

Modeling the Global Economic and Environmental Implications of Biofuels Production: Preliminary Results for the Medium Term

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I. Introduction

The recent global expansion of biofuel production led by the U.S. and Brazil, has had a large effect on production, prices, and trade in the agricultural sector. Rapid growth of U.S. ethanol production that relies on corn as feedstock is using an increasing share of the corn crop. As Westcott (2007) shows, about 14 percent of the total corn crop in the U.S. was used in ethanol production in 2005/2006. The increased demand for corn has also led to higher corn prices and to an expansion in the total amount of cropland used to grow corn at the expense of soybeans, cotton, and other crops, whose price consequently also rose.

Biofuel production in Brazil has also had a large effect on global agricultural and energy markets. Brazil began producing ethanol from sugar cane to use as fuel in the 1970s. Agricultural land in Brazil for sugar cane and other crops (particularly soybeans) grew rapidly as cropland and pasture replaced forest and *cerrado* in the Brazilian Amazonia. From 1980 to 1995, around 7 million hectares were converted to agriculture (Cardille and Foley, 2003). However, Brazilian agricultural officials assert that future increases in cropland devoted to sugar cane will come from pastureland rather than from forestland (Guimaraes, 2007).¹

While other countries and regions do not produce a large amount of ethanol, some of these regions, such as the European Union (EU), affect world markets as consumers of ethanol. For example, F.O. Licht estimates that the EU consumption of fuel ethanol

¹ Guimaraes points out that currently 210 million hectares of pasture land are able to sustain 206 million heads of livestock. He adds that with the expected increases in livestock productivity, the same amount of livestock will need only 147 million hectares of pastures, freeing up 63 million hectares for other agricultural uses.

under the EU biofuel directive will be nearly 2 billion gallons per year in 2010 (F.O. Licht, 2006).²

Given the complexity of agricultural markets, their interaction with other markets, and their global nature, evaluating the repercussions of a growing market for biofuels is not simple. Economists found very quickly that most existing agricultural models lacked the necessary components and data to account for biofuel production at this scale exposing a need to improve the current analytical modeling frameworks and data systems. To help cover this gap, the Economic Research Service (ERS) of the U.S. Department of Agriculture developed FARM II, a revised and updated version of the Future Agricultural Resources Model (FARM).

This research further revises FARM II to examine the impacts of biofuel development and production on a global basis under a set of economic, policy, and technological scenarios and examines the economic and environmental tradeoffs, as well as the distribution of benefits and costs across countries, regions, producers, and consumers. This is the first of two papers that summarize results from the FARM II model adapted to incorporate biofuels. This paper focuses on ethanol on the medium term; that is, around year 2015. We assume that while improvements in current technology and the impact of biotechnology will improve yields and technical plant efficiency, the medium term impact of ethanol from cellulose and other technological breakthroughs will be small. A second paper will examine the longer term with the impact of ethanol from cellulose as the main focus.

This paper begins by summarizing the energy picture to provide some context for the growing global importance of biofuels. Then we examine the major technical and

² However, the EU is a significant producer of biodiesel.

policy drivers of biofuels production. A brief review of recent efforts to model biofuel production is presented next and we follow this with a description of the revised FARM II model and databases used in this study. Then we describe the scenarios examined, and present preliminary results and conclusions.

II Biofuels in Perspective

Why Biofuels?

In 2005, a total of 460 quadrillion BTUs (Quads) of energy (equivalent to 49.4 billion barrels of oil) were produced globally for various uses, up from 287 Quads in 1980 (USDOE, 2005).³ Petroleum is the largest energy source, accounting for 35 percent of the total, followed by coal with 26 percent, natural gas (23 percent), hydroelectric power (6.2 percent), natural gas plant liquids (2.5 percent), and other sources (1.4 percent).

Most primary energy production goes towards transportation and electricity generation. Coal and natural gas are primarily used for the latter and petroleum for the prior (about 50 percent of oil demand is used for transportation, USDOE, 2007). Energy demand across countries depends on their Gross Domestic Product (GDP), which varies widely, and energy intensity (e.g., BTUs per dollar GDP), which is more uniform (when using purchasing power parities). For example, 2005 energy intensity for India was 7000 BTU per dollar, for Brazil 6300, Japan 6500, China 7900, and the U.S. 9100 (USDOE, 2007).

Because liquid biofuels are primarily used as a substitute of petroleum products in transportation, this section focuses on trends in petroleum and petroleum products. While post World War II global demand for petroleum rose in most years (fig. 1), the real price of petroleum was remarkably stable in the first half of the period (1946-1973) averaging

³ The BTU (British Thermal Unit) is a basic unit of energy equivalent to the heat required to increase the temperature of one pound of water by one degree Fahrenheit.

about \$21 per barrel at 2007 prices (fig. 2). The 1974 Arab embargo, Iranian revolution of 1979, and the Iran-Iraq war that began in September 1980, resulted in a period of high oil prices, as oil peaked in 1980 at \$91-97 per barrel at 2007 prices (fig. 2). After relative stability during the 1990s with oil averaging about \$25 per barrel, the price of oil began a steady increase led by supply disruptions in the Middle East, Venezuela, and Nigeria, rapidly growing demand in heavily populated countries like China and India,⁴ and the depreciation of the U.S. dollar. As a result, the real average price of oil rose to between \$61-\$69 per barrel in 2006, even higher in 2007, and in early 2008 reached an all-time high after adjusting for inflation.

Figures 3 and 4 show petroleum consumption by region and in a subset of countries from 1980 to 2005. Oil consumption in most regions increased steadily with the exception of a decrease in the early 1980's following the economic downturn and the preceding energy crisis of 1979. Petroleum consumption is concentrated in wealthier countries like the United States and Europe (fig. 4). However, demand is increasing at a faster rate in the U.S. and China relative to the rest of the world. Japan, Europe, and South America have had relatively little growth in recent years.

The recent run-up in oil prices, which has led to corresponding increases in the price of transportation fuels, gasoline (fig. 5 and 6) and diesel, has renewed interest in many countries in developing renewable sources of energy, particularly biofuels. While biofuels are currently a small portion of the total fuel mix, they do play a growing role in transportation in some regions of the world and are expected to become more important

⁴ With a population of 1.3 billion and 1.1 billion, respectively, China and India have been growing rapidly in recent years. As a result, energy consumption per capita in China has grown from 17.8 million BTU in 1980 to 51.4 million BTU in 2005 and in India from 5.9 million BTU to 14.8 million BTU in the same period (USDOE, 2007c). For comparison, energy consumption per capita in 2005 was 177 million BTU in Japan and 341 Million BTUs in the U.S. Consequently, rapid growth in energy consumption in countries like China and India is likely to continue in coming years, keeping pace with their economic development.

in the future. In 2005, about 12 billion gallons of ethanol were produced globally (F.O. Licht, 2006).

Figure 7 shows the trend in oil price since 1980 with a range of forecasts for the medium term. The rise in oil prices in recent years has made biofuels more competitive on a cost basis. While the price of oil in inflation-adjusted terms is not very different from the price in 1980, analysts believe (USDOE, 2007) that the contribution of demand growth led by economic growth in poorer populous countries like China and India will continue to put pressure on oil prices. It has been projected that 43% of the growth in demand for transportation fuel to 2030 will come from non-OECD Asia (USDOE, 2007). For that reason there is an expectation that biofuels will remain competitive. A variety of feedstocks are being considered for biofuels, but most ethanol production currently is from corn and sugar, and biodiesel from soybeans, rapeseed and other oil seeds. About 90 percent of biofuel production takes place in the U.S., Brazil and the EU. The U.S. and Brazil have focused on ethanol production, while biodiesel production is more important in Europe.

A tropical climate allows Brazil to rely more on sugar cane for ethanol production than the U.S. where corn is the primary feed stock. On average, costs for producing ethanol from sugar cane are lower than from corn (see section on data). Sugar cane-based ethanol also has a more favorable energy balance, the ratio of energy inputs required to grow the plant relative to the amount of energy it produces, of 3.7 to 4.5 compared to 1.4 to 1.0 for corn (F.O. Licht, 2006). Figure 8 shows the share by region and country of world ethanol production. Worldwide, feedstocks for ethanol production are currently about equally split between sugar cane and corn (F.O. Licht, 2006).

Technical and Policy Drivers of Biofuels Production

While a number of factors have led biofuels to become more important in some regions than in others, the price of gasoline and the presence of government support have been central. The use of biofuels for transportation fuel can essentially be separated into four periods. The first is the period of the growth of the automobile industry when discoveries of easily extractable petroleum reserves made biofuels uncompetitive on a cost basis. Second, the 1970s when politically driven supply shocks led to increased oil prices and concern over the reliance on foreign oil reserves in many countries. Third, the late 1980s and 1990s that saw a return of lower oil prices and stagnation in the growth of biofuels in most countries. Fourth, the current period where increasing oil prices driven by demand growing faster than supply have created expectations that prices will remain at historically high levels into the foreseeable future.

Competition between petroleum and biofuels for transportation energy is not new. Many early automobiles ran on biofuels or a mixture of biofuels and petroleum based fuels, but the continued discovery of accessible reserves of petroleum made biofuels continually less competitive on a cost basis. By the early 1970's almost no ethanol was produced in any country for automobile fuel. The concentration of oil reserves in the Middle East made the global economy more susceptible to political turmoil which came to a head in 1973 and 1979. Nearly all biofuels production for transportation takes place in the U.S., Brazil, and the EU.

United States. Gasoline and diesel constitute about 98 percent of transportation fuel in the U.S. with ethanol accounting for most of the remainder sold mostly as E10 or gasohol (a 90 percent gasoline 10 percent ethanol mixture). In volume, close to 5 billion

gallons of corn-based ethanol were produced in 2006 (fig. 8). A bushel of corn can produce approximately 2.65 gallons of ethanol using a wet mill process (see Box 1) or 2.75 gallons using the dry mill process (Shapouri and Salassi, 2006). This means that with existing technology the entire current corn production in the U.S. (which constitutes 40% of total global corn production) would only yield enough ethanol to satisfy 15 percent of total domestic U.S. transportation energy demand (USDOE, 2006a).⁵ This calculation assumes that corn yields will remain at current levels. However, as shown in Figure 9, from 1975 and 2005 U.S. corn yields almost doubled, from 5.4 metric tons per hectare (80 bushels/acre, up from 30 bushels per acre in 1930, Fernandez-Cornejo, 2004) to around 9.4 metric tons per hectare (close to 150 bushels/acre). More than half of this increase can be attributed to genetic improvements that made possible higher yielding seed varieties; other contributing factors were improvements in pest and nutrient control (Fernandez-Cornejo, 2004). Moreover, as shown by a study by the University of Illinois (Tannura et al., 2008), helped by favorable weather, average corn yield growth accelerated in recent years to 3.4 bushels per year in the 1996/2005 period up from 1.5 bushels per year in the 1960/1995 period.

Ethanol policy in the U.S. has primarily relied on a gasoline tax rebate to provide incentives for increased production. This has changed in recent years as interest in biofuels has grown in response to rising oil prices. A more detailed discussion of biofuels policy in the U.S. is provided in Box 2. Ethanol production increased gradually until 2002 after which the rate of growth has increased. The banning of MTBE in many states beginning around 2002 was a significant stimulus to the production of ethanol

⁵ Biodiesel production is much lower at 91 million gallons in 2005.

beyond the ethanol tax rebate that was responsible for growth previously.⁶ Just from 2003 to 2005 the use of ethanol mixed in gasoline increased 70% (USDOE, 2007). Continued diffusion of automobiles that can run on higher ethanol gasoline mixes is important for growth in the market for E85 that remains limited to date. Five million flexible fuel vehicles (FFVs) were sold in the U.S. from 1992 to 2005 (USDOE, 2007). FFVs can run on up to 85% ethanol but few do currently due to the limited availability of refilling stations with E85. The growth of biofuels has significant governmental support going into the future through the 2007 version of the Renewable Fuel Standard (RFS) in the Energy Bill and also in the Farm Bill (see Box 2). Projections for biofuels production over the next 15 years under the RFS are shown in table 1.⁷

Brazil. Due to a combination of climate and government policy, Brazil has substituted biofuels for fossil fuels in transportation far more than any other country. As shown in Figure 11, the decision of the Brazilian government to expand ethanol production following the first oil crisis in 1973 set off a significant and sustained growth that has accelerated in the past few years. From 1975 through the late 1990s Brazilian policy relied on direct intervention into production and consumption decisions in a number of ways. A discussion of Brazilian biofuels policy is summarized in Box 3. Following 15 years of slowing growth, the policy was realigned towards the use of tax rebates and subsidies to move towards a market based market-based approach.

While there was approximately a 50% increase in sugar cane yields (from 47 to

⁶ MTEB was banned for environmental (water quality) reasons after it was found in groundwater following leaks in pipelines and underground storage tanks (USDOE, 2003).

⁷ It appears that the ethanol production forecast in the most recent Energy Outlook prepared by the Energy Information Administration (USDOE, 2007) shown in fig. 10 will already be exceeded by the ethanol production shown in the most recent RFS (table 1). For example, the Energy Information Agency forecast 12 billion gallons of ethanol production for 2015 (which represents a 7.7 percent of U.S. gasoline use), while the RFS calls for 15 billion gallons of corn-starch ethanol (plus additional amounts of cellulosic ethanol and biodiesel).

72 metric tons per hectare) between 1975 and 2006 (figure 12) most of the increased production of sugar cane has come from the expansion in area from 2 to 7 million hectares. Brazil has produced a sizeable amount of sugar cane for centuries but most was used to make sugar (Box 1). As Figure 12 shows, the share of sugar cane devoted to ethanol production, which was around 20 percent between 1965-75, increased rapidly after 1975 overtaking sugar in only a few years and reaching 65 percent in 1987. The trend reversed during the 1990s with ethanol's share declining to about 50 percent as price of oil decreased but ethanol's share is expected to increase again with the rise in ethanol relative price. In 2005, Brazil produced 382.8 million tons of sugarcane that was used to produce around 4 billion gallons of ethanol and 26 million tons of sugar (MAPA, 2007).⁸

Much of the continued growth and confidence in ethanol to continue to supply automobile fuel is the result of the successful large scale launch of flex fuel vehicles in Brazil in 2003. Supply disruptions and low oil prices had caused problems in previous years making consumers less comfortable with buying cars that were designed to run primarily on ethanol. Flexible fuel vehicles allow for use of E85 when ethanol is available and competitive, but also can run on gasoline if the market changes. The move towards market based policies has also been a success in terms of motivating supply growth.

⁸ Sugarcane is processed in about 330 mills across the country. The majority are located in the central southern part of the country (AgraFNP, 2007). Biodiesel remains a much smaller part of Brazil's biofuels production, but that may change in the future. Plantings of soybeans have increased significantly in recent years.

Whether the biofuels sector can continue to grow without a considerable expansion in land for corn in the U.S. (or sugar cane in Brazil) depends on whether yields will continue to increase as they have done in recent decades.

European Union. The history of biofuels in the EU is relatively short compared to the U.S. and Brazil. In 2004, the EU produced about 768 million gallons of biofuels (CRS, 2006). The Biofuels Directive put forth in 2003 promotes meeting a quarter of all transportation energy demands from biofuels by 2030 (Box 3). The EU started producing a measurable amount of biofuels in the early 1990's. Total production had increased to 500,000 tons in 1997. Following a brief drop in 1998, production has increased steadily to the current levels. Over this time both biodiesel and ethanol productions have increased steadily with the former constituting a bulk of production. Rapeseed production is the feedstock for most of this and is primarily grown in Italy, Germany, and France (USDA, 2008). In contrast to the U.S., the ethanol that is produced in the EU relies primarily on wheat.

An additional challenge in coordinating biofuels production in the EU is the diversity of countries that are member states. There is a wide range in targets for each country. The UK target is 0.3% of transportation energy while the Czech Republic has a target of 2.9%. The fact that diesel automobiles are relatively more common in the EU has avoided having to rely on the spread of flex fuel vehicles with ethanol since a car that can run on petroleum diesel can typically run on biodiesel as well.

Rest of the World. While the effect of biofuels on food prices remains a concern in many poorer countries there is increasing interest in developing the sector in some regions. According to F.O. Licht (2006), Canada produces 60 to 66 million gallons of

ethanol using corn, wheat, and barley, although it is still a net importer. Mexico produces about 16 million gallons of ethanol, but imports more than 30 million gallons per year. Interest in ethanol is also growing in some South American countries. Argentina's government enacted a mixture requirement, while corn producers in Chile have seen ethanol as a solution to overproduction problems. In Africa nearly all ethanol production occurs in South Africa where molasses is the major feed stock for hydrous ethanol.

China is the fourth largest producer of ethanol behind the U.S., Brazil, and the EU. India also has the potential for large scale ethanol production from sugar cane given that it is one of the largest sugar producers in the world. Thailand currently has limited ethanol for fuel production, but it does have a favorable climate for sugar production and the government has become involved in promoting the growth of the industry (F.O. Licht, 2006).

III An Overview of Recent Biofuels Models

In response to increased interest in biofuels in recent years, a number of partial and general equilibrium models have been adapted or developed to consider potential implications of an expanding biofuels sector. This section provides a summary of the most recent studies based on these models and describes their basic structure, assumptions, scenarios, and main findings.

Birur, Hertel, and Tyner (2007)(BHT) examine the implications of a growing biofuels industry on the agriculture sector and land use globally using a global computable general equilibrium framework (CGE). More specifically, BHT incorporate biofuels into GTAP-E (Truong, 1999; Burniaux and Truong, 2002; McDougal and Golub, 2007), a version of GTAP that includes a global energy database and model. Biofuels are

integrated into the model from both the consumption and production side, and agro-ecological zones (AEZs) are integrated to model land use change following Lee et al. (2005). Three types of biofuels are considered; ethanol from sugar cane, ethanol from corn, and biodiesel from oilseeds.⁹ Factors influencing the biofuels sector include crude oil prices, the replacement of MTBE with ethanol, and ethanol subsidies.

BHT validate their model by using 2001 as a baseline and compare model predictions with actual 2006 data. The model predicts a 178% increase in ethanol production for the U.S. from 2001 to 2006 compared to the actual observed increase of 174 percent. Prediction for corn production growth was 7 percent compared to an observed 11 percent. For Brazil, the model predicted a 38 percent increase in production of ethanol from sugarcane, while the actual increase was 24 percent. For EU biodiesel, the observed change from 2001 to 2006 was 410 percent and the model predicted 415 percent. The share of oilseeds predicted to go towards biodiesel ranged from 5.6% to 27.2% over the time period. All non-biofuel agricultural outputs are predicted to decrease except for coarse grains. Most of the changes in agricultural outputs in Brazil and the EU can be attributed to oil prices. So, the MTBE and ethanol subsidy shocks in the U.S. do not significantly reverberate to other regions. Oil seed production is predicted to go up by 16% in the EU. Non-oilseed grains are predicted to drop in total production by 4%. As expected, oil prices have the largest effect on global prices. However, the prices of agricultural commodities only increased slightly with coarse grains being the exception. The largest expansion of land as a result of higher oil prices

⁹ Taheripour, Birur, Hertel, and Tyner (2007) document the process of introducing these three types of biofuels into version 6 of GTAP (Dimarana, 2007). The biofuels are introduced in three databases. One assumes there are no intermediate uses for biofuels. The second assumes that a portion of ethanol from corn is used as an additive for gasoline. The third allows for byproducts in biofuels production by accounting for distillers dried grains with solubles (DDGS) for ethanol generated from corn.

is in less-productive AEZs. Land for coarse grain production in the U.S. was predicted to increase by 4%, which mostly drew from other grain sectors that lost 7%. The same story held for Canada and the EU that increased acreage in biofuel feedstock grains at the expense of other agricultural outputs.

In a related paper, Birur, Hertel, and Tyner (2007b) examine the 2006-2010 period using the same modeling structure and scenarios. They predict that ethanol capacity will reach 13.4 billion gallons, which is used as a binding production level in the model projections to 2010. It is projected that the share of corn going to produce ethanol will more than double at the expense of feed grain and exports (16% to 38%). The production of all other agricultural goods decreases by a significant amount. Land allocated to the production of coarse grains increases to meet the increased demand. Acreage in the corn belt goes up by 10%, but the largest increases are in less productive areas. The EU mandate to 2010 represents a 281% increase over current biofuel production. Oilseed production increases by 26% as prices double, although this is far short of what is needed to meet the mandate. Exports in oilseeds are almost completely eliminated. Across AEZs in Europe, land used for oilseed production increases from 7 percent to 30 percent. Trade in oilseeds is expected to increase sharply as countries like Brazil expand production to meet the increase in demand.

Tokgoz et al. (2007 revised) use a multi-product multi-country deterministic partial equilibrium model to consider the effect of growth in U.S. ethanol production on various aspects of the agriculture sector including planted acreage, crop prices, livestock production and prices, and trade. Within this framework three scenarios are considered: higher oil prices with large-scale adoption of FFVs; 7 million acres are removed from the

Conservation Reserve Program; and a drought equivalent to that of 1988 occurs together with a 14.7 billion gallon ethanol mandate. This study is an extension of Elobeid et al. (2006) that found that the production of ethanol would grow until the incentive to expand disappear by elevated corn prices. Additional assumptions made in Tokgoz are that the demand for ethanol mixed with gasoline at greater than 10% will be minimal to at least 2017, and the price of distillers' grains determined by demand from domestic and international markets for feed grains is made endogenous in contrast to Elobeid's.

The baseline predicts that meeting this scale of ethanol production will require corn acreage to expand to 94 million acres as a result of prices reaching \$3.40 per bushel. Corn expands primarily at the expense of soybeans. Livestock production shrinks and the higher costs are passed on to consumers. U.S. agriculture is not made less competitive relative to other countries since higher prices are expected to be a global phenomenon.

The high oil price scenario assumes that prices are \$10 per barrel greater than the baseline. Land use change depends critically on the rate of adoption of FFVs that can run on E85. If adoption is high, ethanol production would reach 29 billion gallons requiring 112 million acres of corn. Soybean and wheat planting go down as a result. Corn prices are projected to reach \$4.40 per bushel. Food prices would increase 1.1 percent overall while meat prices go up by 5 percent and eggs go up 7 percent. The scenario involving a removal of 7 million acres of land from CRP lowers crop prices only in the short run. The third scenario that combines a severe drought with an ethanol mandate finds that price inflation is moderated by the presence of international trade and a decrease in carryover stocks of corn and wheat. Livestock producers would make moderate production cuts.

Elobeid and Hart (2007) examine the connection between increasing oil prices and increasing production of ethanol and inflation in agricultural commodity prices using the same multi-commodity, multi-country modeling system as Tokgoz. The central focus of the paper is to assess the downstream effects of these changes in the energy markets on food prices and food security focusing on developing countries. The model is partial equilibrium, econometric, and non-spatial. It also endogenously includes supply and demand for agricultural products from temperate climates in all countries. It includes an extension to the international market for ethanol, which provides a link to energy markets. Other endogenous variables include prices, production, consumption and trade in ethanol. The baseline is constructed using the U.S. and international commodity models calibrated on 2006 historic data, which is then projected to the period 2007-16.

The first scenario involves a \$10 increase in oil per barrel and FFVs are limited. The second scenario is the same as the first but assumes greater penetration of FFVs. As expected, countries that rely more heavily on rice are less vulnerable to the effects of increased corn demand for ethanol. Countries that rely on wheat and sorghum fall in between. So, Sub-Saharan Africa and Latin America are more negatively affected than Southeast Asia.

Gurgel, Reilly, and Paltsev (2007)(GRP) focus on the long-run (2000 to 2100) land use implications of growth in the global biofuels industry in a CGE framework based on MIT's Emissions Prediction and Policy Analysis model (EPPA). EPPA is a recursive-dynamic multi-regional CGE model. GRP consider both current corn and sugar based ethanol and the development of viable cellulosic ethanol production technology by adapting EPPA to include multiple agricultural sectors, multiple land types, and explicitly

account for natural areas. The set of model runs also vary whether there is a greenhouse gas mitigation policy.

EPPA uses GTAP data for base information aggregating the data into 16 regions and 21 sectors. The base year of the model is 1997, and then the economy is simulated recursively at 5-year intervals from 2000 to 2100. Given its original motivation, EPPA models the energy sector in detail. Productivity growth in labor, energy, and land are exogenously determined (1% per year for land). The role of bioenergy in both electricity production and uses that currently rely on petroleum are both included. The arrival of cellulosic technology is endogenous. Five types of land are identified: cropland, pasture, harvested forest, natural grasslands, and natural forest. Both liquid and electric biomass compete with crops for cropland. GRP differ from most other studies that model land transformation. GRP find that the liquid biofuels technology dominates electricity generation from biomass in both the scenario with a climate policy and without. Total biofuel production with a climate policy is more than 6 fold greater than without by the year 2100. Also notable, tropical and subtropical regions in the Americas become significant biofuel production regions. Comparing the different land transformation approaches, there was not a significant difference in total biofuels production, but there was a difference in which types of land tended to be brought into biofuel production. Using the land supply elasticity, increased intensification avoids the loss of natural area land. So, the essential finding of GRP is that if cellulosic technologies for creating ethanol become viable there will be widespread expansion of plantings of these crops, comparable to the amount of land currently under crops globally, over the next century.

Ludena, Razo, and Saucedo (2007) estimate the potential for biofuels in Latin America using current production and cropland area and then estimate how much production could expand to 2025 while still meeting food production and security needs. They find that there is enough land for the production of both food and biofuels, although smaller countries may need to decide which to produce domestically and which to import.

Nagavarapu (2007) uses a CGE model of regional agricultural and labor markets to look at the effect of a change in U.S. trade barriers to ethanol on Brazil. Data on labor choices is taken from household surveys, land use and production decisions, and output prices. A baseline is estimated on data from 1982 to 2005. In a scenario where ethanol demand is perfectly elastic at a price 5 percent above the baseline, sugar cane and ethanol production increase 28 percent and 94 percent, respectively. Changing the perfect elasticity point to 10 percent above the baseline increases sugar cane production 56 percent.

Dixon et al. (2007) use a dynamic CGE model to assess the effect of policy aimed at reducing the cost of biomass-based transportation fuel on the wider economy. The baseline is constructed from observed data from 1992 to 2004 that is projected to 2020. The treatment scenario then compares the projection assuming a substitution of biofuels for petroleum. It is found that a 25 percent replacement leads to a reduction in oil prices, an increase in employment, and an increase in export prices.

Banse, van Meijl, and Woltjer (2007) look at the global and regional effects of the EU Biofuel directive in a CGE model that is a modification of the GTAP-E multi-sector multi-region AGE model. Intermediate inputs are separated into energy and non-energy sectors. The energy inputs are a capital-energy composite that accounts explicitly for

inputs of cereals, vegetable oils, and sugar beet or cane to produce biofuels. Land as an input is included by modeling land demand assuming a degree of substitutability between uses for different land types. They also model agricultural labor and capital markets separate from non-agricultural markets.

The baseline scenario in Banse et al. is based on an elaboration of one of the four IPCC emissions scenarios. The policy scenarios include blending requirements of 5.75 percent (low) and 11.5 percent (high) that each member state would have to meet. Sensitivity analysis is done with respect to the price of crude oil and the elasticity of substitution between different biofuel feedstocks. In the baseline case food prices decline as a result of productivity outpacing demand growth even though biofuel production does increase due to an increase in crude oil prices. Although biofuels would not reach the 5.75 percent target. Under the low blending requirement the share of biofuels in Brazil would decrease by 7 percent as a result of the relative increase in biofuels crops relative to oil. As expected, growth in oilseed production in the EU increases from 5 percent in the baseline case to 29 percent in the low scenario and 49% in the high scenario. Global land in agriculture increases in the high scenario.

IV The Model and Data

By generating stress on natural resources, global increases in human populations and economic activities may threaten long-run agricultural and environmental sustainability. Evaluations of how economic growth may be maintained without sacrificing environmental amenities in the 21st century are hampered, however, by the lack of appropriate modeling tools. To help overcome this problem, the Economic Research

Service (ERS) of the U.S. Department of Agriculture developed the Future Agricultural Resources Model (FARM).

The FARM Database

The Future Agricultural Resources Model (FARM) is an integrated modeling framework designed to analyze global changes related to long-run agricultural and environmental resources. This model was originally developed by Roy Darwin and others (Darwin et al., 1995; Darwin and Kennedy, 2002). Darwin and his collaborators were among the first to model global economic production by agro-ecological zones (AEZ), where land is divided into classes based on climate and other physical characteristics that affect the suitability of land to grow different crops and the productivity of land for different uses.

Previous versions of FARM have been used primarily to analyze the impacts of greenhouse gas emissions on agriculture (Darwin et al., 1994, 1995; Darwin, 1999, 2003, 2004b; Darwin and Kennedy, 2000). Other applications include: costs of sea level rise (Darwin and Tol, 2001); the impacts of changes in agricultural technology on land use (Ianchovichina et al., 2001); the costs of protecting global ecosystem diversity (Lewandrowski et al., 1999); and the effects of trade deregulation and population growth on tropical forests (Darwin et al., 1996).

The FARM framework can be visualized in terms of an environmental and economic component (Darwin et al., 1995). The environmental component consists of a geographic information system (GIS) that links land cover and climate data with land and water resources. Climate is linked with land resources by agro-ecological zones defined primarily in terms of the length of the growing season. Growing season is the period

during a year that soil temperature and moisture conditions support plant growth.¹⁰

Climate is linked with water resources through surface and subsurface runoff—the amount of precipitation that is not evapotranspired back into the atmosphere.

Evapotranspiration is the combined loss of water from a given area in a specific time by evaporation from the soil surface and by transpiration from plants.

As more precise data have become available since FARM's inception, ERS revised the FARM modeling framework and updated its underlying database. The current version of FARM, also called FARM II, includes a revised database with a new land and water resources database linked with production of agricultural and forestry commodities by enhanced agro-ecological zones (AEZs). Major updates include: First, the environmental data are calibrated to 1997 values, rather than 1990. Second, the land-cover characteristics are organized by country and 0.5° lat.-long. grid, rather than 12 aggregate regions and 0.5° latitude-longitude grid.¹¹ Third, because the initial resolution of the land-cover characteristics data is 1.0 km², each country-grid combination may have multiple land-cover characteristics, rather than just one. Fourth, agro-ecological zones, which were initially called land classes, are derived from actual contemporary monthly temperature and precipitation data, and plant hardiness zones (PHZ) and thermal regimes are used in conjunction with length of growing season to distribute commodities to land

¹⁰AEZs defined primarily by length of growing season but also defined by thermal regime (TR) and plant hardiness zones (PHZ). The length of growing season is the number of days with soil temperature higher or equal than 5 °C, where soil temperature is calculated from air temperature using 21 and 10 day lags in spring and fall, respectively. There are 6 classes of growing seasons: 0-60 days, 61-120 days, 121-180 days, 181-240 days, 241-300 days, and 301-365 days. Thermal regime is the average daily temperature during growing season and divided into 7 classes (TR1 less than or equal to 10 °C, in increments of 5 °C until TR7 greater than 35 °C. Moisture regime is the average daily precipitation during the growing season. Plant hardiness zones derived from minimum monthly temperatures. There are a total of 9 PHZs, starting with min monthly temp. less than or equal to -45 °C (PHZ=1) and moving up in intervals of 10 °C and ending with greater than or equal to 25 °C (PHZ=9). There are two types of AEZs: irrigated and rainfed (indicated by prefix 'i' or 'r'). Irrigated cropland refers to areas equipped to provide water to crops. Data are from Doll and Siebert (1999) in 0.5° lat-long resolution.

¹¹ Land cover classes included are Cropland, Grassland, Tundra, Coniferous Forest, Nonconiferous Forest, Mixed Forest, Scattered Trees, Shrubland, Built-Up Land, and Other Land.

covers.¹² Finally, data on U.S. agricultural water withdrawals are organized by U.S. State, rather than for the U.S. as a whole and data on population density help define actual land use.

The database includes the following information on land and water resources: basic land covers by country and 0.5° lat.-long. grid; rainfed and irrigated agro-ecological zones, thermal regimes, and plant hardiness zones by 0.5° lat.-long. grid; freshwater withdrawals by country and sector, and agricultural withdrawals by U.S. State; and potential irrigation water requirements by 0.5° lat.-long. grid. The database also contains the following information linking these resources with world economic production: crop, livestock, and forestry commodity production by country; population density by country and 0.5° lat.-long. grid; estimated average commodity product of land by length of growing season and thermal regime; estimated commodity production by country, land cover, and 0.5° lat.-long. grid; and agricultural water withdrawals for livestock and irrigation by country, land cover, and 0.5° lat.-long. grid. To illustrate, figures 15-21 show the global distribution by land cover, thermal regime, plant hardiness, and length of the growing season.

FARM's economic component consists of a multi-sector global computable general equilibrium (CGE) model of the global economy implemented in the General Algebraic Modeling System (GAMS). Both the static and dynamic versions of this model have been previously described and applied to diverse issues relating to trade liberalization (Roe, Somwaru and Diao, 2006; Diao, Roe and Somwaru 2002; Diao, Somwaru and Roe 2001; Diao and Somwaru 2000).

¹² The meteorological data were prepared by the University of East Anglia's Climate Research Unit (New et al., 2000). There are 67,420 grids with weather observations.

As a CGE modeling framework, FARM II, accounts for all production and expenditures within each of its country/regions. A representative household in each region supplies primary factors to producers and maximizes utility with respect to household consumption, government consumption, and saving. Representative producers in each sector maximize profits associated with the utilization of four primary factors—land, water, labor, and capital. FARM II explicitly models production systems including land by AEZ. Assuming constant returns to scale, capital and labor are freely mobile among national sectors while land and water endowments are fixed by agro-ecological zones. For simplicity, no independent government savings or borrowing is assumed, with the government spending all its tax revenues on consumption or household transfers. Investment is assumed to exactly equal depreciation so the capital stock remains constant. Government policies are typically simulated by imposing charges on inputs and outputs.

FARM II incorporates the latest version of the Global Trade Analysis Project (GTAP) database, version 7, which represents the world economy as of 2004. The CGE model is calibrated using the GTAP database but modified so that national production and value-added data is distributed proportionally as per FARM's environmental database, by land use and AEZ. Table 2 summarizes the sectors and country/regions used in this study.

For this application, the GTAP sector data were aggregated into 25 sectors, including 8 agricultural commodities (six crops—paddy rice, wheat, other grains, oilseeds, sugar crops, other crops—cattle and other livestock). In addition, we include 17 other sectors: forestry products, coal, oil, gas, other minerals; fish, meat and dairy; other processed food; vegetable oils and fats; sugar; lumber; manufacturing non-metallic;

chemical, rubber, and plastic products; petroleum and coal products; other manufacturing; transportation services; services; and capital goods.

For the Biofuels study it was necessary to split some of the GTAP existing sectors to explicitly account for corn, soybeans, and ethanol. For example, the sector “other grains” was split into corn and “rest of other grains,” and the sector “oilseeds” was split into the sectors “soybean” and “other oil seeds.” Two ethanol sectors were created based on the two major sources of the feedstock: Corn ethanol produced mostly in the U.S. and sugar-cane ethanol produced mostly in Brazil. Figures 22 and 23 summarize the cost of production of ethanol in the two major ethanol-producing countries, the U.S. and Brazil, and also show the dependence of ethanol cost on the price of their respective feedstocks.

Key agricultural and non-agricultural sectors data, especially for those sectors related to biofuels in the global GTAP database, were expanded because detailed and accurate data are necessary to simulate consistent commodity impacts. Given the importance of input requirements (such as purchased variable inputs) in the production of individual commodities, we use alternative data sources to develop these cost flows as well as returns to the factors of production of all new commodities introduced in the database. In particular, for the U.S. we use data from the Agricultural Resource Management Surveys (ARMS) and from ERS’ official farm income and productivity accounts to reflect updated production and intermediate cost of farm commodity activities intermediate cost of farm commodity activities. Utilizing the environmental database we improved the accuracy of resource allocation globally, especially land use, by farm activity in the production of the various farm outputs. A benefit of such detailed

data on costs and supply-response is that it allows complete specification and interaction of the sectors/commodities in the model.

Unlike other global modeling platforms that utilize elasticities in nested production specification to accommodate the lack of detailed commodity data on intermediates and factors of production, we were in the position to augment the global database to estimate directly own and cross effects of the commodities and industries specified. A benefit of such up-to-date detail on costs and supply-side requirements for specific crops and livestock is that it allows us to capture more accurately the impacts of future biofuel expansion. For example, the farm resources needed to produce corn determine the supply response not only for corn but for all other related commodities that compete for similar resources. We also attempt to capture the interaction of upstream and downstream industries related to biofuels, such as dry corn milling sector/industry and similar sugar/ethanol activities in the U.S. and Brazil, respectively, in a consistent manner. In sum, we introduce disaggregated industries to capture the farm and downstream industries linkages and interactions that are essential for the FARM II model in order to simulate and accurately quantify the impacts on the farm sector.

Given the farm sector's dynamic changes and especially the relevance of biofuels for the global FARM II model, we replaced aggregated farm activities with detailed commodity/ industry activities and specific value-added accounts and the entire global environmental and economic database was rebalanced.

For the biofuel study, the data are aggregated into 15 countries/regions: Canada, United States, Mexico, Brazil, other Western Hemisphere, European Union (EU25), Russia, China, India, other East Asia, other South Asia, OPEC countries, Oceania, Africa,

and the rest of the world (table 2). Finally, we consider the following endowments: land, unskilled labor, skilled labor, capital, natural resources, and irrigation water.

Scenarios

In this preliminary analysis we consider two scenarios, both for the medium term. The basic scenario with trend productivity assumes that the U.S. producers attempt to meet the Revised Renewable Fuels Standard for the medium term (around 2015); that is, the U.S. will have a total production target of around 15 billion gallons per year of conventional biofuels (ethanol from corn starch). In the case of the U.S., the productivity gains for the basic scenario are consistent with USDA's baseline projections (USDA, 2008). The basic scenario also assumes that Brazilian producers will attempt to meet the ethanol production estimates set up in the national energy plan published by the Brazilian Government (EPE, 2007), which implies that there will be moderate increases in productivity (table 3).

In the second scenario, we assume there will be additional productivity gains in the U.S. as predicted by some experts (Schicker, 2008). For Brazil we assume productivity gains with respect to the basic Brazilian scenario of 10 percent. It is also assumed that for the medium term there will not be a substantial amount of cellulosic ethanol. Table 3 shows the yields and other technical data related to the production of corn-based ethanol in the U.S. and sugar cane-based ethanol in Brazil in accordance with the two medium-term scenarios considered.

Preliminary Results

Selected preliminary results from the model simulations are summarized in table 4 and figures 24-25. All impacts resulting from the two scenarios are measured as percentage

changes from the model baseline for the 2004/2005 world economy. Overall global welfare change effects are presented in Table 4.¹³ In both scenarios, greater production of corn-based and sugar cane-based ethanol leads to moderate global welfare gains led by Brazil. The U.S. has small gains. Main losers are OPEC countries.

As a result of the 220 percent increase in production of corn-based ethanol in the U.S. and 120 percent increase of sugar cane-based ethanol in Brazil, U.S. corn production increases by about 33 percent, U.S. corn prices increase by 23 percent while corn ethanol prices decrease by about 8 percent. U.S. land devoted to corn increases by 18 percent (fig. 24). In Brazil, the 120 percent increase in sugar cane-based ethanol leads to an increase in sugar cane production of 53 percent. Sugar cane prices rise by about 24, sugar ethanol price decrease by about 20 percent, and land use increases by 52 percent (fig. 25).

In the alternative (higher productivity scenario), as corn-based ethanol raises by about 220 percent, U.S. corn production increases by 39 percent, U.S. corn prices increase by 23 percent while corn ethanol prices decrease by 9 percent. Corn acreage increases by 16 percent (fig. 24). In Brazil, the increase (120 percent) in sugar cane-based ethanol leads to sugar cane production increases of almost 55 percent and sugar cane prices increase by 24 percent. Land used to grow sugar cane increases by about 51 percent (fig. 25).

Summary and Concluding Comments

This paper presents the first part of an effort to evaluate the global potential for biofuel adoption under different economic, policy, and technological assumptions. The analysis

¹³ This paper uses the widely accepted equivalent variation (i.e., consumers' willingness to pay) to measure the social welfare gains or losses due to the increased ethanol production (e.g., to meet the Renewable Fuel Standard-- in the U.S.) The EV measurement of welfare uses the status-quo (pre-policy) prices as the base and addresses the question: what income would be equivalent to the change brought about by the policy (Varian, 1984).

is based on the revised Future Agricultural Resources Model (FARM II), which is an integrated modeling framework developed by USDA's Economic Research Service designed for analyzing global changes related to long-run agricultural and environmental sustainability. FARM II includes a new land and water resources database linked to the production of agricultural and forestry commodities according to agro-ecological zones characterized by irrigated or rain-fed production conditions, length of growing seasons, temperature regime, and plant hardiness zones. This database has been incorporated into a computable general equilibrium (CGE) model of the global economy based on the GTAP 7 database modified to reflect FARM II economic structure. FARM II has been adapted for the analysis of the implications of biofuel production and provides a global framework with links between the agricultural and energy sectors, trade policy, and land resource use at a fine spatial scale. This paper includes preliminary simulation results of a controlled experiment under two technological and policy scenarios focusing on the medium term.

Further work, currently under development, includes addition in the model of biodiesel component and second generation feedstocks.

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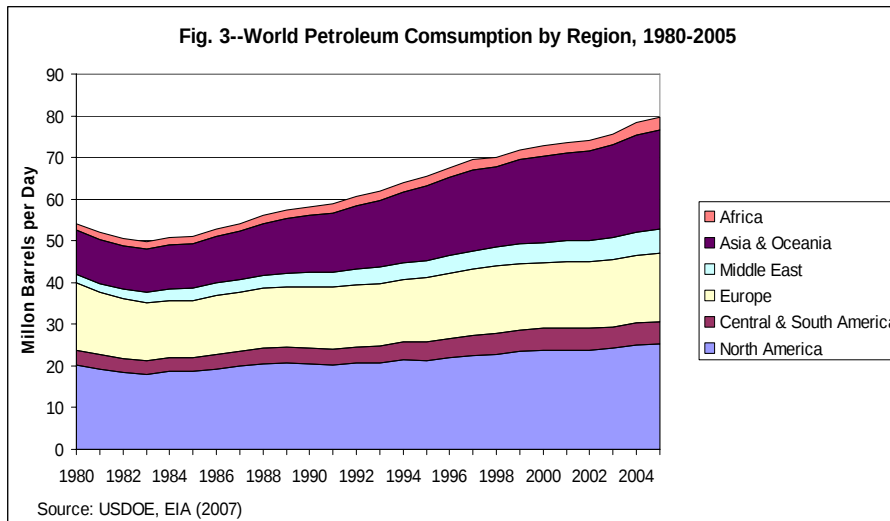
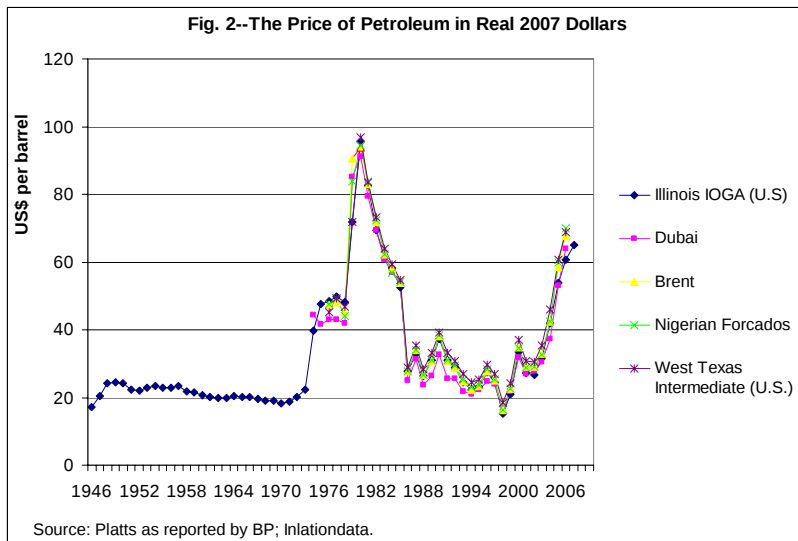
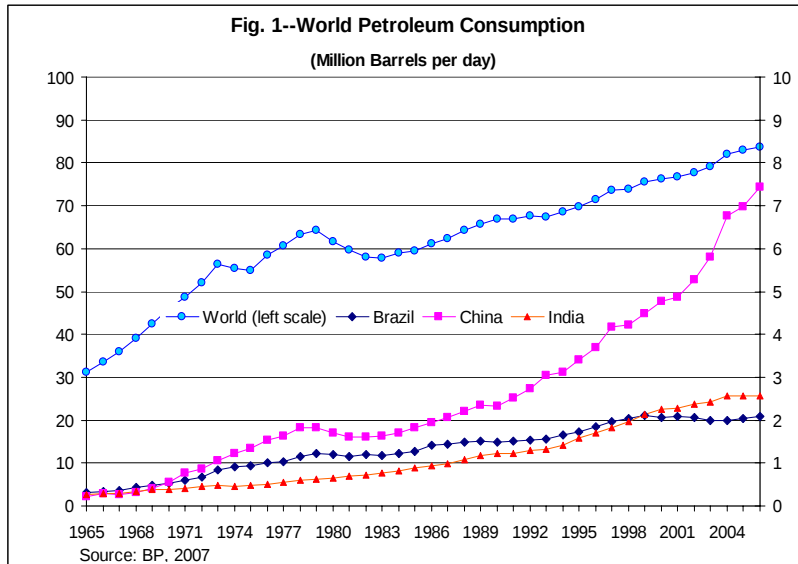


Fig. 4--Petroleum Consumption - Selected Countries

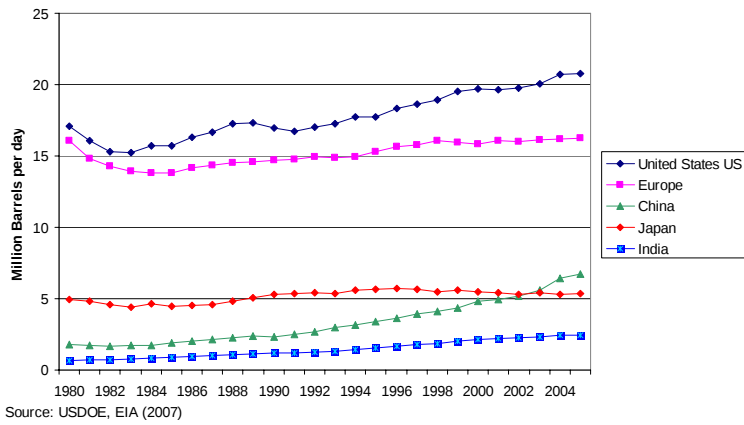


Fig. 5--U.S. Retail Price of Gasoline

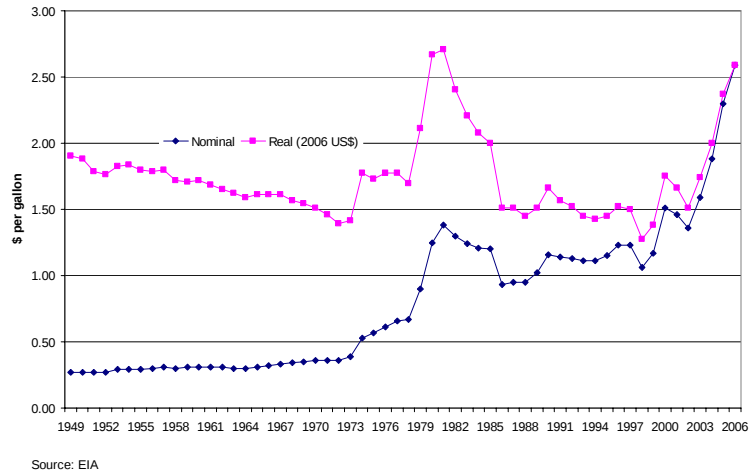
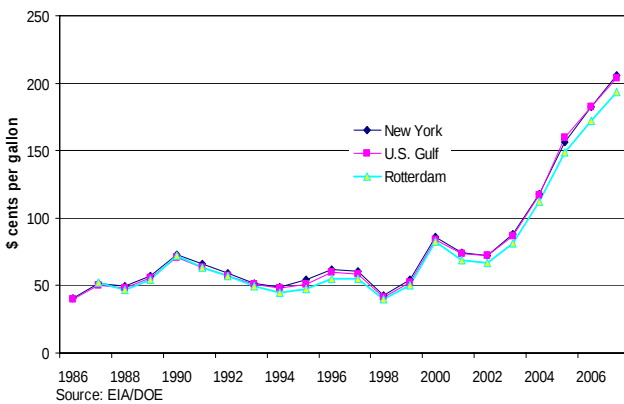
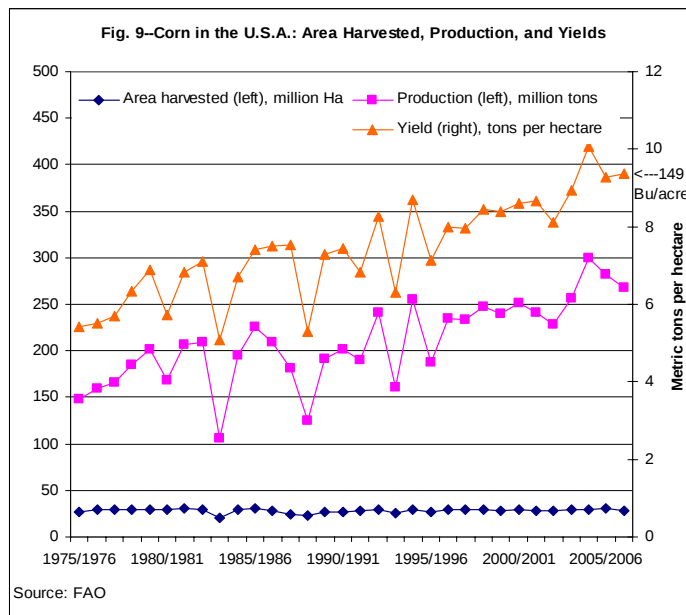
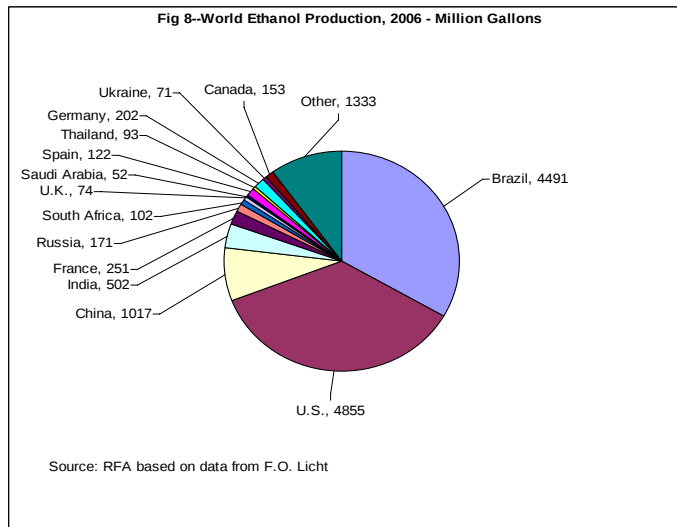
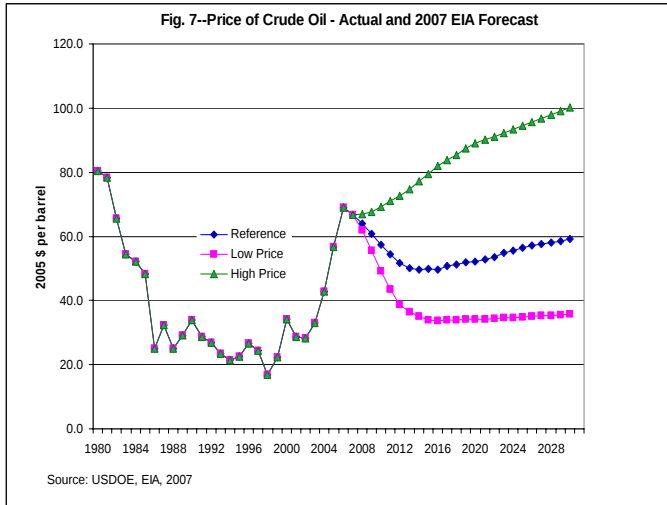
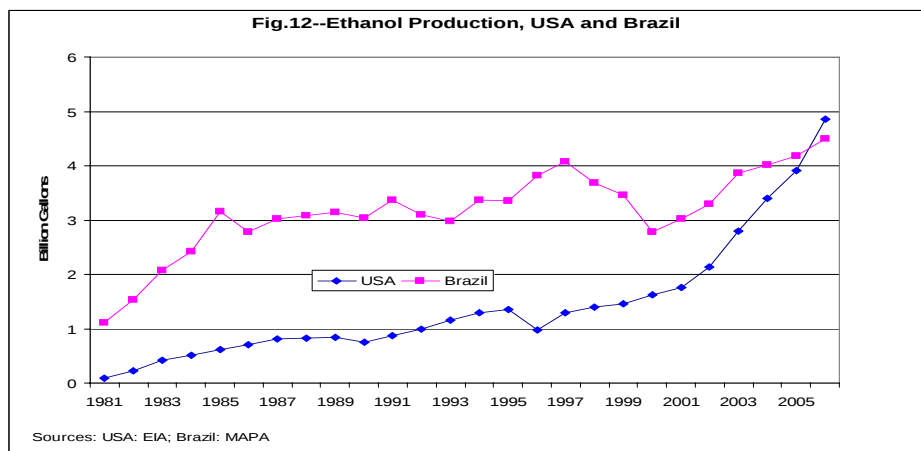
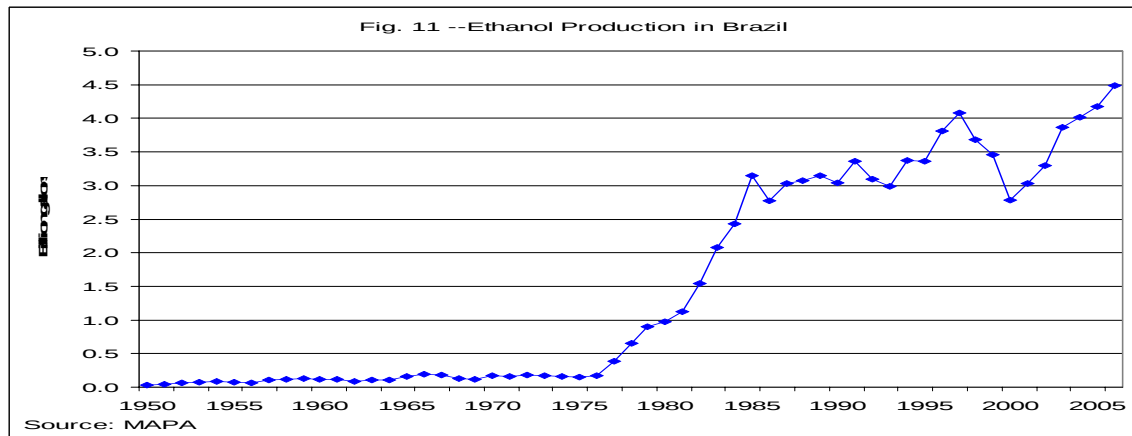
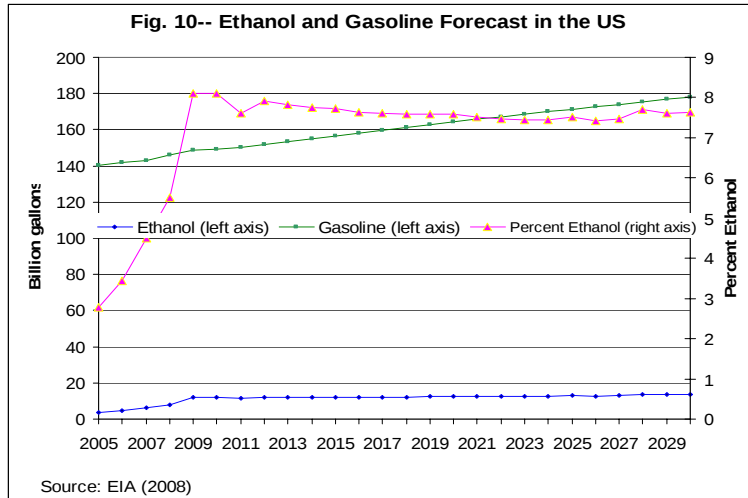
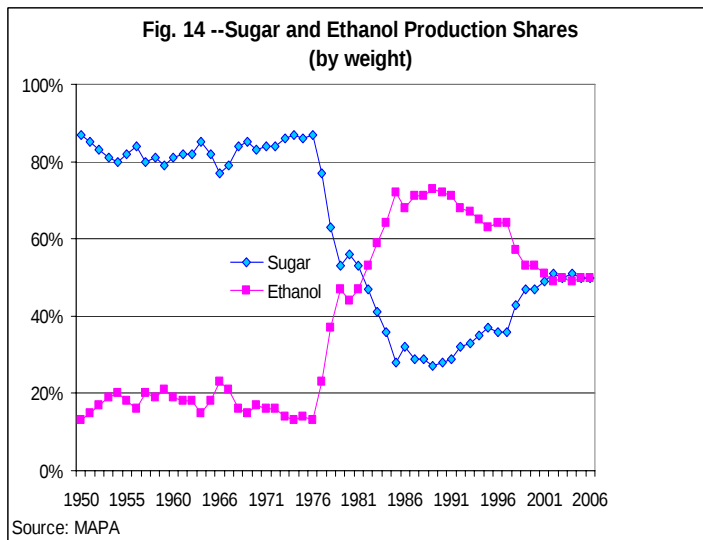
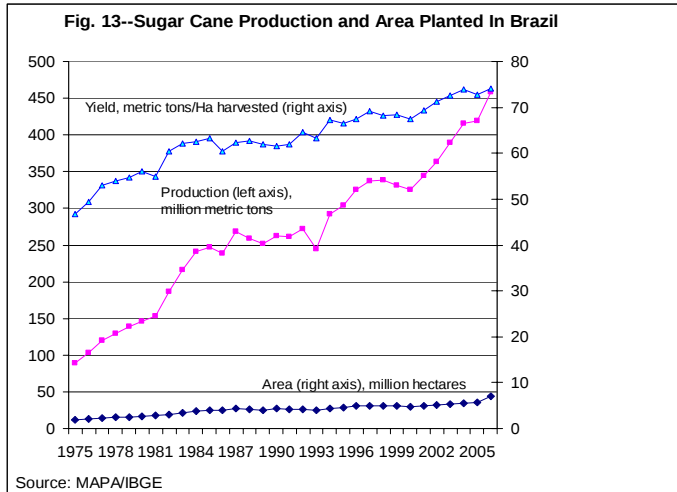


Fig. 6--Spot Price of Motor Gasoline









Distribution of Cropland in 1997 (percent/0.5 degree grid)

Derived from: U.S. Geological Survey, EROS Data Center. *Global Land Cover Characteristics Data Base Version 2.0.*, 2001; Food and Agriculture Organization of the United Nations. *FAOSTAT Agriculture Data.* 2001; Döll, P. and S. Siebert. *A digital global map of irrigated areas.* 2000; Siebert, S. and P. Döll. *A digital global map of irrigated areas—An update for Latin America and Europe.* 2001.

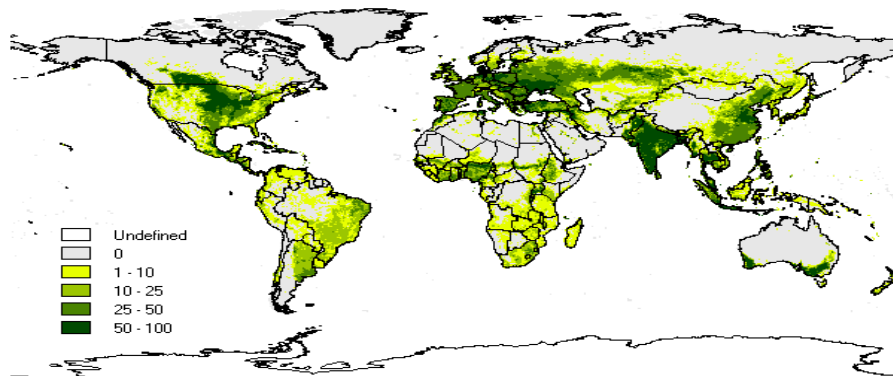


Figure 15. Distribution of Cropland

Distribution of Irrigated Land in 1997 (percent/0.5 degree grid)

Derived from: Döll, P. and S. Siebert. *A digital global map of irrigated areas*. 2000; Siebert, S. and P. Döll. *A digital global map of irrigated areas—An update for Latin America and Europe*. 2001; U.S. Geological Survey. EROS Data Center. *Global Land Cover Characteristics Data Base Version 2.0*. 2001; Food and Agriculture Organization of the United Nations. *FAOSTAT Agriculture Data*. 2001.

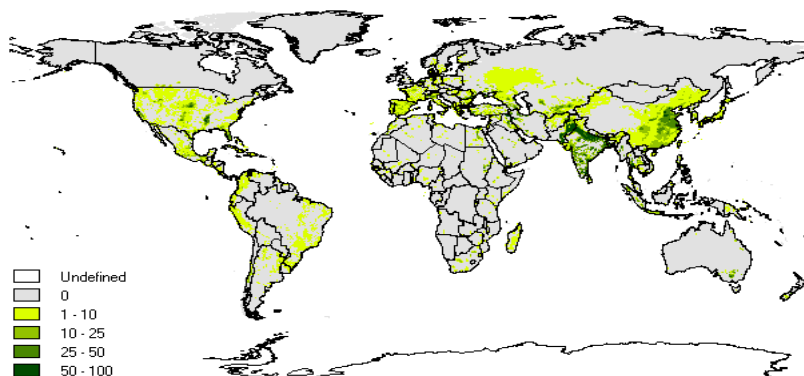


Figure 16. Distribution of Irrigated Cropland

Distribution of Grassland (percent/0.5 degree grid)

Derived from: U.S. Geological Survey. EROS Data Center. *Global Land Cover Characteristics Data Base Version 2.0*, 2001.

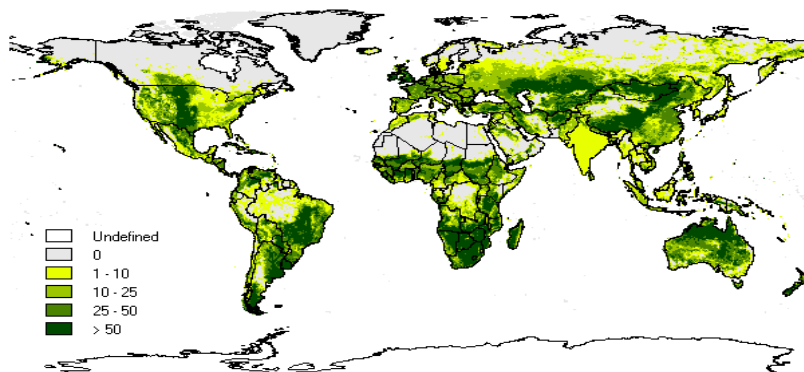


Figure 17. Distribution of Grassland

Distribution of Nonconiferous Forestland (percent/0.5 degree grid)

Derived from: U.S. Geological Survey. EROS Data Center. *Global Land Cover Characteristics Data Base Version 2.0*, 2001.

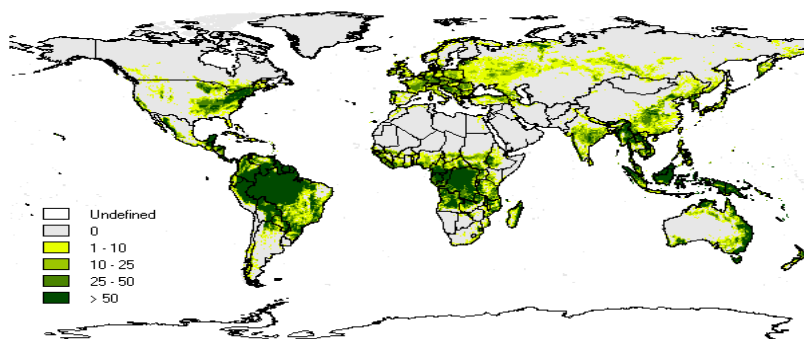


Figure 18. Distribution of Nonconiferous Forestland

Plant Hardiness Zones, 1978-1997

Derived from: University of East Anglia. Climate Research Unit. CRU05 0.5 Degree 1901-1995 Monthly Climate Time-Series. East Anglia, Great Britain.

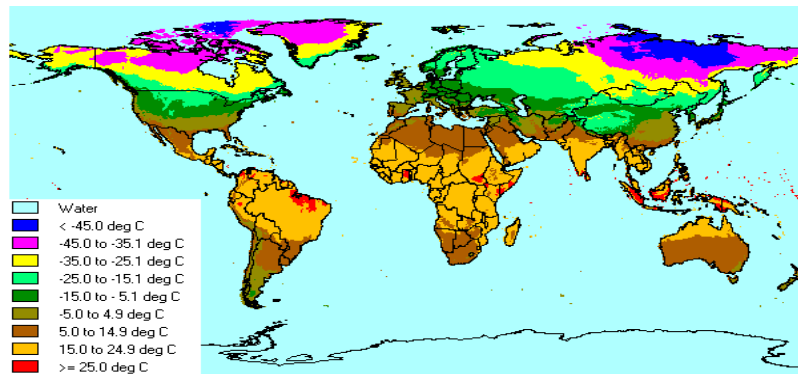


Figure 19. Distribution of Plant Hardiness Zones

Rainfed Thermal Regimes in 1997

Derived from: University of East Anglia. Climate Research Unit. CRU05 0.5 Degree 1901-1995 Monthly Climate Time-Series. East Anglia, Great Britain.

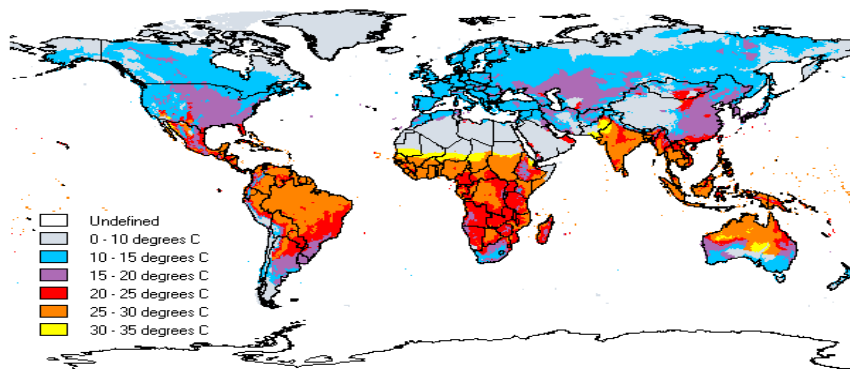


Figure 20. Distribution of Rainfed Thermal Regimes

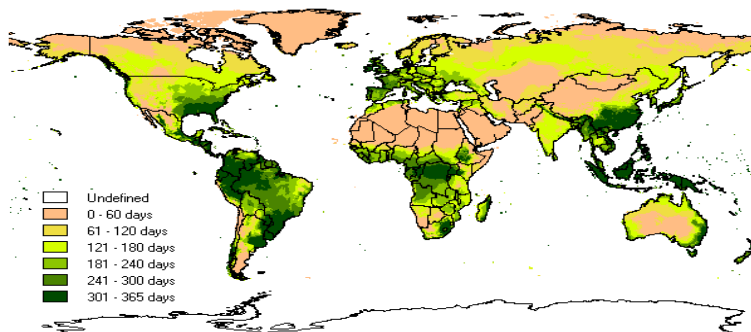
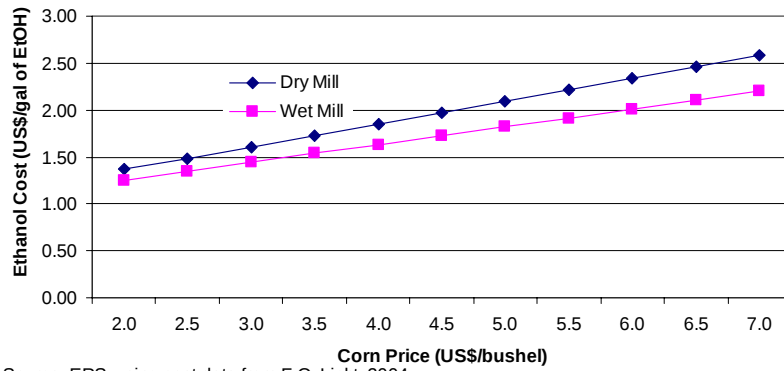


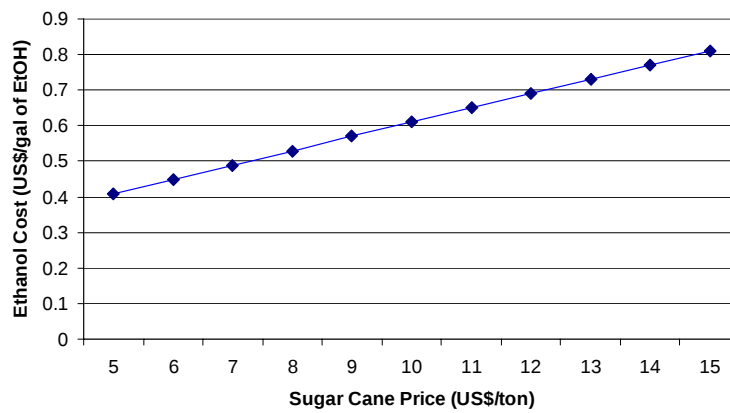
Figure 21. Distribution of Length of the Growing Season

Figure 22--Estimated Ethanol Cost and Corn Price in the U.S.



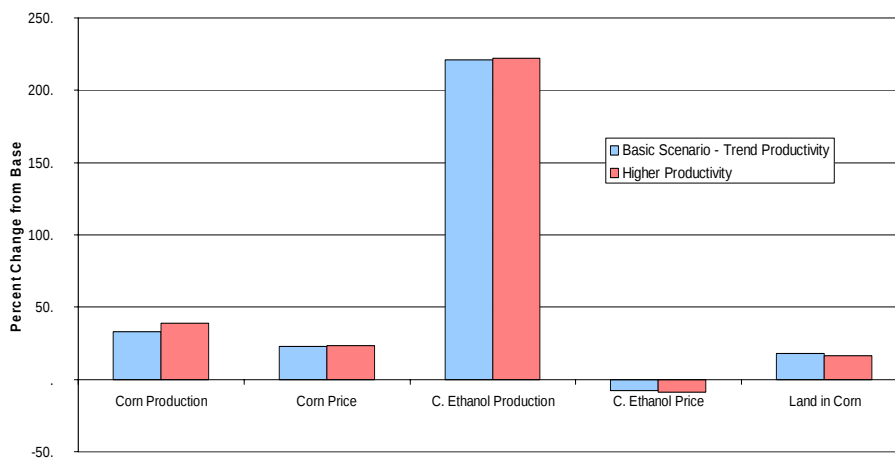
Source: ERS, using cost data from F.O. Licht, 2004

Figure 23--Estimated Ethanol Cost and Sugar Cane Price in Brazil



Source: ERS calculations using cost data from F.O. Licht, 2004

Figure 24-- Production, Prices, and Land Use at Medium Term under Two Scenarios USA



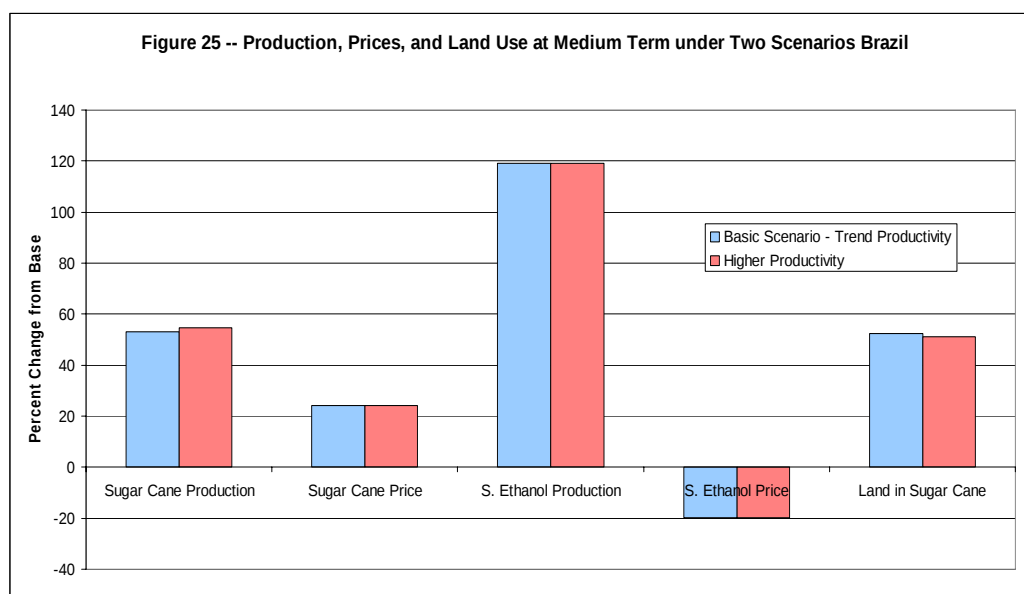


Table 1. The Revised Renewable Fuels Standard (billion gallons)

Year	Conventional Biofuel (from corn starch)	Advanced Biofuel (Other than from 1)	Cellulosic Biofuel	Biomass-based Diesel	Undifferentiated Advanced Biofuel	Total RFS
	1	2=3+4	3	4	5	6
2008	9.0					9.0
2009	10.5	0.6		0.5	0.1	11.1
2010	12.0	1.0	0.1	0.7	0.2	13.0
2011	12.6	1.4	0.3	0.8	0.3	14.0
2012	13.2	2.0	0.5	1.0	0.5	15.2
2013	13.8	2.8	1.0		1.8	16.6
2014	14.4	3.8	1.8		2.0	18.2
2015	15.0	5.5	3.0		2.5	20.5
2016	15.0	7.3	4.3		3.0	22.3
2017	15.0	9.0	5.5		3.5	24.0
2018	15.0	11.0	7.0		4.0	26.0
2019	15.0	13.0	8.5		4.5	28.0
2020	15.0	15.0	10.5		4.5	30.0
2021	15.0	18.0	13.5		4.5	33.0
2022	15.0	21.0	16.0		5.0	36.0

Source: U.S. Congress; Renewable Fuels Association (RFA), Renewable Fuels Standard
<http://www.ethanolrfa.org/resource/standard/>

Table 2-- Model Aggregation – Regions, Sectors, and Endowments

Countries/Regions (15)		Commodities/Activities (25)	
SSA	Africa	osd	Oilseeds
BRA	Brazil	ocr	Other Crops (vegetables, fruit, nuts; plant-based fibers; and other crops not elsewhere specified)
CAN	Canada	gro	Other Grains
CHN	China	pdr	Paddy Rice
E_U	EU25	c_b	Sugar, Cane and Beets
IND	India	wht	Wheat
MEX	Mexico	ctl	Cattle (including raw milk, wool, and silk-worm) cocoons.
OCE	Oceania	oap	Other livestock
OPE	OPEC	frs	Forestry products
OEA	Other East	coa	Coal
OSA	Other South	oil	Oil
OWH	Other Western Hemisphere	gas	Gas
ROW	Rest of the World	min	Other minerals
RUS	Russia	fmm	Fish, meat dairy including fishing; bovine cattle, sheep and goat meat products, other meat products, and dairy products
USA	United States	opf	Other processed food (includes processed rice, food products, and beverages and tobacco products)
Endowments		vol	Vegetable oils and fats
		sug	Sugar
LAND	Land	lum	Lumber
UNSKLAB	Unskilled labor	nmm	Manufacturing non-metallic including textiles, wearing apparel, leather products, mineral products, paper products, publishing.
SKLAB	Skilled labor	crp	Chemical, rubber and plastic products
LABOR	General labor	p_c	Petroleum and coal products
CAPITAL	Capital	omn	Manufacturing, other including ferrous metals, other metals, metal products, motor vehicles and parts, transport equipment, electronic equipment, other machinery and equipment, other manufactures
NATRES	Natural Resources	trs	Transportation services including water transport, air transport, other transport
WATER	Water for irrigation	srv	Services including electricity, gas manufacture, distribution, water, trade, construction, communications, financial services, insurance, other business services, recreational and other services, public administration and defense, education, health, ownership of dwellings
		cog	Capital goods

Table 3--Scenarios for Corn-Based Ethanol in the U.S. and Sugar Cane-Based Ethanol in Brazil- Medium Term

		Estimates for Medium Term (2014/2015)	
		Basic Scenario with trend productivity	Scenario with productivity above trend
Yields and other Technical Data			
<i>Corn-Based Ethanol in the U.S 1/</i>			
Corn yield, bushels/harvested acre		167.0	200.0
Ethanol yield, gallons/bushel		2.74	2.90
Ethanol yield, gallons/acre		457.6	580.0
Ethanol production from corn, Billion gallons 2/		15.0	15.0
<i>Scenarios for Sugar Cane-Based Ethanol Market in Brazil 3/</i>			
Sugar cane yield, metric tons per hectare		79.0	86.9
Ethanol Yield, cubic meter per metric ton		0.053	0.053
Ethanol yield, cubic meter per hectare 4/		4.16	4.61
Ethanol Production, million cubic meters		36	36

1/ Yields for basic scenario from USDA baseline (USDA, 2008); increased productivity from Schikler, 2008.

2/ From RFS, table 1, for corn starch.

3/ Yields for basic scenario from EPE (2007); Increased productivity with 10% higher yields.

4/ Ethanol in co-production with sugar. Yields change as a function of the share of ethanol produced, see figure 14.

Table 4--Welfare Changes with Ethanol Production - Percent

Country/Region		Basic Scenario – With Trend Productivity	With Productivity above trend
Brazil	BRA	1.48	1.52
USA	USA	0.02	0.04
			-
OPEC countries	OPE	-0.32	0.32
			-
European Union	E_U	-0.01	0.01
			-
Rest of the World	ROW	-0.07	0.07

Box 1--Biofuel Production Processes

Ethanol

Ethanol is used in motor fuel in two ways. Anhydrous alcohol is an oxygenate that has been used to replace MTBE. Hydrous alcohol directly substitutes for gasoline and can be used for motor fuel in conventional cars at a concentration up to 10 percent and up to 85 percent in flexible fuel vehicles. The process of producing ethanol differs depending on the feedstock. Corn and sugar cane are the primary feedstocks for ethanol production. Generally, it is less costly to produce from sugar-based feedstocks like sugarcane or molasses compared to grains like corn.

Sugar cane is ideally grown in sub-tropical or tropical climates because it requires plenty of water and higher temperatures. Unlike typical row crops sugar cane regrows from the same roots for a number of growing cycles. Time to maturity ranges from 6 to 24 months depending on conditions. Harvested sugar cane is taken to factories where the first step is to extract juices from the fibrous material (bagasse). The bagasse is typically burned to provide energy to power ethanol plants. The sugary juice is then fermented with yeast to produce ethanol. The final step is to concentrate the ethanol through a process called distillation. Normal distillation procedures can concentrate ethanol up to 96%.

Ethanol from corn is more costly to produce because, in addition to the higher cost of the feedstock and energy used in the process, it is necessary to first convert starches in corn into sugars in a process called saccharification. There are two general methods for producing ethanol from corn; wet milling and dry milling. Dry milling facilities have lower construction costs and achieve higher ethanol yields per unit of input. In the U.S., 82% of ethanol plants are dry mill (RFA, 2008). In dry mills all the corn kernel material is ground to a powder which is combined with enzymes and water that is heated. Starches are converted to sugars in a process called saccharification through the addition of an enzyme called glucamylase. As with sugar cane, ethanol is produced through fermentation by the addition of yeast. The remaining unfermented coarse grains and soluble materials are separated. The concentrated solubles are called Condensed Distillers Solubles, and the coarse grains produce Dried Distillers Grains with Solubles (DDGS). These are used as a source of protein in livestock feed (RFA, 2008; Schroeder, 2003).

In wet milling ethanol plants, grains are ground and then heated for one to two days in a sulfure dioxide solution to separate the starches that will be turned into sugars from the rest of the hulls and fibrous material. Germ meal is added to the hulls and fiber from the corn to produce a high protein component called gluten that is added to livestock feed, particularly for poultry. No matter what the feed stock producing the oxygenate anhydrous ethanol requires an additional dehydration step (F.O. Licht, 2004).

Still not commercially proven, converting cellulosic material into ethanol requires still more steps in the production process. Cellulosic material is converted to ethanol by acid hydrolysis, enzymatic hydrolysis, and thermochemical processes. The primary difficulty lies in efficiently extracting sugars from a complex network of polymers that are designed to resist being broken down (USDOE, 2006a). The essence of the process to convert plant materials to fuel is as follows. Various forms of plant material provide a feed stock of cellulosic material, which is pretreated in different ways to remove the polymers that are intertwined with cellulose. Enzymes are then added to perform hydrolysis which breaks down cellulose to sugars. The sugars are then fermented to make ethanol. The pretreatment stage is currently costly and much of the research on technologies based on cellulosic feedstock is focused on this stage (Mosier et al., 2005). Research is also continuing in feedstock engineering and microbe fermentation.

Ethanol production costs come from fixed capital, variable operating costs, and feedstock. Larger plants achieve significant economies of scale in lowering costs, although feedstock costs make up the biggest portion of the total. The scale of ethanol operation in Brazil has made it competitive against oil priced at \$30 to \$40 per barrel, which is far below current prices (F.O. Licht, 2004).

Biodiesel

Biodiesel is a fuel substitute produced by combining oils and fats with an alcohol, typically methanol or ethanol through a process called transesterification (Sheehan et al., 1998). The two most common sources of biodiesel are soybeans and rapeseed. The scientific term for biodiesel is fatty-acid methyl-ester fuel (USEPA, 2006). An attractive quality of biodiesel is that most petroleum diesel engines can run on biodiesel without modification, as opposed to ethanol that can only be used up to a volume of 10% in traditional non FFVs. This technological convenience is a result of the similarity in chemical structure of biodiesel and petrodiesel (Duffield et al., 1998).

Box 2--Biofuels Policies in the United States

Ethanol, Taxes, and Tariffs

A key component of transportation energy policy is the gasoline excise tax (paid at the point of purchase) that was first enacted in 1932. The gas tax increased steadily over the years with a more significant one time increase in 1990. It has remained at 18.4 cents/gallon since 1997.

The gas tax is central to biofuel policy. Incentives for the use of fuel ethanol and biodiesel have been created by exempting a portion of the gas tax if a minimum amount of ethanol is included in the fuel. The development of the

ethanol tax credit along with other policies to promote the development of renewable fuel sources began in the 1970's in response to the energy crises of 1973 and 1979 (F.O. Licht, 2006).

The legislation that initiated the growth of biofuels was the Energy Tax Act within the National Energy Act of 1978. The ETA exempted all of the gas tax if ethanol was at least 10% by volume (E10). At the time, the gas tax was \$0.04 per gallon, which equates to a subsidy of \$0.40 for each gallon of ethanol. The exact level of both the gas tax and the ethanol blend credit has fluctuated through the enactment of a series of legislation. These include the Crude Oil Windfall Profit Tax (WPT), the Surface Transportation Assistance Act (STAA), the Tax Reform Act (TRA), the Omnibus Budget Reconciliation Act (OBRA), and the Energy Policy Act. Many states have also provided exemptions for the use of biofuels to state taxes.

Currently, under the American Jobs Creation Act of 2004 (H.R. 4520, Title III, Subtitle A) blenders can receive tax credits (Volumetric Ethanol Excise Tax Credit) equal to 51 cents per gallon of ethanol blended with gasoline in any proportion. As Westcott (2007) observes, this makes ethanol more economical to produce, as part of that credit is, in effect, passed back from blenders to ethanol producers.

Ethanol imports are subject to a tariff of 54 cents per gallon, although imports from designated Central American and Caribbean countries are duty-free up to a maximum of 7 percent of the U.S. ethanol market (Westcott, 2007)

Policy to Build the Ethanol Infrastructure

The government often plays an important role in developing markets that must overcome large initial investments that are prohibitive for any individual private sector operation to make. For instance, the construction and operation of airports is typically done by the public sector. The U.S. government has sought to overcome similar hurdles in developing ethanol in multiple ways. The OBRA of 1990 created an income tax credit of \$0.10 per gallon to expand ethanol production facilities specifically designed for small producers (30 million gallons per year or less). In addition to federal programs, a number of states have also provided funds for ethanol plant construction. Policy has also sought to influence demand by creating incentives to expand the production of cars that can run on higher ethanol blends, such as E85. The Corporate Average Fuel Economy (CAFÉ) standard included in the Alternative Motor Fuels Act of 1988 gave car producers a credit of 1.2 miles per gallon for flexible fuel vehicles. (For more on the CAFÉ standard see Bamberger, 2003).

The Energy Bill and the Renewable Fuel Standard

In the 2005 Energy Bill a Renewable Fuel Standard (RFS) was enacted to work together with the ethanol gas tax exemption to support biofuels. The underlying regulatory foundation for the RFS is the statutory requirement set in the Clean Air Act to increase the use of renewable fuels (40 CFR part 80). It directs the EPA to require minimum volumes of renewable fuels be used over a time schedule. The 2005 RFS requirements were for 4 billion gallons in 2006 increasing to 7.5 billion gallons in 2012 (Yacobucci, 2006). These provisions were increased significantly and extended with the RFS in the 2007 Energy Bill. Total renewable biofuel requirements for a selection of years are 8 billion gallons in 2008, 15.2 billion gallons in 2012, and 36 billion gallons in 2022. It is expected that ethanol from corn will plateau in 2015 and the additional growth beyond that will be provided by cellulosic technologies which not currently commercially viable. The RFS does allow the EPA administrator specific waivers in the schedule. The mandate can be withdrawn if it is determined that there will be severe economic or environmental harm from meeting it. A waiver can also be used if cellulosic biofuels do not advance adequately.

Additional provisions for biofuels support are provided elsewhere in the 2007 Energy Bill. It provides a credit to renewable energy production facilities that are powered by renewable energy in place of fossil fuels, gives competitive grants for establishing an infrastructure for gasoline blend refueling, and seeks to improve information and labeling of biofuels. Also, it defines research needs to improve technology related to biofuels, and better understand the effects of an expanding biofuels sector. Support for biofuels is also provided by setting forth a requirement for federal fleets to increase alternative fuel consumption by 10% annually.

Biofuels and the Farm Bill

For the first time, the Farm Bill of 2002 included an energy title (Title IX) that created a number of measures for expanding biofuels (Duffield and Collins, 2006). The Energy Efficiency Improvements Program creates a loan and grant program for rural households and businesses to adopt renewable energy systems. The Value Added Grant Program created in the Agricultural Risk Protection Act of 2000 provides money for investments made to develop ethanol and biodiesel. It was amended in the 2002 Farm Bill.

Gasoline Oxygenate

Demand for ethanol as a gasoline oxygenate has increased in response to regulation to prohibit the use of MTBE. While MTBE improves air quality by more completely combusting gasoline to prevent the release of harmful tailpipe emissions, it has been found to be carcinogenic to humans and appears to accumulate in groundwater in some areas. Ethanol is also an oxygenate so E10 gasoline has been used as a replacement to gasoline with MTBE. The steep decline in the use of MTBE in 2002 coincided with significant growth in the use of ethanol (USDOE, 2006b).

Box 3--Biofuels Policies in Other Countries

While concerns about reliance on foreign oil and rural employment led Brazil to aggressively and directly support the growth of sugar based ethanol in the 1970's, climate change mitigation has been central to the European Union's effort to increase the use of biofuels in the last ten years. At the same time, political support for biofuels remains limited in many developing countries like China and Mexico due to concerns over rising food prices.

Brazil

Brazil's status as the global leader in biofuels and the second largest producer of ethanol is the result of more than 30 years of active policy intervention. Support for biofuels started during the energy crisis in 1973 with a national ethanol program called Proálcool (Koizumi, 2003). Besides providing the country with greater protection from global oil supply disruptions Proálcool addressed the overproduction problems that had existed in its sugarcane industry in the early part of the 20th century that led to the creation of production quotas to maintain higher prices (Koizumi, 2003). The Brazilian government heavily subsidized loans for expanding sugarcane fields and constructing ethanol distilleries through the National Economic and Social Development Bank (BNDES). The World Bank also provided investment funds (AgraFNP, 2007). The direct control of the ethanol market maintained the industry through the 1980's and 90's by mandating ethanol blend requirements as oil prices decreased significantly.

Brazil deregulated the ethanol program in the late 1990's by eliminating Proálcool, which removed ethanol price standards and subsidies. Also, Petrobras was no longer given a monopoly over distribution. Without direct control of production and prices the government influences ethanol markets in response to supply and demand side factors by adjusting the ethanol gas blending requirement between 20 and 25% (USDOE, 2007). The introduction of flex-fuel vehicles in 2003 has also been important for the more recent growth in the ethanol industry. The ability to run on any gas ethanol mixture provides flexibility that the ethanol-only cars introduced in the 1980's lacked. With the combination of aggressive ethanol policies and a favorable climate for producing sugarcane Brazil now produces half of the world's supply of sugar-based ethanol and also has the lowest unit cost of production (F.O. Lichts, 2004).

The European Union

The biofuels sector in the EU differs markedly from Brazil in both policy and production. Growing conditions are not as favorable for corn or sugarcane, making ethanol less attractive, so biodiesel from rapeseed makes up a majority of production. Also, the diversity among Member States in terms of economy and agriculture requires that directives allow some flexibility in meeting standards. The first important biofuels document in the EU was the 1997 White Paper on Renewable Energy that outlined the potential for biofuels in the European Union (COM 599 final). The first substantive policy was the EU Biofuels Directive (2003/30/EC) published in 2003 that required Member States to have biofuels account for 2% of transportation fuel use by the end of 2005, and 5.75% by December, 2010.

The Energy Taxation Directive (2003/96/EC), also adopted in 2003, encouraged EU Member States to provide either tax reductions or tax exemptions for biofuels, although no uniform standard is set allowing flexibility across states (COM(2005) 628 final, Annex 9). Some Member States including France and Austria have enacted a requirement for fuel to contain a required ethanol mix, which is likely to be adopted in other countries (COM(2005) 628 final, Annex 9). Biofuels are also supported in the 2003 Common Agriculture Policy (CAP) that designates a maximum of 45€ per ha in aid for growing energy crops on non set-aside land with a maximum total area of 1.5 million ha for the EU as a whole (CAP Action Plan, 2003). In 2005, 1.8 million ha of the 97 million ha of arable land in the EU were used for growing raw materials for biofuels (COM(2005) 628 final, Annex 7).

Action Plans for biomass and biofuels in 2005 and 2007 updated projections for potential growth. The "Renewable Energy Roadmap" and the "The Energy Policy for Europe" released in 2007 have set a goal for 20% of energy to be renewable by 2020 and half of that to come from biofuels (Bolter et al., 2007).

Other Countries

Support for biofuels in Canada has grown since the government ratified the Kyoto Protocol in 2002. A Renewable Fuel Standard has been the central policy approach proposed to achieve a 5% renewables level for gasoline by 2010 (F.O. Lichts, 2006). Already in place is a federal excise tax exemption in proportion to the ethanol mix (F.O. Licht, 2006). Some provinces have taken additional measures, such as minimum ethanol blends, to promote biofuels. The initial goal was for 35% of fuel consumption to contain 10% ethanol using corn as the primary feedstock. To expand ethanol production a gasoline exemption tax of US \$0.28/gallon was enacted together with subsidies for production facilities valued at \$73 million (Klein et al., 2004). Argentina enacted in April, 2006 a 5% biofuel mix requirement accompanied by tax breaks for producers (F.O. Licht, 2006). Thailand, which has favorable conditions for growing sugar cane, looks to follow Brazil's lead by mandating gasoline to contain 10% ethanol. China is also focusing on developing biofuels through the development of E10 gasoline blends, although this exists on a trial basis currently.