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Review

First generation biofuels compete

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Rising petroleum prices during 2005–2008, and passage of the 2007 U.S. Energy Independence and Security Act with a renewable fuel standard of 36 billion gallons of biofuels by 2022, encouraged massive investments in U.S. ethanol plants. Consequently, corn demand increased dramatically and prices tripled. This created a strong positive correlation between petroleum, corn, and food prices resulting in an outcry from U.S. consumers and livestock producers, and food riots in several developing countries.Other factors contributed to higher grain and food prices. Economic growth, especially in Asia, and a weaker U.S. dollar encouraged U.S. grain exports. Investors shifted funds into the commodity's future markets. Higher fuel costs for food processing and transportation put upward pressure on retail food prices.From mid-2008 to mid-2009, petroleum prices fell, the U.S. dollar strengthened, and the world economy entered a serious recession with high unemployment, housing market foreclosures, collapse of the stock market, reduced global trade, and a decline in durable goods and food purchases. Agricultural commodity prices declined about 50%.Biotechnology has had modest impacts on the biofuel sector. Seed corn with traits that help control insects and weeds has been widely adopted by U.S. farmers. Genetically engineered enzymes have reduced ethanol production costs and increased conversion efficiency.

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Introduction

This article analyzes the U.S. corn-based ethanol industry, its impacts on food prices, and the role of biotechnology.

Recent economic history

Rising petroleum prices during 2005–2008 and the passage of the 2007 U.S. Energy Independence and Security Act with a renewable fuel standard of 36 billion gallons of biofuels by 2022, generated incentives for a massive investment in U.S. corn-based ethanol plants. Most of these approximately 200 ethanol plants are located in the Midwestern United States (Fig. 1). Since the early 2000s, ethanol production has increased sixfold from about 2 to 12 billion gallons (Fig. 2).

As petroleum prices increased in early 2008 and more ethanol plants came on-line, corn demand for ethanol increased dramatically and prices increased threefold to nearly $8.00 per bushel. Although this nominal price surpassed the record prices experienced in the early 1970s, adjusted for inflation they were not record high (Fig. 3). The simultaneous occurrence of the increase in world demand for petroleum and U.S. policy incentives to produce corn-based ethanol resulted in a strong positive correlation between petroleum prices, corn prices, and food costs resulting in an outcry from U.S. consumers and livestock producers, food riots in several developing countries, and debate about U.S. energy policy, especially biofuel mandates and subsidies.

Others factors contributed to higher commodity prices. Economic growth, especially in Asia, increased U.S. grain export demand [1]. A weak U.S. dollar encouraged U.S. grain exports, and drove up petroleum prices expressed in dollars. Investors shifted funds from capital markets to commodity future markets causing commodity prices to rise sharply. While the ethanol boom influenced food prices, some of the increase in retail food prices could be attributed to the higher fuel costs for transportation of raw materials to the processing plants and food to the retail outlets.

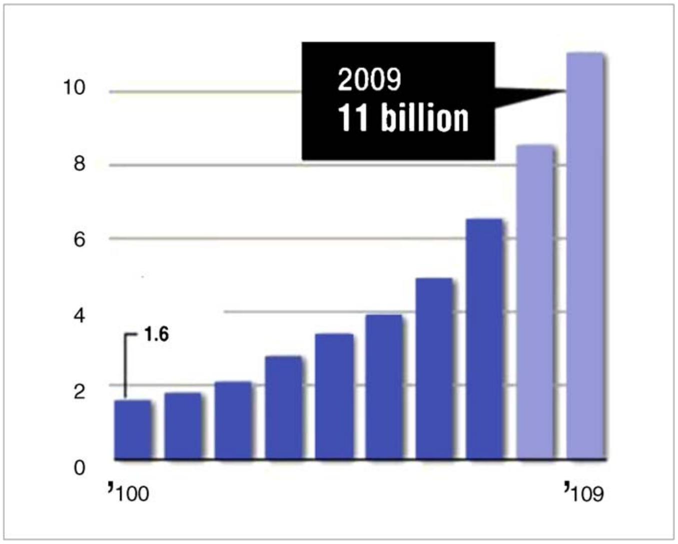

FIGURE 2

U.S. ethanol production (gallons). *Source*: Fastech LLC, March 2009.

From mid-2008 to mid-2009, economic conditions changed dramatically. Petroleum prices fell from $140 to $50 per barrel. The U.S. dollar strengthened, the world economy entered the most serious recession since the 1930s with high unemployment, housing market foreclosures, collapse of the stock market, a reduction in global trade, and a decline in durable goods and food purchases, especially away-from-home food consumption. Agricultural commodity prices declined about 50%. Despite the lower cost of corn for ethanol production, less liquid fuel demand due to the global recession eroded profit margins in the ethanol industry (Fig. 4).

Production of corn-based ethanol

Ethanol is an alcohol produced by yeast from sugars through fermentation [2]. Fuel ethanol is ethanol that has been highly

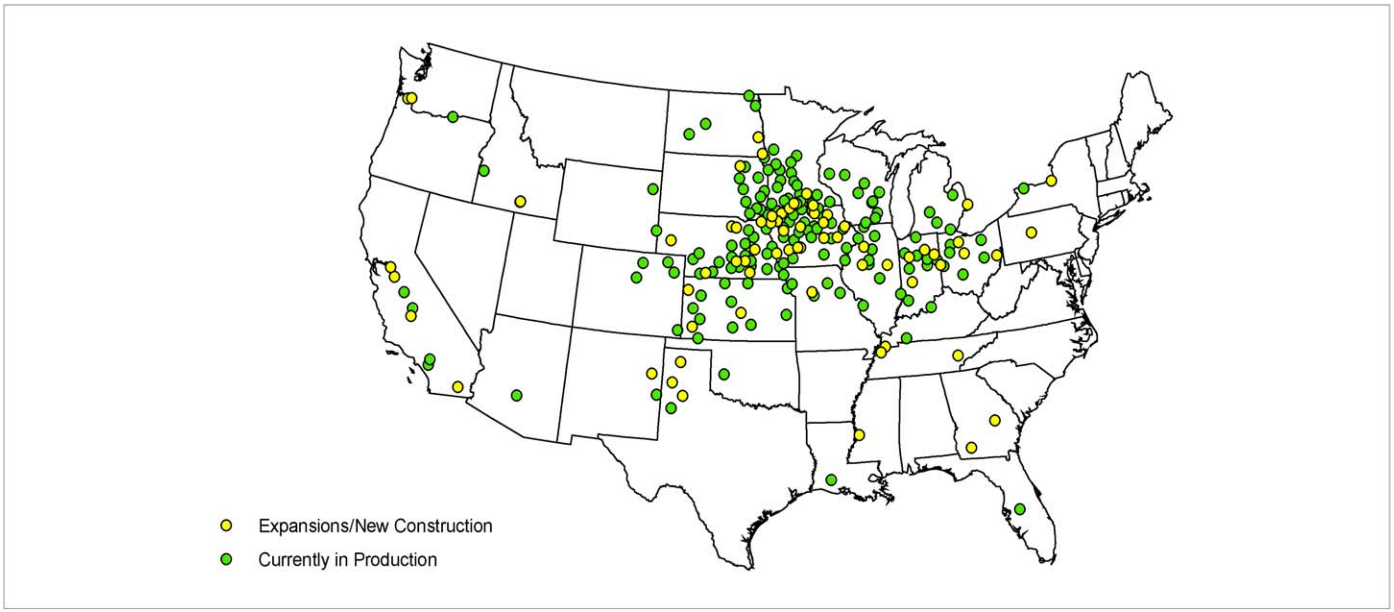

FIGURE 1

U.S. ethanol plant locations. *Source*: www.renewable-ag.com.

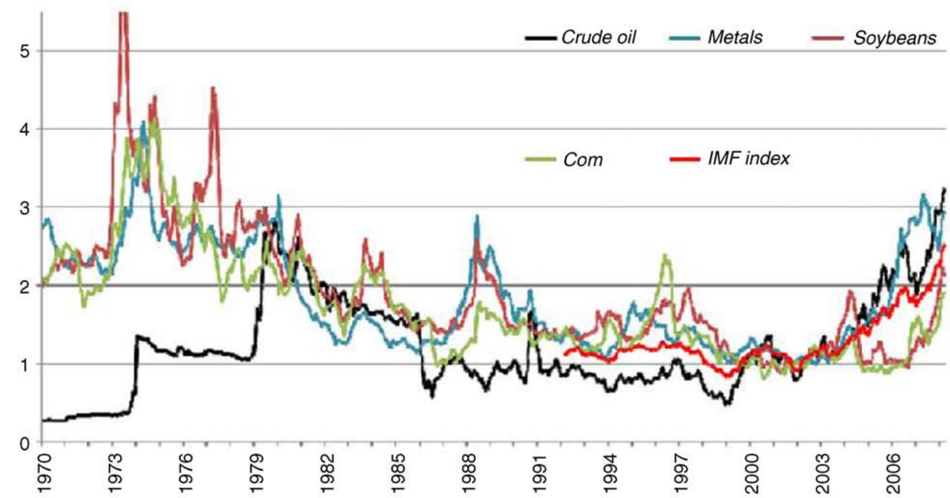

FIGURE 3

Deflated commodity prices and indices, 1970–2008 (2002 = 1). *Source*: Abbott et al., What's Driving Food Prices, Farm Foundation, July 2008.

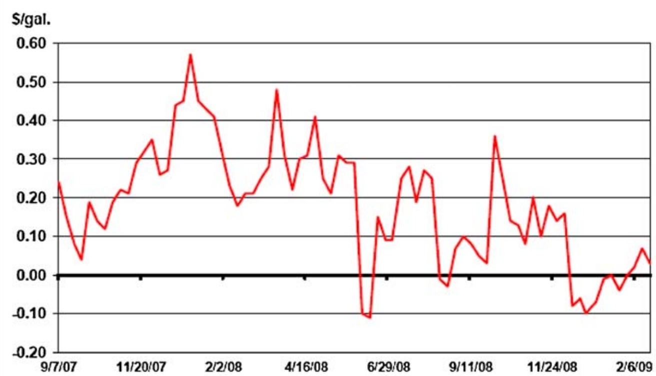

FIGURE 4

Ethanol producer net returns. *Source*: Glauber, USDA Chief Economist, February 2009.

concentrated to remove water and blended with gasoline (Fig. 5). All cars and trucks in the United States with gasoline engines can burn a 10% blend of ethanol with gasoline. Flex-fuel vehicles can burn up to an 85% blend of ethanol.

Corn is a valuable feedstock for ethanol because it contains a large amount of carbohydrates. A modern ethanol plant can produce approximately 2.7 gallons of ethanol from one bushel of corn plus about 17 pounds per bushel of distillers dried grain with soluble DDGs. (Note: There are 56 pounds per bushel of corn grain.) DDGs are a primary co-product of ethanol production which can be fed to livestock. Over 70% of the ethanol plants in the United States use a dry-grind process. Wet milling is primarily used to produce high fructose corn syrup for food uses such as sweeteners for soft drinks and baked goods. In a dry mill, the corn is ground, and a heat-stable enzyme and water are added. This slurry is cooked, converted to corn mash and another enzyme is added. Then the fermentation process begins.

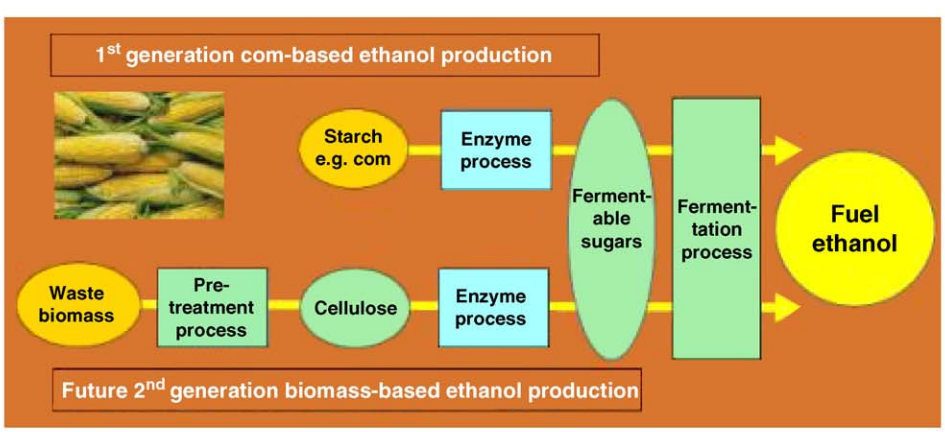

FIGURE 5

Ethanol production process. *Source*: Enzyme Use for Corn Fuel Ethanol Production, Novozymes, July 2007.

TABLE 1

Renewable fuels standards

Year	Renewable biofuel	Advanced biofuel	Cellulosic biofuel	Biomass-based diesel	Undifferentiated advanced biofuel	Total RFS
2008	9					9
2009	10.5	0.6		0.5	0.1	11.1
2010	12	0.95	0.1	0.65	0.2	12.95
2011	12.6	1.35	0.25	0.8	0.3	13.95
2012	13.2	2	0.5	1	0.5	15.2
2013	13.8	2.75	1		1.75	16.55
2014	14.4	3.75	1.75		2	18.15
2015	15	5.5	3		2.5	20.5
2016	15	7.25	4.25		3	22.5
2017	15	9	5.5		3.5	24
2018	15	11	7		4	26
2019	15	13	8.5		4.5	28
2020	15	15	10.5		4.5	30
2021	15	18	13.5		4.5	33
2022	15	21	16		5	36

Source: Renewable Fuels Association.

After fermentation the liquid portion is distilled producing ethanol of 92–95% purity. The remaining water and solids is centrifuged to separate the liquid from the solid. The solid material is the DDGs. The residual water is recycled into the beginning of the dry-grind process.

Government mandates

The U.S. Energy Independence and Security Act of 2007 contains a renewable fuel standard with a target of 36 billion gallons by 2022 (Fig. 6). The conventional biofuel category encompassing ethanol from corn grain is mandated to increase to 15 billion gallons by 2015 and remain at that level. Except for modest amounts of biodiesel from vegetable oils such as soybean oil, most of the rest of the mandated renewable fuels must come from biomass or cellulosic feedstocks (Table 1).

The food vs. fuel debate

Factors driving food prices are complex. Some are related to long term trends while others are caused by recent market events and policy decisions [3].

Rapid economic growth in developing countries such as India and China over the past decade has increased demand for raw materials ranging from petroleum and steel to agricultural commodities. When *per capita* income rises, countries experience a dietary transition with increased demand for animal protein which requires livestock feed such as corn and soybeans.

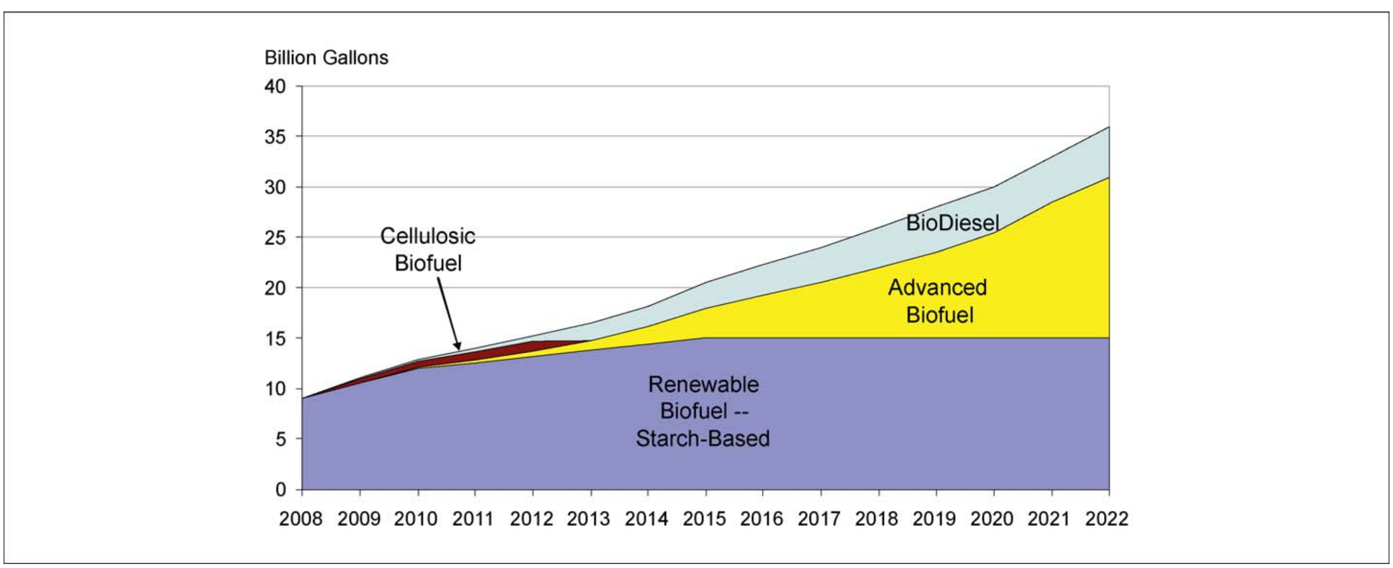

FIGURE 6

U.S. renewable fuel standard. *Source*: Steve Meyer, Paragon Economics Inc., March 2009.

Review

Lack of investments in agricultural research, especially public research, in recent years has contributed to a slower rate of global agricultural productivity growth at a time when global agricultural commodity demand has been increasing. This has put upward pressure on food prices.

Since 2001, world grain stocks have declined due to world demand growing faster than production [1]. With tight stocks (see Fig. 7), commodity prices have become more inelastic and risen even more rapidly as consumer concerns about future food supplies increased. Weather concerns such as a drought in Australia and a late, wet spring and flooding in the U.S. Midwest in 2008 added to the price increases. By mid-2008 grain supplies reached minimal 'pipeline' levels, and prices rose to ration the short-run use of the limited supplies until the 2008 harvest occurred. The last time the 'stocks-to-use' ratio for grains, including corn, was as tight as in 2008 was in 1972–1973 when the United States sold large volumes of grain to the former Soviet Union and the Nixon Administration put in place wage and price controls because of inflation and food shortage concerns. In 2008, the combined food/bioenergy/feed demands heightened the inelasticity of the grain stocks–price relationship resulting in higher and more volatile commodity prices.

Exchange rates influence commodity prices. Most commodities, including petroleum and grains, are priced in U.S. dollars, but are purchased in local currencies. When the value of the U.S. dollar depreciates relative to other currencies, as occurred during the past several years, commodity prices increase. A decline in the value of the U.S. dollar is linked to greater demand for U.S. agricultural commodity exports, as well as higher petroleum prices (Fig. 8).

In 2008, higher petroleum prices increased production costs for farmers, especially nitrogen fertilizer and diesel fuel. Higher petroleum prices also increased the cost of transportation of inputs to the farms, commodities from the farms to processing plants, and finished foods to the retail outlets.

Recent commodity and food price behavior

From mid-2008 to mid-2009, commodity prices collapsed 50% from record high in nominal dollars [4]. World food prices fell nearly 40% in the last half of 2008 after increasing nearly 60% during the previous 12 months (Fig. 9). The recent world recession, driven initially by collapse of the U.S. housing and stock markets, resulted in high unemployment, loss of family income, a sharp decline in the value of pension and other investment funds, and an unwillingness of many to spend on goods and services. Lower demand for petroleum resulted in a sharp decline in fuel prices. Lower commodity prices and transportation costs have contributed to the decline in food prices relative to a year ago. A slightly stronger dollar also has contributed to a decline in export sales.

U.S. consumer food prices increased sharply in 2007–2008 (Fig. 10). In the United States in 2005 and 2006, food prices increased by an average rate of only 2.4% (Table 2). In 2007 and 2008 they increased 4.0% and 5.5%, respectively [5]. Perrin [6] estimated that in 2007–2008 the increased demand for corn for ethanol contributed to about a 1% increase in food prices. The direct impact of higher corn prices on foods is relatively small because the value of the corn in breakfast cereals or similar food products is a relatively small proportion of the price of the final good. However, grain prices do impact livestock feed costs and

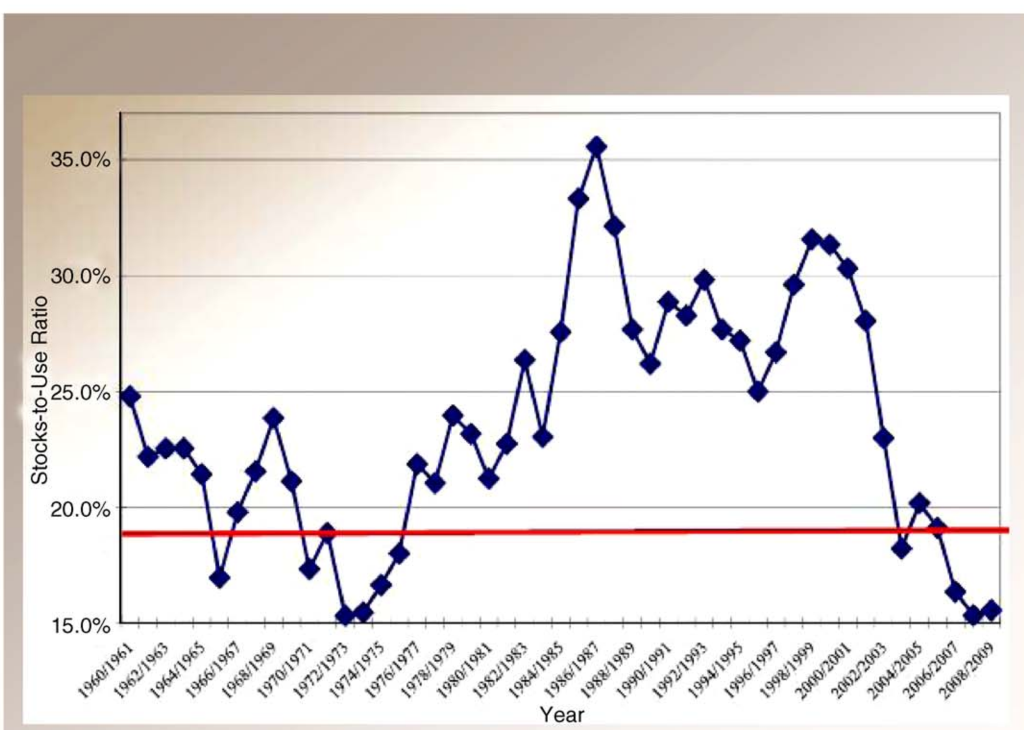

FIGURE 7

Stocks-to-use ratio for total grains in the world (1960–2009). *Source*: Chris Hurt, Indiana Ag Outlook 2009.

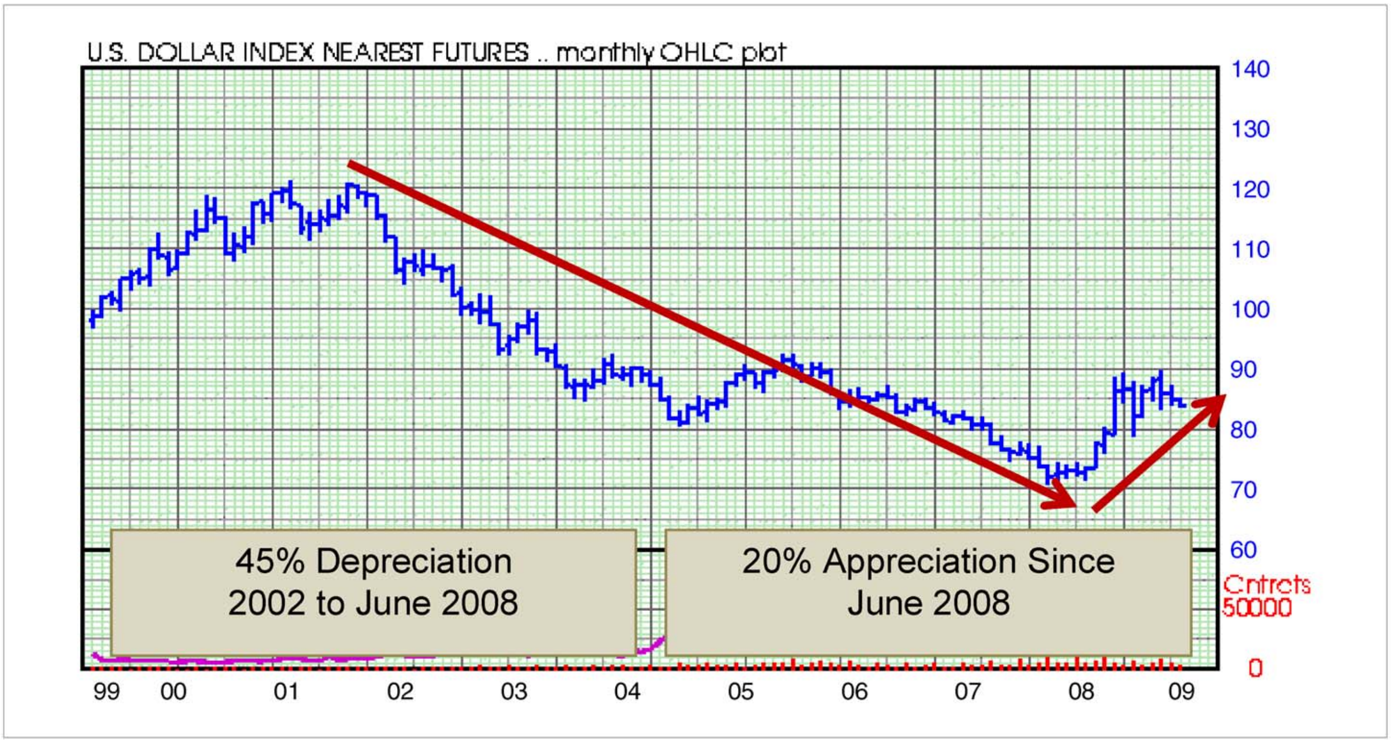

FIGURE 8

U.S. dollar exchange rate. *Source*: Barchart.com, May 2009.

eventually the consumer price of meat and other livestock products. Because broilers and eggs involve a relatively short production cycle, increases in grain prices in 2007–2008 impacted broiler and egg prices rather quickly (Table 2). Increases in retail beef and pork prices were more modest and delayed due to the longer production cycle.

Commodity prices are highly correlated. For example, the increase in planted corn acres in the United States in the 2007–2008 marketing year was in response to the increased demand for corn for ethanol, but given a relatively stable total crop area, concurrently there was a reduction in the acreage planted to other crops in the United States such as wheat and soybeans. Thus, less production of these substitute crops caused their prices to rise also, contributing to upward pressure on food prices for products such as breakfast cereals, bakery goods, and cooking oils.

In 2009, food prices are expected to increase in the 3.0–4.0% range due to lower agricultural commodity and energy costs combined with a weaker economy. Livestock prices are expected to increase less in 2009 than in 2008.

The fierce food/biofuel price debate of 2008 subsided in 2009. But it is important to realize that these price increases were the result of a complex set of inter-related economic and policy events.

The livestock vs. fuel debate

The U.S. livestock sector was adversely impacted by the sharp increase in feed costs in 2008. However, the higher price of corn grain was partially offset by the increased availability of DDGs from the ethanol industry. DDGs can be readily used (up to 40%) in cattle rations because ruminants can more easily digest this feed source. The amount of DDGs used in swine and poultry rations is more limited (typically 5–10% of the ration).

These increases in grain prices in 2007–2008 occurred at a time when livestock prices, especially pork, were already declining. The U.S. swine sector has faced negative profit margins as a result of low pork prices and higher feed costs for nearly two years (Fig. 11). Pork profit margins continued to erode in 2009 because some countries refused to import pork as a result of the ''swine flu'' scare (H1N1).

In 2008, several livestock organizations called for a reduction in the blend subsidy, a reduction or removal of the ethanol import tariff, and/or a modification in the renewable fuel standard. To date, no such actions have been taken by the U.S. government.

Subsidies

Currently, there is a $.54 per gallon import duty on ethanol and a $.45 per gallon subsidy for domestic blenders of ethanol with gasoline. The import tariff is primarily directed at preventing the importation of Brazilian sugarcane-based ethanol. The 2008 U.S. Food, Conservation, and Energy Act (U.S. Farm Bill) reduced the ethanol blend subsidy from $.51 to $.45 per gallon. Tyner [7] provides an excellent summary of biofuels legislation and policy analysis. Thompson *et al.* [8] analyze potential ethanol policy changes to ease the pressures on corn prices. Their analysis looks at renewable fuel standard mandates, world oil price levels, and import tariff effects on ethanol production and the demand for corn grain.

If the import tariff and/or blend subsidy were reduced, profit margins would be even lower for the ethanol industry (see Fig. 4). One legislative proposal suggests replacing the fixed $0.45/gallon subsidy with a variable rate subsidy that reflects changes in petroleum and corn prices, i.e., the corn ethanol blend subsidy would increase when corn prices increase and/or petroleum prices decrease [7].

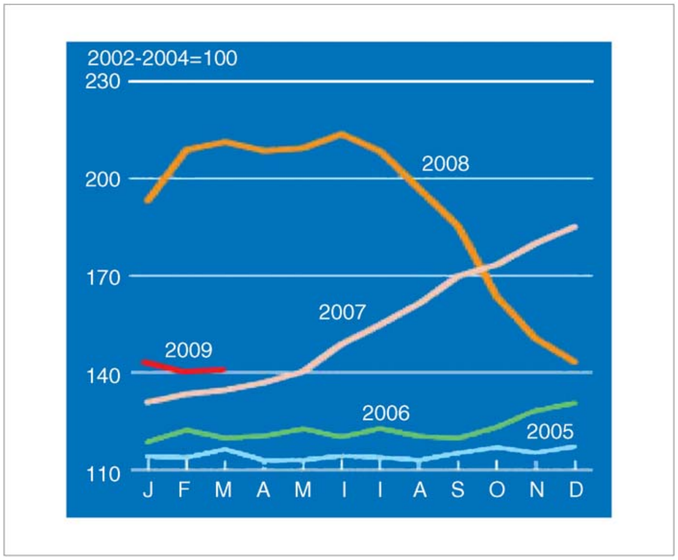

FIGURE 9

FAO food price index. *Source*: Brian Wright, University of California Berkley. Snyder Lecture, Purdue University, April 17, 2009 .

There has been some expansion of U.S. biodiesel processing capacity, especially from soybean oil, in response to the renewable fuel standard mandate [9]. When diesel prices exceeded \$4.00 per gallon and soybeans approached \$16 per bushel in early 2008, even with the \$1.00 per gallon tax credit, the profit margins were relatively modest for biodiesel producers. The decline in petroleum prices in early 2009, despite concurrent declines in soybean prices, significantly tightened the biodiesel processor profit margins. Under current price relationships, vegetable oil based biodiesel is not economically viable without government subsidies. Also vegetable oils compete for various food uses.

The blending wall

In 2008, higher petroleum prices reduced gasoline consumption. In 2009, despite lower petroleum prices, the U.S. recession has further reduced gasoline consumption (Fig. 12). Gasoline use declined from 143 billion gallons in early 2008 to 137 billion gallons in early 2009 [9].

Ethanol production capacity in mid-2009 was estimated at 12.4 billion gallons, but the industry was operating 16% below capacity. Lower petroleum prices, the relatively high price paid by some ethanol plant managers for corn in 2008, and the reduction in the blend subsidy substantially reduced profit margins for the ethanol industry. In fact, in 2009 several firms, such as VeraSun, filed bankruptcy and sold several of their plants. Construction stopped on a few plants and some were idled.

If petroleum prices continue to increase in 2010, and the world economy has not recovered significantly from the current recession, and given the renewable fuel standard of 12 billion gallons of ethanol in 2010, the U.S. ethanol industry will approach the blend wall, i.e., with a 10% blend of ethanol in each gallon of gasoline there would be almost enough ethanol to blend with every gallon of gasoline consumed in the United States [10]. The U.S. Environmental Protection Agency is considering increasing the current 10% blend ratio to 15%. The automotive sector argues that despite the increased sales of flex-fuel cars, the majority of the cars in the

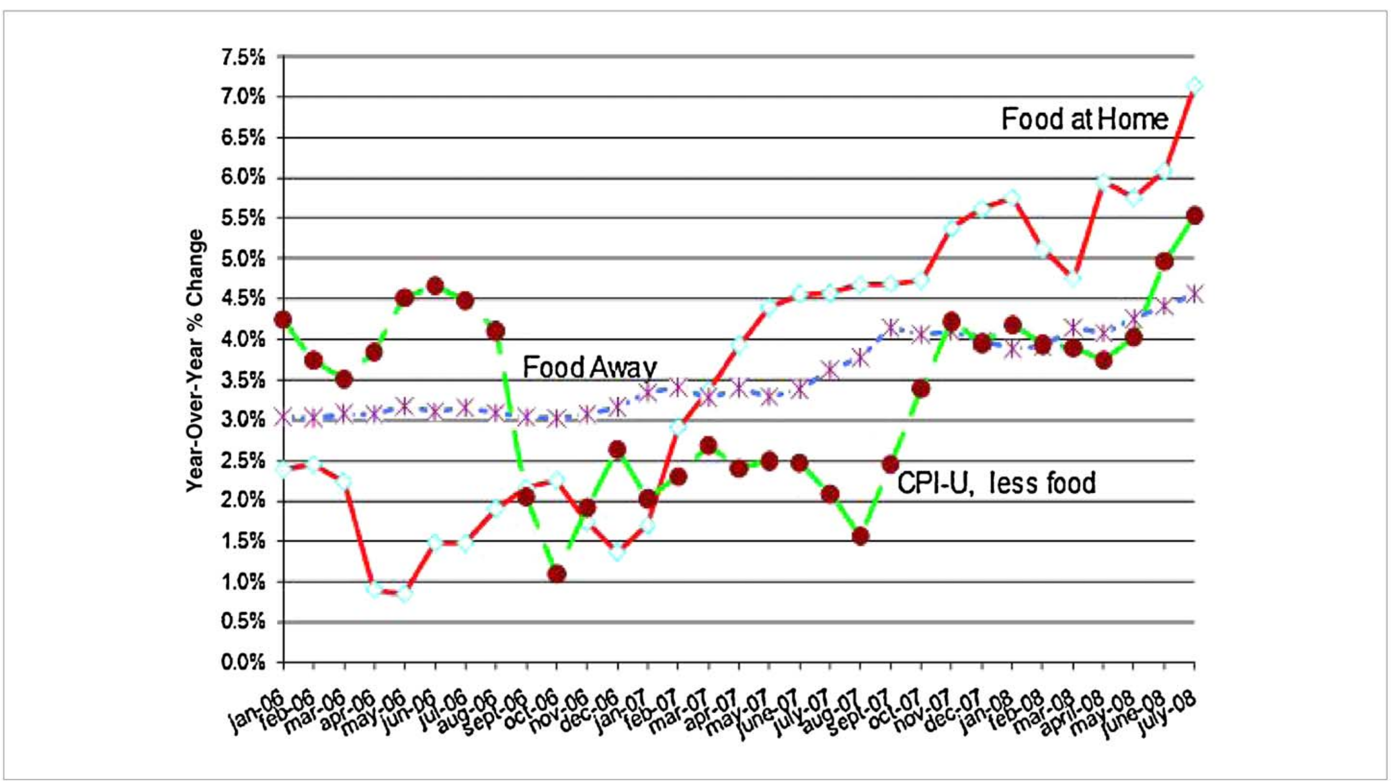

FIGURE 10

Retail food price changes, year-over-year annual rates, by months, 2006–July 2008. *Source*: Corinne Alexander, Department of Agricultural Economics, Purdue University, August 2008.

TABLE 2

U.S. food price changes

Consumer price indexes	Relative importance[a]	Final 2005	Final 2006	Final 2007	Final 2008	Forecast 2009[b]
	Percent	Percent change				
All food	100.0	2.4	2.4	4.0	5.5	3.0–4.0
Food away from home	44.3	3.1	3.1	3.6	4.4	3.5–4.5
Food at home	55.7	1.9	1.7	4.2	6.4	2.5–3.5
Meats, poultry, and fish	12.2	2.4	0.8	3.8	4.2	2.0–3.0
Meats	7.9	2.3	0.7	3.3	3.5	1.5–2.5
Beef and veal	3.8	2.6	0.8	4.4	4.5	1.5–2.5
Pork	2.4	2.0	−0.2	2.0	2.3	1.5–2.5
Other meats	1.7	2.4	1.8	2.3	3.1	0.0–1.0
Poultry	2.3	2.0	−1.8	5.2	5.0	2.0–3.0
Fish and seafood	2.1	3.0	4.7	4.6	6.0	4.0–5.0
Eggs	0.7	−13.7	4.9	29.2	14.0	−5.0 to −4.0
Dairy products	6.2	1.2	−0.6	7.4	8.0	−4.0 to −3.0
Fats and oils	1.6	−0.1	0.2	2.9	13.8	3.0–4.0
Fruits and vegetables	8.2	3.7	4.8	3.8	6.2	3.5–4.5
Fresh fruits and vegetables	6.2	3.9	5.3	3.9	5.2	4.0–5.0
Fresh fruits	3.1	3.7	6.0	4.5	4.8	4.0–5.0
Fresh vegetables	3.1	4.0	4.6	3.2	5.6	3.5–4.5
Processed fruits and vegetables	1.9	3.3	2.9	3.6	9.5	3.0–4.0
Sugar and sweets	2.1	1.2	3.8	3.1	5.5	3.0–4.0
Cereals and bakery products	7.9	1.5	1.8	4.4	10.2	2.5–3.5
Nonalcoholic beverages	6.7	2.9	2.0	4.1	4.3	3.0–4.0
Other foods	10.1	1.6	1.4	1.8	5.2	3.0–4.0
Market basket of farm foods:						
Farm value	N.A.	−0.4	−3.1	18.3	3.8	N.A.
Farm to retail price spread	N.A.	5.2	0.4	0.9	7.5	N.A.
Retail price	N.A.	3.9	−0.3	4.5	6.7	N.A.

Source: USDA-ERS, Briefing Room, March 25, 2009.

[a] BLS estimated expenditure shares, December 2008.

[b] Forecasts updated by the 25th of each month. *Source of historical data*: Bureau of Labor Statistics Forecasts by Economic Research Service.*Source:* USDA-ERS, Briefing Room, March 25, 2009.

national fleet were not designed for an ethanol blend greater than 10%. However, in countries such as Brazil cars are designed to operate on more than a 10% blend, and in fact many run on a 100% ethanol fuel. The other limiting factor for the sales of E85 cars in the United States is the lack of infrastructure, i.e., relatively few service stations have pumps dedicated to E85. In recent months, given the lower miles per gallon with E85 compared to regular gasoline and the very small price differential between E85 and regular gasoline, there has been no economic incentive for drivers to purchase E85 cars or fuel.

Environmental concerns

The debate continues on the benefits of ethanol blends with gasoline. Some critics argue that with the fertilizer and diesel fuel required to produce corn, plus the energy required to operate the ethanol plants, there is a relatively modest net energy gain. Plus some worry that with increased corn acreage and higher input use there will be greater potential for environmental damage from soil erosion, and chemicals and fertilizers entering the surface and ground water.

Others suggest, however, that with improved corn hybrids that yield more per unit of fertilizer applied, plus conservation and no-till farming systems, there is no significant adverse environmental impact from increased corn production. Also ethanol/gasoline blends enhance air quality, especially in larger cities where smog has been a problem. Ethanol is more environmentally friendly than methyl tertiary butyl ether (MTBE)—a fuel additive or oxygenate that improves the burning of hydrocarbons and reduces air pollution. MTBE is a carcinogen and was found in ground water from leaking fuel tanks in states such as California. Its use has been restricted by U.S. Environmental Protection Agency regulations and ethanol has become the preferred substitute in gasoline as an oxygenate.

Robertson *et al.* [11] provide an insightful comparative analysis of the potential environmental harm of both grain-based and biomass/cellulosic-based ethanol production. They point out that without proper management, corn-based ethanol can increase the carbon debt, increase soil erosion, and additional use of agricultural chemicals and fertilizer can pollute ground and surface water. But these potential environmental hazards can be mitigated with

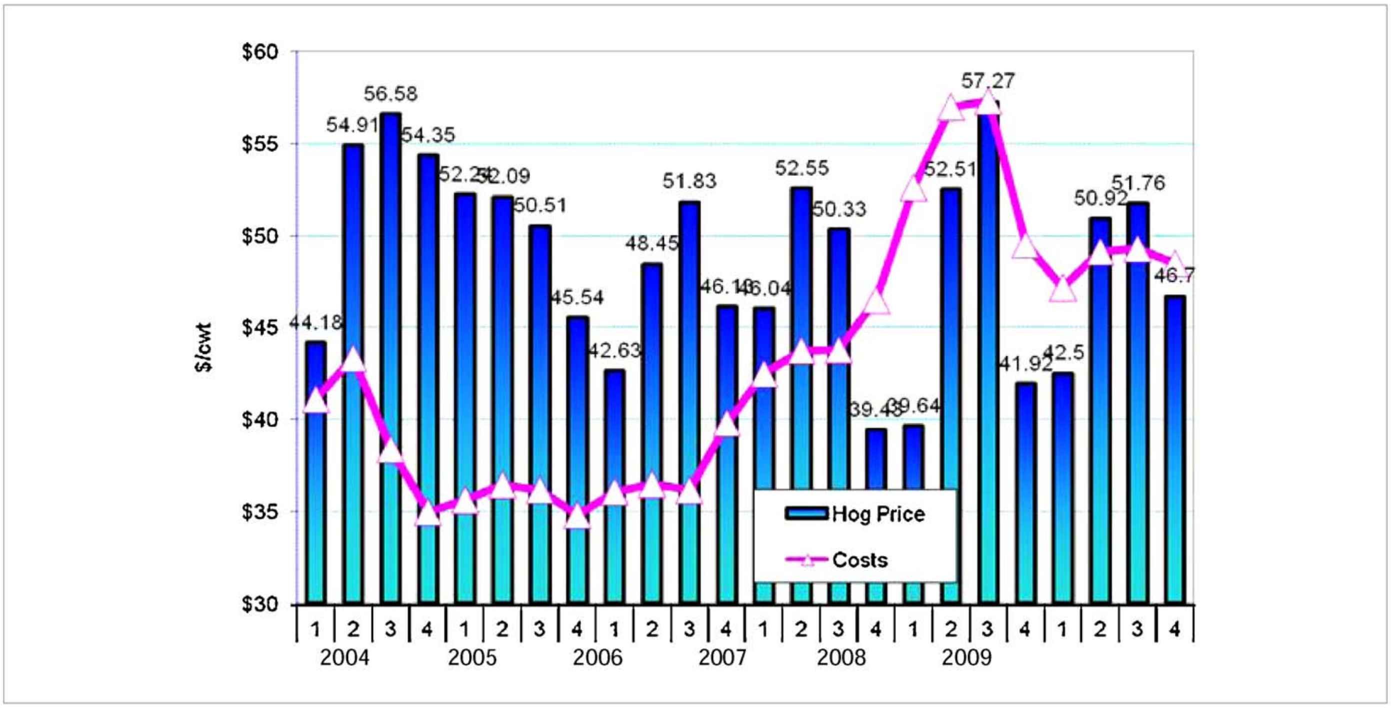

FIGURE 11
Estimated hog prices and costs per live hundredweight. *Source*: Chris Hurt, Department of Agricultural Economics, Purdue University, April 2009.

no-till farming systems, adoption of precision-farming methods that foster fertilizer applications according to the nutrient uptake of the plants, planting of cover crops plus riparian strips along rivers and bodies of water that can sequester soil carbon and intercept nitrate leakage and phosphorus runoff, and adoption of transgenic crops that can reduce the need for pesticides and/or increase drought stress-tolerant varieties which can increase water and nutrient efficiency.

Babcock *et al.* [12] report that once all corn and ethanol direct and indirect impacts are calculated, corn-based ethanol can reduce carbon emissions. But the results depend on whether (1) natural gas or coal is used to power the ethanol plant, (2) distillers grain is dried or sold wet, and (3) expansion in corn production comes mainly from a reduction in acreage of lower valued crops or if idled conservation or forest land is brought into production. In the Western U.S. Corn Belt where many of the ethanol plants are located, cattle feedlots are close by and wet distillers grain can be more readily utilized. Also in the United States most of the expansion in corn production has been the result of rotational changes, i.e., rather than a two-year corn/soybean rotation farmers have shifted to a three-year corn/corn/soybean rotation. Corn acreage increased dramatically in 2007 in response to the demand for corn. By 2008, higher corn production costs (especially for fertilizer and diesel fuel) and relatively higher soybean prices resulted in a shift back towards more soybean acres (see Fig. 13).

World perspective

Approximately two-thirds of the world ethanol production is in two countries—United States (corn grain based) and Brazil (sugarcane based) (see Fig. 14). The volume of ethanol produced per acre is much greater for sugarcane than for corn. Hence, the cost of production per gallon of ethanol is less for sugarcane.

Hertel *et al.* [13] using the GTAP model, provide useful insights into the global land use and potential environmental impacts of U.S., EU and Brazilian biofuel policies. It is important to analyze the combined impacts and not just individual country impacts of these biofuel policies, due to the relative price responses and international ramifications for land use for corn, soybeans and sugar cane production. It is also relevant to estimate whether the increased biofuel production comes from adjustments among crop land, pasture land or forest land. Greenhouse gas emissions can be much greater if forest land is cleared directly or indirectly as a result of these biofuel policies, in contrast to shifts in land use among existing crop and pasture land.

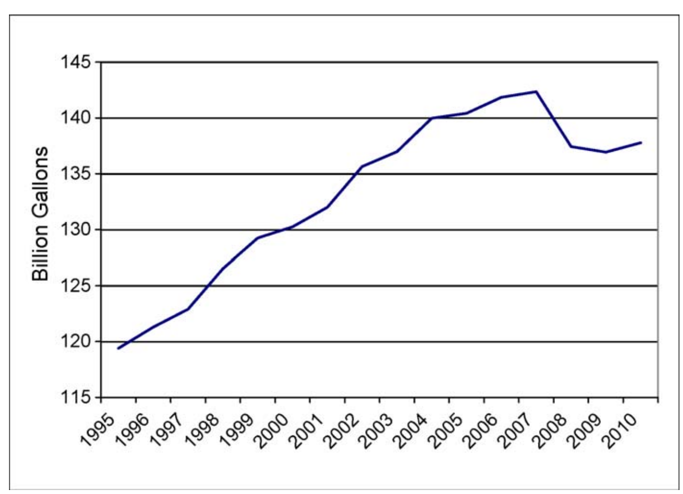

FIGURE 12
U.S. blended gasoline consumption. *Source*: Energy Information Administration.

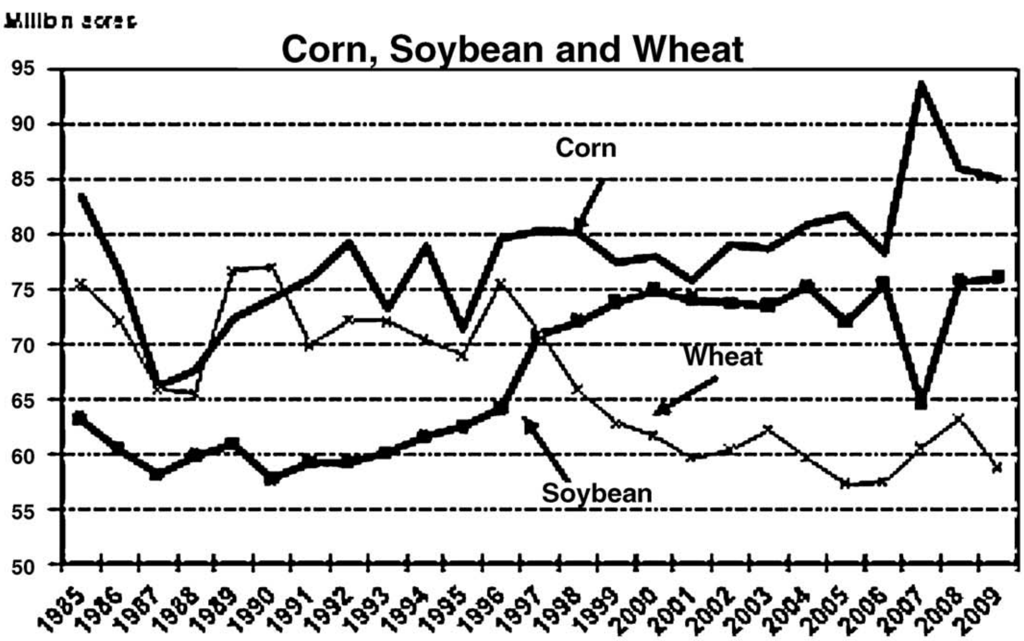

FIGURE 13
U.S. corn, soybean, wheat and cotton planted acreage. *Source*: Glauber, Chief Economist, USDA, February 2009.

Developing country perspective

The sharp rise in commodity prices in global markets in 2008 was a double-edged sword for developing countries. For market-oriented farmers, in contrast to subsistence farmers, this increased their income. However, for low-income consumers, especially in urban areas, who are dependent on the market for their food, increases in food prices had a negative impact. The impacts of higher food prices are especially severe for low-income consumers because they often spend from 25% to 50% of their disposable income on food. Although higher food prices do adversely impact high-income consumers, those who spend 15% or less of their income on food experience a much less severe impact from food price increases than those who spend 25–50%. Expenditures on food consumed at home in 2007 in the United States were only 5.7% compared to 8.6% in the United Kingdom, 11.4% in Germany, 13.7% in France, 14.5% in Italy, 14.6% in Japan, 24.6% in Brazil, 28.7% in Russia, 32.4% in India, 34.9% in China, 38.8% in Egypt and 45.7% in Pakistan [5]. Hence, even though the impact of the increased

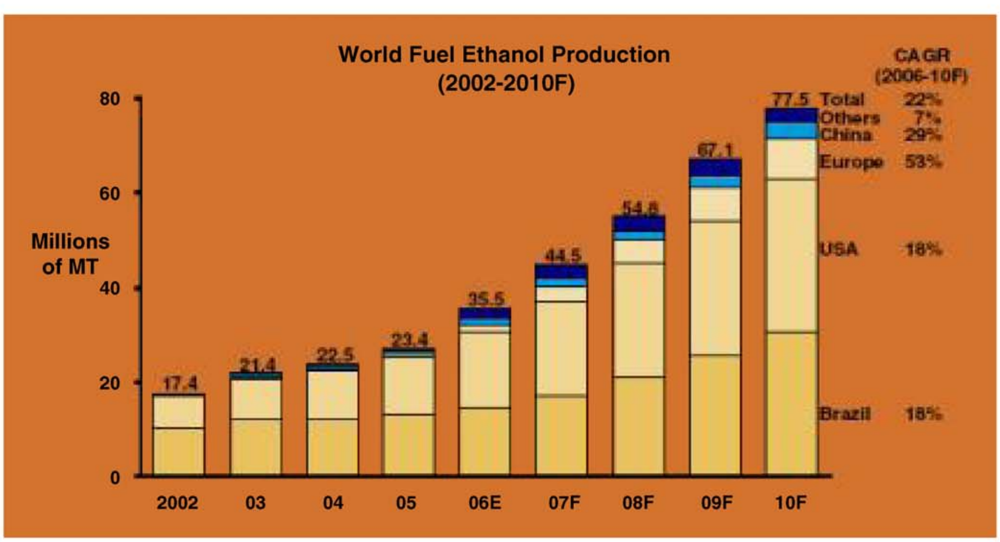

FIGURE 14
World fuel ethanol production. *Source*: Enzyme Use for Corn Fuel Ethanol Production, Novozyme, July 2007.

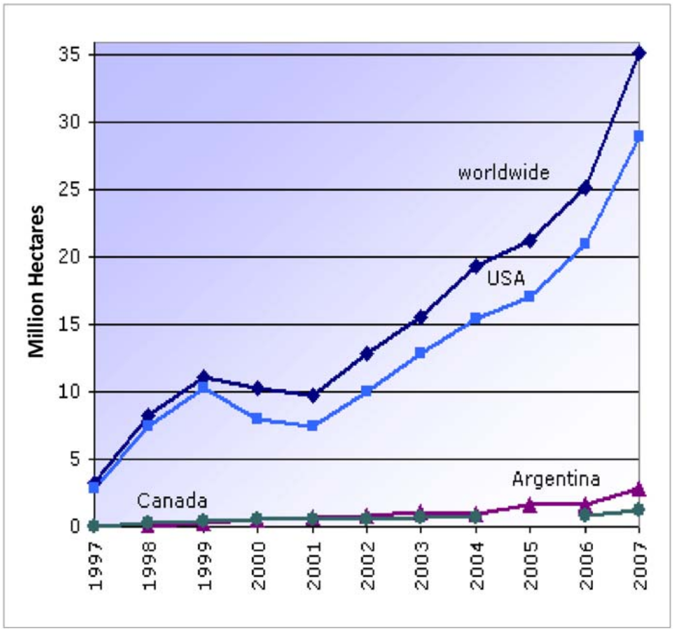

FIGURE 15

Adoption of transgenic corn. *Source*: GMO Compass, October 9, 2008. www.gmo-compass.org.

demand for corn for ethanol had a relatively modest impact on food prices in the United States, any food price increases, from whatever source, can have a much greater adverse impact on low-income consumers in developing countries.

Von Braun [14] provides a perspective on the impacts of food price increases on developing countries. Higher food prices cause the poor to limit food consumption. This can result in under-nutrition and adverse health impacts, especially for children who are already at risk. Ivanic and Martin [15] further note that food price increases in 2008 probably increased overall poverty in low-income countries.

As indicated previously, many factors contributed to food price increases in 2008–2009. Although biofuels have been blamed for higher food costs to low-income people, especially in the developing world, it was only one factor, and probably not the primary contributing factor.

Role of biotechnology

Biotechnology has had rather modest impacts on the biofuel sector to date. The adoption of transgenic crops has grown rapidly in many countries during the past decade. According to James [16], in 2008, 13.3 million farmers in 25 countries planted 125 million hectares of transgenic crops. Herbicide tolerant soybean adoption predominates in the three major producing countries (United States: 92%, Argentina: 98%, and Brazil: 64%). Adoption of transgenic corn represents 80% of the area in the United States, 84% in Canada, and 84% in Argentina (Fig. 15).

In the United States, while transgenic corn has minimized yield losses by reducing insect and weed pressure, other techniques such as marker-assisted selection have helped breeders develop hybrids with more desirable agronomic traits and higher starch content. As these varieties with higher starch content are adopted, provided there are price incentives for growers, the ethanol industry will be able to further increase the per acre yield of ethanol. Also as cellulosic fermentation techniques are improved, corn cobs and corn stalks can be harvested and fermented to produce ethanol. Consequently, corn will be a source of ethanol from both the grain and cellulosic components. However, the total biomass furnished by corn will still remain less on a per ace basis than sugarcane. On average, corn grain generates 354 gallons of ethanol per acre in the United States versus 662 gallons per acre from sugarcane in Brazil [17].

Increases in area planted and yields have contributed to the availability of corn for ethanol production in the United States. To satisfy this surge in demand for corn for ethanol, the proportion of corn destined for export and domestic livestock feed has declined.

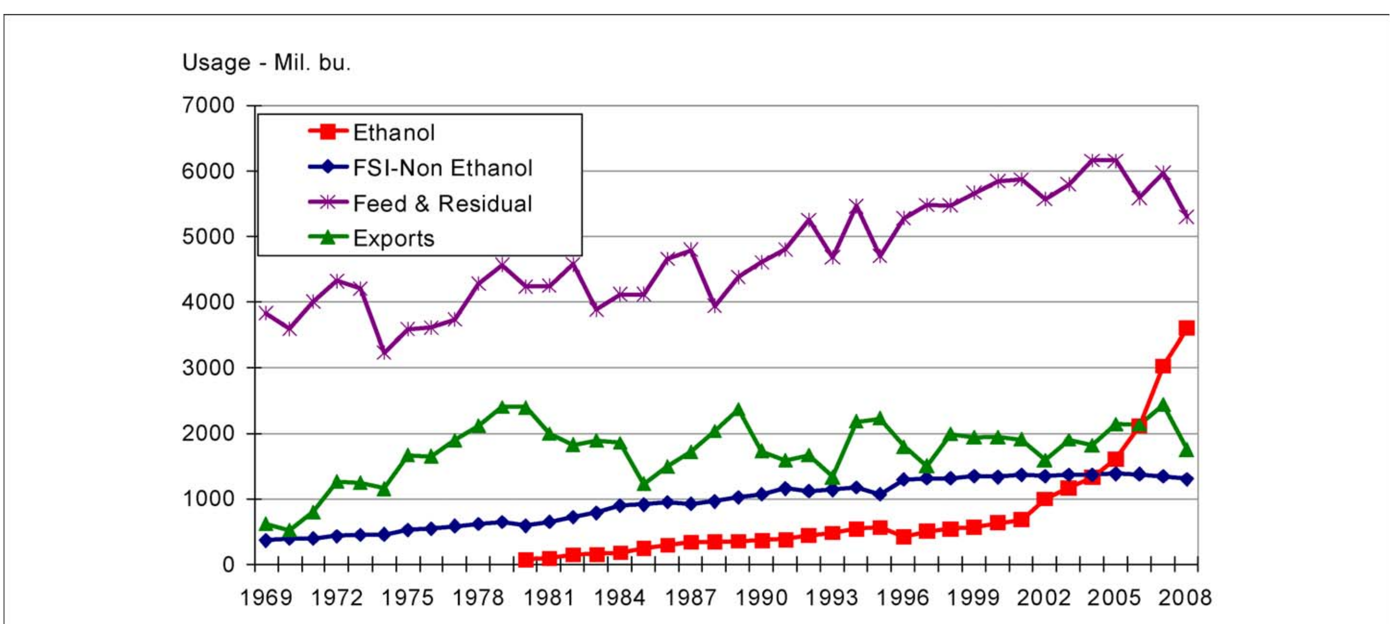

FIGURE 16

U.S. corn production and usage by category. *Source*: Steve Meyer, Paragon Economics, Inc., March 2009.

For example, in the 2008–2009 marketing year, 37% of the total corn supply was used to produce ethanol in contrast to 12% for exports and 39% for livestock feed use. As recently as 2005–2006, only 12% of the corn supply was used for ethanol, 16% for exports, and 46% for livestock feed (Fig. 16).

With continued genetic improvements in corn through marker-assisted conventional breeding as well as transgenic approaches, over the next five to ten years it should be feasible to continue to increase corn yields and meet the 15 billion gallon renewable fuel standard for corn-based ethanol and increase the quantities of corn required for export and domestic livestock feed markets. Drought-tolerant varieties may soon be available which could result in more stable yields and a potential expansion of corn production into more drought-prone regions. However, if petroleum prices return to the record high levels of 2008, this would make ethanol production more profitable and increase corn prices again, but petroleum-based input costs would also increase. This would imply price volatility and uncertain profit margins for corn producers as they attempt to balance higher corn yields and prices against higher fuel and fertilizer production costs.

According to the Biotechnology Industry Organization [18], ethanol yields have increased 20% from 2.5 gallons per bushel in 2000 to almost 3.0 gallons per bushel. New 'no cook' enzymes have been developed to extract sugars from corn at room temperatures, greatly reducing the energy inputs, reducing costs, and improving the environmental profile of ethanol from corn starch. Further scientific breakthroughs are expected that will facilitate the use of corn stover, cobs, and other biomass to generate ethanol.

Conclusions

In 2007–2008, a series of several concurrent worldwide events resulted in a sharp increase in commodity and food prices. Among the most important were: long-term trends towards the dietary transition to more grain-fed livestock products in several developing nations, the low stocks-to-use ratio for grains in the early 2000s, the weak U.S. dollar, high petroleum prices largely driven by economic development in several Asian countries, and government policies (e.g. U.S. renewable fuel standard mandates and subsidies) that provided incentives for the biofuel sector to build ethanol plants.

Since mid-2008, a major world recession has resulted in a dramatic decrease in world petroleum prices, commodity prices have fallen sharply, and there has been substantial moderation in food price inflation. U.S. government biofuel policies remain in place—a long-term renewable fuel standard coupled with an import tariff on ethanol and a domestic blender's subsidy. Consequently, the use of corn for ethanol will continue to increase, albeit at a slower pace than in the recent past as the 15 billion gallon mandate is reached in 2012. In 2009, some ethanol companies filed bankruptcy, construction was halted on others, and there was excess capacity in the U.S. ethanol industry.

Long term trends suggest, however, that higher petroleum prices will probably occur in the years ahead given the world's finite supply of petroleum. There will be continued economic and government policy pressures for energy independence, coupled with governmental policies to encourage environmentally friendly sources of energy. Corn grain as a feedstock for ethanol will probably plateau in the next few years as the mandate of 15 billion gallons of ethanol from corn grain is achieved. At that point, cellulosic sources will become increasingly important if the mandate of 36 billion gallons of biofuels is to be achieved in 2022. The key to success with cellulosic feedstocks will be scientific and technological discoveries that drive down production costs in the field and the processing plants, so that cellulosic ethanol is price competitive with gasoline and the current corn-grain based ethanol sources. Discoveries in biotechnology will be crucial to increase effectively the yield of biomass crops as well as efficiency of fermenting the biomass material in the ethanol plants.

Increased investment in improved plant genetics and farming practices should facilitate growth in grain yields and the ability to satisfy food, feed and biofuel demands at reasonable prices. The world population is projected to reach 9 billion by 2050, and once the world recovers from the current recession and per capita incomes increase, the dietary transition is likely to accelerate, with growth in the demand for animal protein which will require more feed grains and oilseeds. This suggests a tight supply-demand balance for grains, with price volatility which could result from adverse weather, significant climate change and/or political decisions that generate food scares and food price inflation in future years. Thus, the recent food/biofuel debate may be revisited in future years.

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Review

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