16.9	0.5	4.7	10.6	0.1	10.6	27.7	5.2	5.4
srv	6,546.0	247.0	1,085.2	4,372.0	485.8	3,880.7	17,082.9	1,142.2	2,288.5
trn	2,201.4	64.7	907.1	2,371.6	143.8	2,090.7	6,841.2	779.5	1,498.6

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 57. CHK Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	0.1	-	0.2	0.3	1.2	0.1	0.3	1.9	-
wht	65.0	-	0.6	0.1	0.9	4.0	231.1	0.6	5.3
gro	11.4	-	8.2	6.1	0.3	315.2	261.0	0.4	8.4
v_f	517.7	1.1	168.4	285.7	7.1	924.0	105.2	66.0	433.6
osd	1,585.5	1,084.4	1,451.4	4.6	3.4	99.5	424.7	34.5	39.0
c_b	-	-	0.1	1.0	0.3	0.4	0.1	-	8.1
pfb	154.0	6.2	10.6	2.2	0.8	62.6	114.6	17.2	85.6
ocr	72.6	182.5	9.9	90.0	21.8	862.5	134.4	1.4	317.8
ctl	6.0	-	0.2	18.1	0.0	46.1	21.9	1.7	5.4
oap	1,137.9	7.1	28.5	362.2	5.6	805.4	783.6	115.9	180.3
rmk	0.0	0.1	0.6	0.0	1.1	-	1.6	1.9	3.5
wol	0.6	-	27.0	2.8	2.4	1,056.0	14.2	7.9	16.0
frs	30.6	0.3	7.6	0.8	1.2	300.4	134.1	488.5	509.0
fsh	4.9	0.6	3.6	106.0	3.8	160.3	134.2	3.5	23.8
coa	9.1	-	0.5	164.2	1.0	214.4	1.9	5.2	8.0
oil	1.8	23.2	50.0	-	-	412.3	247.6	468.3	7,328.2
gas	-	-	-	1.1	-	1.3	39.4	7.1	20.6
omn	48.6	471.4	472.5	66.3	631.6	997.7	223.4	54.0	889.8
ofb	2,013.6	477.9	1,222.5	2,407.1	274.3	5,907.3	2,978.1	442.1	755.6
clt	1,075.8	237.3	550.7	39,787.7	560.2	23,069.8	3,895.9	78.9	1,616.4
wdp	1,001.3	227.8	386.5	2,552.9	18.3	4,230.7	1,779.7	640.4	176.1
p_c	164.0	4.6	31.3	208.8	79.1	4,432.5	161.7	601.5	1,034.9
crp	4,005.9	80.8	261.8	4,959.4	1,036.4	26,900.5	6,509.6	2,295.8	2,262.8
mfg	11,446.1	411.7	1,296.4	26,453.8	1,059.4	62,564.1	24,461.2	4,230.6	1,849.5
ely	5.6	-	12.5	637.3	0.5	0.5	54.5	28.8	11.2
gdt	33.4	-	22.7	-	-	11.2	110.5	8.6	37.2
wtr	13.9	0.4	4.1	3.4	0.1	8.5	22.4	4.2	4.4
srv	2,592.2	107.7	493.0	14,490.3	355.7	2,483.8	8,246.0	551.7	1,098.0
trn	1,670.3	36.3	660.3	672.7	90.0	1,152.2	3,753.4	476.1	972.6

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 58. IND Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	-	-	0.1	0.1	-	-	-	0.3	
wht	-	-	-	-	-	0.1	-	0.1	0.8
gro	0.5	-	0.3	0.5	-	0.1	-	0.1	0.8
v_f	83.8	-	3.6	29.8	-	184.7	219.3	4.7	750.8
osd	1.1	0.1	0.1	1.0	-	7.3	1.4	2.3	
c_b	-	-	-	-	-	-	-	-	0.1
pfb	202.6	48.8	48.1	2.2	-	105.7	34.8	18.2	252.0
ocr	10.4	1.4	1.2	11.4	-	102.2	18.3	1.1	101.4
ctl	-	-	-	-	-	0.7	0.2	0.2	1.0
oap	8.7	0.2	0.9	11.4	-	10.1	27.1	2.5	41.2
rmk	-	-	0.1	-	-	-	0.2	0.2	0.5
wol	0.5	2.1	5.3	151.9	-	216.0	16.9	3.2	19.3
frs	3.4	0.9	18.6	1.2	-	303.1	8.4	0.9	317.2
fsh	-	-	0.1	0.9	-	0.7	2.6	0.1	6.8
coa	1.8	-	1.8	172.6	-	627.0	1.9	3.8	85.6
oil	5.5	9.6	6,236.8	154.1	-	2,471.5	144.8	52.6	2,441.0
gas	-	-	-	-	-	0.1	-	0.6	
omn	7.9	24.7	270.2	187.3	-	479.0	81.3	23.4	575.9
ofb	136.4	177.5	614.8	27.0	-	1,378.4	116.9	7.3	191.3
clt	47.7	6.5	32.3	299.6	-	729.4	294.8	24.4	207.0
wdp	170.9	6.7	10.3	47.4	-	339.6	494.2	121.7	109.8
p_c	119.1	2.0	9.3	517.7	-	185.1	140.1	16.0	847.6
crp	736.1	34.0	39.3	1,377.6	-	1,916.2	1,674.3	358.3	2,189.6
mfg	2,453.4	110.0	160.3	2,262.2	-	6,340.7	10,759.8	1,022.9	3,573.5
ely	3.9	-	14.5	5.9	-	0.3	40.4	21.1	16.1
gdt	0.1	-	0.1	-	-	0.0	0.3	-	0.4
wtr	2.0	0.1	0.6	1.3	-	1.4	3.3	0.6	0.8
srv	1,484.6	114.0	198.0	1,815.0	-	1,667.3	4,675.1	294.1	696.2
trn	521.8	28.9	205.7	450.1	-	509.0	1,574.0	174.7	295.0

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 59. OFE Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	39.4	-	0.4	21.4	3.4	17.8	0.3	0.7	10.1
wht	1,280.2	-	16.7	60.6	160.3	859.0	706.7	32.4	44.1
gro	2,346.1	254.2	335.4	728.1	7.7	253.1	85.0	4.3	149.9
v_f	1,234.7	5.8	263.3	964.2	73.3	1,572.9	147.3	12.1	408.3
osd	1,782.7	327.6	232.7	206.5	78.1	212.8	566.4	0.5	163.4
c_b	0.6	-	0.4	0.9	0.8	2.7	0.2	0.1	1.4
pfb	689.7	36.2	54.6	97.9	10.4	883.6	48.4	139.4	618.2
ocr	865.7	360.6	409.3	649.2	127.1	2,419.0	717.3	10.6	1,003.9
ctl	86.8	-	1.4	1.0	0.1	197.0	40.4	5.0	41.0
oap	1,253.3	22.7	36.8	359.8	35.1	753.6	387.9	61.9	133.4
rmk	0.1	0.2	1.7	0.5	3.7	0.1	5.0	5.8	10.8
wol	0.7	21.6	1.4	70.0	2.4	348.5	18.9	0.5	13.5
frs	621.1	1.5	28.5	97.8	7.5	978.4	167.0	469.8	343.2
fsh	44.3	5.4	15.9	369.5	9.8	924.6	309.7	7.8	210.5
coa	127.2	-	4.5	3,274.3	3.1	6,349.9	542.0	196.8	246.9
oil	10.6	8.1	467.0	674.8	-	4,488.2	171.2	195.4	59,002.9
gas	250.7	-	63.1	0.0	-	6,390.6	113.2	23.6	4,612.0
omn	269.6	946.4	1,897.4	773.8	581.6	4,818.1	844.8	47.3	1,407.7
ofb	9,796.9	981.0	3,057.2	7,909.8	1,451.8	18,894.3	10,092.9	1,648.7	2,776.6
clt	1,436.8	132.5	525.2	44,474.7	1,263.9	10,933.9	6,456.8	248.7	3,170.7
wdp	4,284.6	457.4	888.4	6,579.1	74.9	12,938.4	7,772.6	444.5	1,133.4
p_c	1,377.4	31.4	141.5	2,079.7	231.8	6,557.2	672.9	130.1	8,792.8
crp	17,040.5	326.5	1,134.7	13,120.5	1,731.7	40,150.3	25,490.4	879.7	3,753.5
mfg	91,202.5	1,634.2	5,612.5	107,450.8	5,158.3	273,378.1	84,900.0	7,440.7	12,904.9
ely	7.5	-	16.5	10.1	0.9	-	73.2	38.7	23.9
gdt	79.8	-	37.8	0.5	-	39.6	250.8	25.2	115.5
wtr	53.8	1.7	15.1	31.9	0.3	30.0	82.3	15.3	16.3
srv	25,961.9	1,265.8	3,607.9	26,536.3	2,991.1	15,854.5	64,770.5	4,619.1	8,682.9
trn	8,245.1	389.8	3,620.1	8,002.0	547.3	6,149.1	24,445.6	2,782.1	4,946.3

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 60. EUF Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	46.9	-	33.5	7.0	87.3	34.0	139.2	2.4	57.9
wht	270.6	-	81.6	1.8	8.4	58.4	2,987.6	350.2	83.7
gro	375.8	121.3	229.0	8.6	3.0	5.7	2,098.3	114.4	73.9
v_f	2,385.5	298.3	2,959.1	431.3	144.0	644.0	14,794.1	466.2	4,411.4
osd	1,302.8	2,083.7	433.1	135.9	42.1	71.6	959.3	485.6	174.3
c_b	0.2	-	1.3	1.8	2.4	3.9	9.3	0.4	4.6
pfb	141.6	52.9	29.1	20.5	5.5	77.4	378.0	314.4	656.4
ocr	1,233.4	1,519.6	1,698.2	158.3	312.6	1,396.2	7,655.4	187.4	4,612.7
ctl	340.7	0.8	16.0	2.9	0.1	29.0	1,617.2	270.1	193.7
oap	478.5	73.6	109.5	439.8	20.9	305.4	4,188.2	491.0	576.8
rmk	0.2	0.6	5.7	1.6	11.2	0.2	15.6	19.4	35.5
wol	5.4	9.1	47.4	38.7	8.7	714.3	127.4	6.5	80.2
frs	499.4	29.3	157.1	23.5	33.4	42.7	1,369.6	1,223.4	776.3
fsh	150.7	8.1	54.0	81.8	5.6	101.7	3,214.1	96.9	547.7
coa	1,016.4	-	1,015.9	259.7	8.4	1,432.4	230.5	1,190.6	1,918.4
oil	24.5	111.7	1,959.8	140.1	0.1	91.5	22,290.8	14,681.8	30,005.2
gas	91.5	-	37.9	-	-	2.1	9,118.1	6,926.7	6,832.8
omn	837.2	1,470.8	1,681.2	303.5	367.5	1,927.4	4,409.5	484.0	2,447.7
ofb	7,820.6	3,912.2	6,994.2	1,844.7	632.9	7,396.4	101,770.4	4,224.6	7,267.1
clt	4,842.0	939.5	1,960.1	29,315.9	6,338.2	11,512.4	70,597.7	17,105.3	31,360.0
wdp	13,368.9	1,643.5	1,236.7	5,230.1	334.7	4,646.4	89,260.4	13,368.3	3,664.5
p_c	1,991.3	53.5	716.6	608.7	226.2	473.3	19,788.3	8,007.1	5,432.3
crp	44,354.1	846.1	3,286.9	12,217.4	2,625.8	17,269.3	239,208.1	10,473.9	7,728.3
mfg	189,713.3	5,808.5	22,448.6	98,162.9	7,327.5	155,838.9	793,172.2	82,622.1	41,082.6
ely	659.0	0.2	903.2	155.2	11.2	10.5	10,569.0	1,761.5	313.2
gdt	92.0	-	84.9	0.4	-	14.5	384.4	41.5	642.7
wtr	176.4	4.7	50.8	108.8	0.9	105.2	261.3	53.8	51.5
srv	86,397.2	3,643.3	11,890.2	50,849.6	8,341.1	56,088.7	202,889.2	15,469.0	24,893.1
trn	23,840.7	793.2	10,204.3	22,795.6	1,416.6	18,490.1	57,630.3	7,707.3	13,373.6

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 61. EUO Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	1.8	0.1	2.5	0.3	1.8	1.4	10.8	22.0	
wht	9.4	-	1.2	1.1	0.9	0.0	92.9	439.1	20.8
gro	29.4	60.5	15.6	1.2	0.4	0.5	264.1	261.1	11.9
v_f	42.8	10.9	367.2	93.1	5.6	28.0	1,229.8	464.5	592.2
osd	56.4	34.1	17.0	52.4	15.5	0.4	27.9	109.6	24.6
c_b	-	-	0.1	0.2	0.3	0.4	0.1	0.7	0.5
pfb	6.0	4.2	3.3	1.1	0.7	1.6	124.3	691.8	80.8
ocr	111.8	190.0	85.0	59.2	213.1	185.1	881.3	373.8	919.5
ctl	0.3	-	0.2	0.3	-	1.3	15.8	39.5	5.4
oap	35.4	1.6	5.5	88.9	1.7	24.5	355.5	273.3	62.6
rmk	-	0.1	0.6	0.2	1.2	-	1.9	1.6	3.9
wol	0.5	-	1.3	2.7	0.7	80.3	19.8	40.8	5.4
frs	4.6	0.6	1.8	2.0	2.1	1.2	44.1	176.1	25.3
fsh	0.4	-	1.0	8.6	0.4	7.4	88.8	21.0	6.4
coa	64.2	-	30.3	44.6	3.8	32.3	22.3	1,418.8	37.2
oil	1.9	7.0	11.4	19.4	-	17.3	61.9	9,210.6	218.7
gas	0.2	-	0.4	-	-	0.3	444.4	12,109.5	111.2
omn	25.2	116.6	167.2	44.0	74.0	222.4	358.5	1,372.0	364.9
ofb	1,365.3	1,591.9	1,253.1	351.3	134.8	626.0	8,607.9	5,935.7	821.3
clt	238.4	27.7	119.7	6,205.5	648.8	1,050.2	13,996.0	3,266.1	1,575.9
wdp	230.8	30.2	43.0	284.3	20.6	205.7	8,897.9	4,995.8	367.9
p_c	71.3	4.4	19.1	139.3	10.1	42.0	1,342.0	2,691.0	317.2
crp	1,374.0	59.3	151.1	1,052.1	667.5	1,470.9	26,155.4	10,168.3	1,411.7
mfg	5,029.3	283.0	889.4	7,771.4	580.7	11,321.2	91,529.6	30,137.8	4,070.6
ely	32.9	-	74.8	32.1	2.7	2.4	687.3	3,329.7	100.3
gdt	13.1	-	14.2	-	-	2.1	72.0	8.6	34.8
wtr	19.3	0.5	5.5	11.9	0.1	11.5	31.0	5.2	5.6
srv	8,379.5	318.2	1,189.7	3,580.6	671.4	5,268.1	20,773.9	1,352.7	2,395.2
trn	1,917.9	62.4	968.2	2,040.5	142.0	1,540.7	5,326.2	585.1	1,262.5

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 62. ROW Imports in Base*

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
pdr	16.3	0.2	4.6	16.1	21.9	1,046.7	9.8	1.8	158.1
wht	1,241.6	0.7	634.0	6.0	294.1	945.1	2,388.8	404.2	305.9
gro	1,014.7	439.1	450.4	87.0	12.6	139.7	805.1	391.6	246.3
v_f	195.3	11.7	161.3	244.5	214.7	383.2	650.1	36.5	1,752.7
osd	267.4	124.0	101.4	75.1	60.7	94.3	156.8	74.2	212.3
c_b	0.0	0.0	0.2	0.3	0.4	0.5	1.8	0.5	1.4
pfb	358.9	32.1	25.7	3.3	26.1	132.7	231.6	186.1	571.6
ocr	176.0	242.4	158.2	213.6	259.4	443.9	598.6	48.9	1,963.5
ctl	99.1	0.2	8.0	2.6	0.2	425.3	219.3	109.8	330.1
oap	65.9	4.2	8.3	85.3	26.4	135.6	418.8	65.2	225.4
rmk	-	0.1	0.7	0.2	1.9	0.0	2.1	2.5	4.2
wol	0.7	1.5	1.7	17.4	1.4	84.5	8.4	4.7	18.4
frs	14.7	8.2	10.0	3.4	4.6	46.2	69.9	74.1	168.3
fsh	1.2	0.3	1.9	17.6	9.2	60.8	61.9	4.6	105.4
coa	83.5	-	92.4	45.9	39.2	278.7	61.7	282.4	365.4
oil	3.5	48.8	28.5	174.6	-	164.5	87.7	1,342.3	7,836.7
gas	0.5	-	0.3	-	-	1.8	43.5	1,847.9	161.9
omn	42.5	435.5	149.3	67.4	173.2	265.7	559.0	207.4	717.6
ofb	2,493.8	2,053.2	2,217.2	1,459.9	1,558.7	6,906.8	11,834.1	1,462.8	7,034.0
clt	603.2	70.3	193.9	12,790.1	2,777.7	10,324.6	10,387.2	558.9	4,766.8
wdp	1,030.1	192.3	187.5	961.5	303.0	2,836.8	7,328.9	1,762.7	2,575.4
p_c	474.4	117.7	138.9	2,316.8	133.4	1,381.9	3,127.8	807.7	5,294.6
crp	3,271.0	238.3	542.6	5,168.7	3,255.0	9,437.3	25,459.4	2,342.7	7,893.1
mfg	21,968.0	1,234.4	1,580.3	22,472.4	7,784.5	51,313.9	107,936.0	12,625.7	20,365.5
ely	26.3	-	63.1	31.5	3.7	1.9	621.5	914.1	978.2
gdt	38.7	-0	21.7	0.1	-	7.1	111.8	17.8	236.9
wtr	25.3	1.0	6.5	14.1	0.1	15.2	35.7	6.5	6.4
srv	20,413.2	836.5	2,271.8	8,740.6	1,613.3	9,645.2	32,622.8	2,365.7	4,476.7
trn	3,432.3	165.1	1,491.0	3,231.7	270.3	3,178.1	9,258.1	1,081.1	1,834.5

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

Table 63. Commodity Imports by Region in Base* (% of Total)

	USA	BRA	RSA	CHK	IND	OFE	EUF	EUO	ROW
Paddy Rice	0.02	0.05	0.02	0.00	0.00	0.03	0.19	0.02	0.67
Wheat	0.03	0.08	0.08	0.02	0.00	0.14	0.26	0.04	0.36
Cereal Grains	0.07	0.01	0.06	0.06	0.00	0.19	0.28	0.06	0.27
Fruits/Veg	0.17	0.01	0.03	0.04	0.03	0.07	0.52	0.06	0.07
Oil Seeds	0.03	0.01	0.07	0.27	0.00	0.15	0.37	0.02	0.08
Sugar Cane	0.12	0.00	0.04	0.18	0.00	0.11	0.41	0.04	0.09
Plant-based Fibers	0.02	0.02	0.03	0.04	0.08	0.28	0.23	0.13	0.18
Other Crops	0.18	0.01	0.03	0.04	0.01	0.14	0.43	0.07	0.10
Livestock	0.37	0.00	0.02	0.02	0.00	0.05	0.35	0.01	0.18
Animal Products	0.11	0.00	0.02	0.16	0.01	0.13	0.44	0.06	0.07
Raw Milk	0.21	0.01	0.05	0.04	0.01	0.14	0.44	0.05	0.06
Wool/Silk	0.02	0.00	0.01	0.33	0.12	0.14	0.30	0.04	0.04
Forestry	0.04	0.00	0.01	0.16	0.07	0.23	0.41	0.03	0.04
Fishing	0.16	0.00	0.01	0.05	0.00	0.22	0.50	0.02	0.03
Coal	0.03	0.02	0.01	0.02	0.04	0.48	0.27	0.07	0.05
Crude Oil	0.27	0.01	0.02	0.03	0.05	0.26	0.28	0.04	0.04
Natural Gas	0.20	0.01	0.01	0.00	0.00	0.18	0.37	0.20	0.03
Minerals	0.07	0.01	0.03	0.10	0.04	0.29	0.33	0.07	0.07
Food Products	0.13	0.01	0.04	0.05	0.01	0.15	0.44	0.06	0.11
Textiles	0.25	0.00	0.03	0.13	0.00	0.13	0.32	0.05	0.08
Wood/Paper	0.27	0.00	0.03	0.04	0.00	0.11	0.43	0.05	0.06
Petroleum/Coal	0.18	0.02	0.04	0.06	0.02	0.18	0.33	0.04	0.13
Chemicals/Plastics	0.17	0.01	0.04	0.06	0.01	0.13	0.43	0.06	0.08
Manuf Products	0.27	0.01	0.03	0.04	0.01	0.15	0.37	0.05	0.07
Electricity	0.07	0.08	0.02	0.03	0.00	0.01	0.53	0.16	0.10
Gas Manuf/Distrib	0.01	0.02	0.03	0.08	0.00	0.19	0.46	0.05	0.16
Water	0.21	0.01	0.05	0.03	0.01	0.14	0.45	0.05	0.06
Services	0.17	0.01	0.04	0.03	0.01	0.16	0.46	0.04	0.08
Transportation	0.22	0.01	0.05	0.04	0.01	0.17	0.37	0.05	0.08

*2008 base with no cellulosic ethanol production

Note: See Table 14 and 43 for definitions.

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