The Potential Role for Corn Ethanol in Meeting the Energy Needs of the United States in 2016-2030

Ross Korves, author

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Contributors:
Jim Porterfield, formerly of the American Farm Bureau Federation
Ken Kindler, Dow AgriSciences
John Hicks, Deere & Company
Martha Schlicher, Vice President, Illinois River Energy, LLC
Representatives of ICM, Inc.
Mike Edgerton, Monsanto
Geoff Cooper, National Corn Growers Association
Tod McGreery, Muse Stancil & Co.
David Morris, Institute for Local Self Reliance
Hosein Shapouri, Office of Energy Policy and New Uses, USDA

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Executive Summary

Corn available for use in ethanol plants will continue to increase in volume after 2015 and could contribute significantly to the nation's renewable energy goals. Corn yields may increase to 289 bushels per acre by 2030 corn crop with total production of 24.6 billion bushels. With no increase in harvested corn acreage from the 2007 level of 85 million acres and growth in other uses of corn, corn available for use in ethanol production would be 12 billion bushels from the 2030 corn crop. This compares to 2.2 billion bushels used for ethanol from the 2006 crop.

If ethanol yield per bushel of corn remains at the current level of 2.75 gallons per bushel, total corn ethanol production in 2030 would be 33 billion gallons, compared to estimates of 7.1 billion gallons for calendar year 2007. If ethanol output per bushel of corn increases to 3.0 gallons per bushel, ethanol production would be 36 billion gallons.

Efficiency of use of commercial nitrogen fertilizer per bushel of corn produced will likely continue to improve from the current level of 0.9 pounds per bushel. The improved efficiency would reduce the amount of nitrous oxide (N_2O), a greenhouse gas, released per bushel of corn produced. Continuation of the current trend of less use of anhydrous ammonia would also reduce the amount of N_2O released in corn production. Commercial applications of phosphate and potash per bushel produced are also expected to decline, but not continue at the trend decline of the last 25 years.

A continued shift to more no-till corn production could reduce the amount of CO_2 released in corn production because no-till corn is considered by some researchers as a carbon sink (more carbon is taken up by the soil than is released to the air in corn production). Some research indicates that minimum tillage programs can also reduce the amount of CO_2 released.

The Agricultural Research Service (ARS) of USDA has begun a five year program, the Renewable Energy Assessment Project (REAP), to determine the amount of corn stover that can be removed without reducing long-term soil productivity. From a review of literature, the researchers estimate that more productive soils that are not highly erodible can be managed to allow some removal of stover.

About 20 percent of nation's corn production is irrigated and continued improvements in irrigation management and higher yields per acre should decrease the amount of water used per bushel of corn produced. Additional

ethanol production per acre of corn produced could be achieved by using fiber from the corn kernel and some stover fiber to produce cellulosic ethanol. Poet, an ethanol plant builder and ethanol producer, is building an ethanol plant that is expected to produce 11 percent more ethanol from a bushel of corn by using the corn kernel fiber and 27 percent more ethanol from an acre of corn by using the corn kernel fiber and corn cobs for cellulosic ethanol production.

Improvements in the efficiencies of dry mill ethanol plants are expected to reduce the thermal energy used in the average dry mill ethanol plant on a per gallon produced basis in 2030 by 27 percent compared to 2007 and reduce electricity use by 46 percent.

A life cycle analysis of carbon intensity using the GREET model from Argonne National Laboratory using production estimates in this report shows the Global Warming Impact (GWI) from corn agriculture (on farm energy use for agricultural practices) could decline by 22% from 26,610 gCO2eq/MMBtu (grams of CO2 equivalent per million Btus) in 2010 to 20,755 gCO2eq/MMBtu by 2030. This is 25% below the current GREET default value of 27,469 gCO2eq/MMBtu.

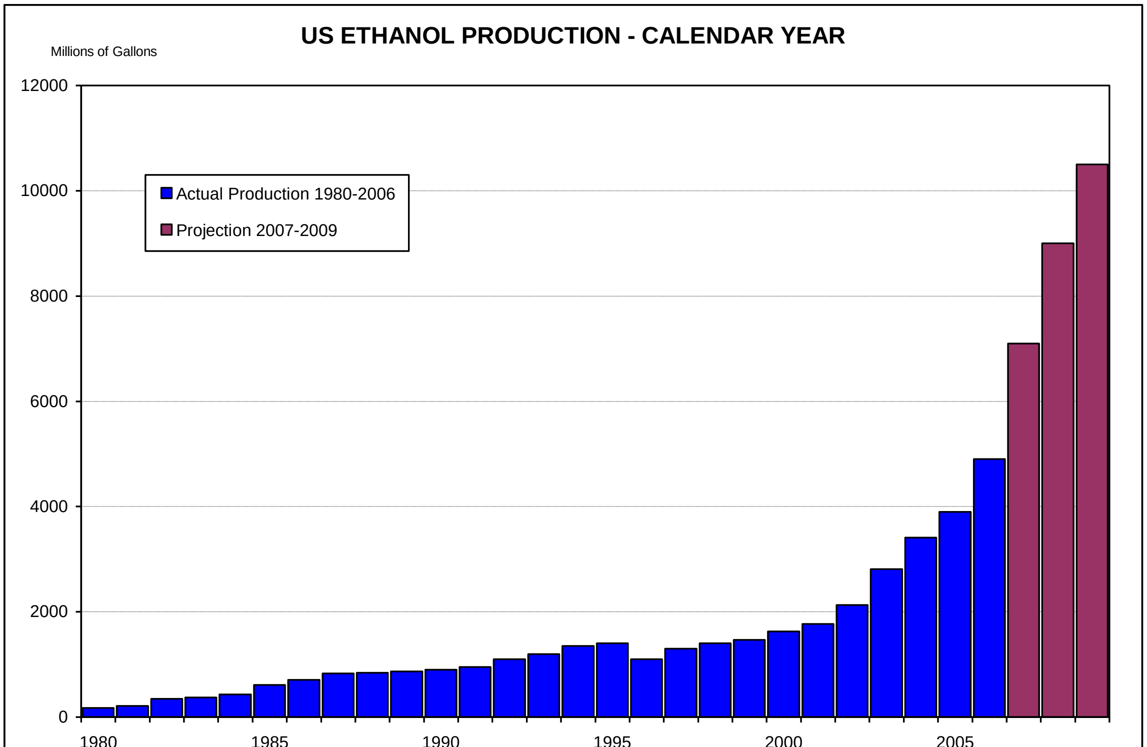
The GWI of the average ethanol plant could decline from 63,959 gCO2eq/MMBtu in 2010 to 46,479 gCO2eq/MMBtu by 2030, a 27% decline. More significantly, the GWI of ethanol produced from the averaged ethanol plant in place in 2030 may be half the GWI of gasoline. The GWI of corn ethanol processed in a plant using a biomass combined heat and power (CHP) system in 2030 could be less than 1/3rd of the GWI of gasoline, 30,502 gCO2eq/MMBtu vs. 98,134 gCO2eq/MMBtu.

Fuel/Year	**gCO2eq per Million BTUs**
Gasoline 2010	97,651
Average ethanol 2010	63,959
Gasoline 2030	98,134
Average ethanol 2030	46,479
Ethanol from biomass CHP 2030	30,502

Introduction

Ethanol produced from corn starch is the most widely produced renewable liquid fuel in the U.S. Production for calendar year 2007 is projected at 7.1 billion gallons, up from 4.9 billion gallons in 2006 and 3.9 billion gallons in 2005. Conservative projections show production at 9.0 billion gallons in 2008 and 10.5 billion gallons in 2009. By 2015 production is expected to be at least 15 billion gallons if market demand and public policy support that level of production.

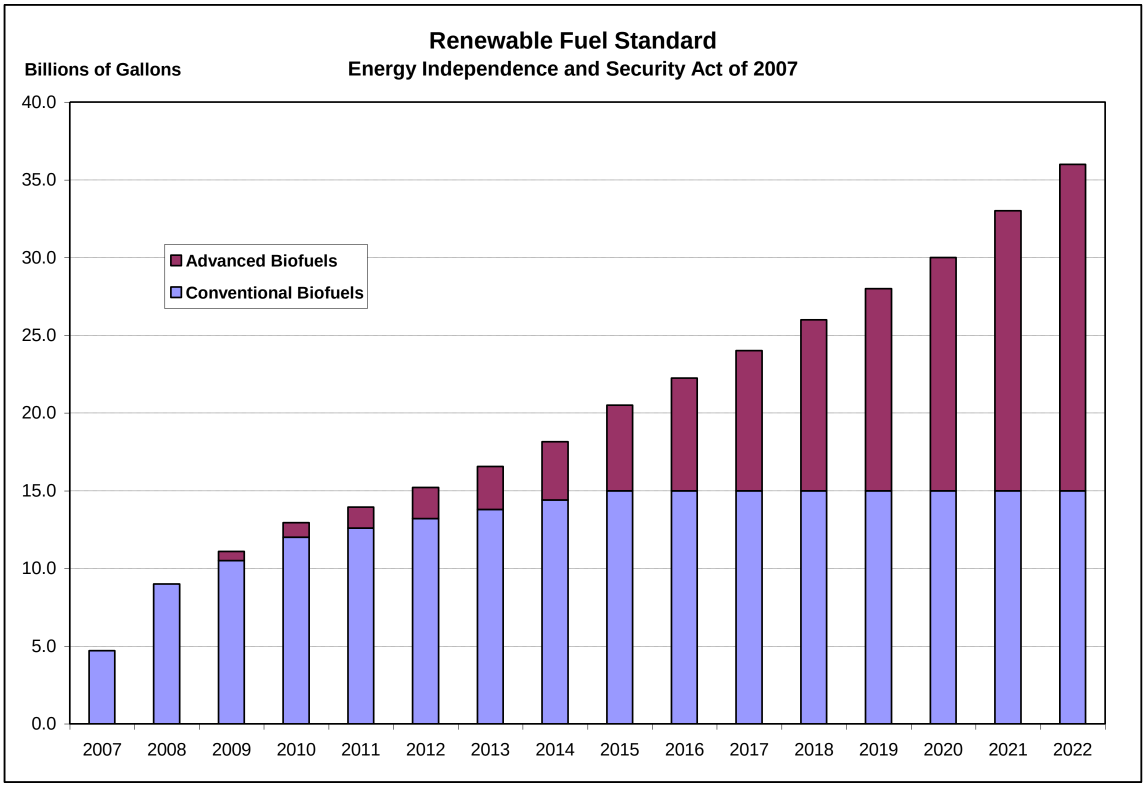
Figure 1



Source: 1980-2006 Renewable Fuels Association

Despite this rapid growth in production and dominant position in the renewable fuels market, corn ethanol is considered "old news" in the broader public policy debate about renewable energy. The majority opinion is that while corn ethanol is the "here and now" renewable fuel, that cellulosic ethanol will be the major growth fuel after 2015. That view is reflected in the Energy Independence and Security Act of 2007 passed by the Senate and House in December 2007 and signed by President Bush. It caps the amount of conventional biofuels (defined as ethanol from corn starch) that would qualify for the credit trading program under the revised renewable fuel standard (RFS) at 15 billion gallons for 2015 and following years. The RFS increases to a total of 36 billion gallons by 2022, but all of the additional growth after 2015 is mandated to come from non-corn starch biofuels.

Figure 2



There is no great surprise in the 15 billion cap on ethanol from corn starch. The projections mentioned earlier show corn ethanol production will be about 15 billion gallons by 2015.

Increases in the price of corn over the past year have caused other users of corn to raise concerns about the price and availability of corn in future years for those uses and the amount available for use in ethanol production.

Though not yet commercially viable, cellulosic ethanol is purported to be much better for the environment with respect to greenhouse gas emissions and its overall carbon footprint. Interest in low carbon fuels has driven policy toward cellulosic ethanol. New technology is expected to expand the feedstock options for cellulosic ethanol production in the years beyond 2015.

Figure 3

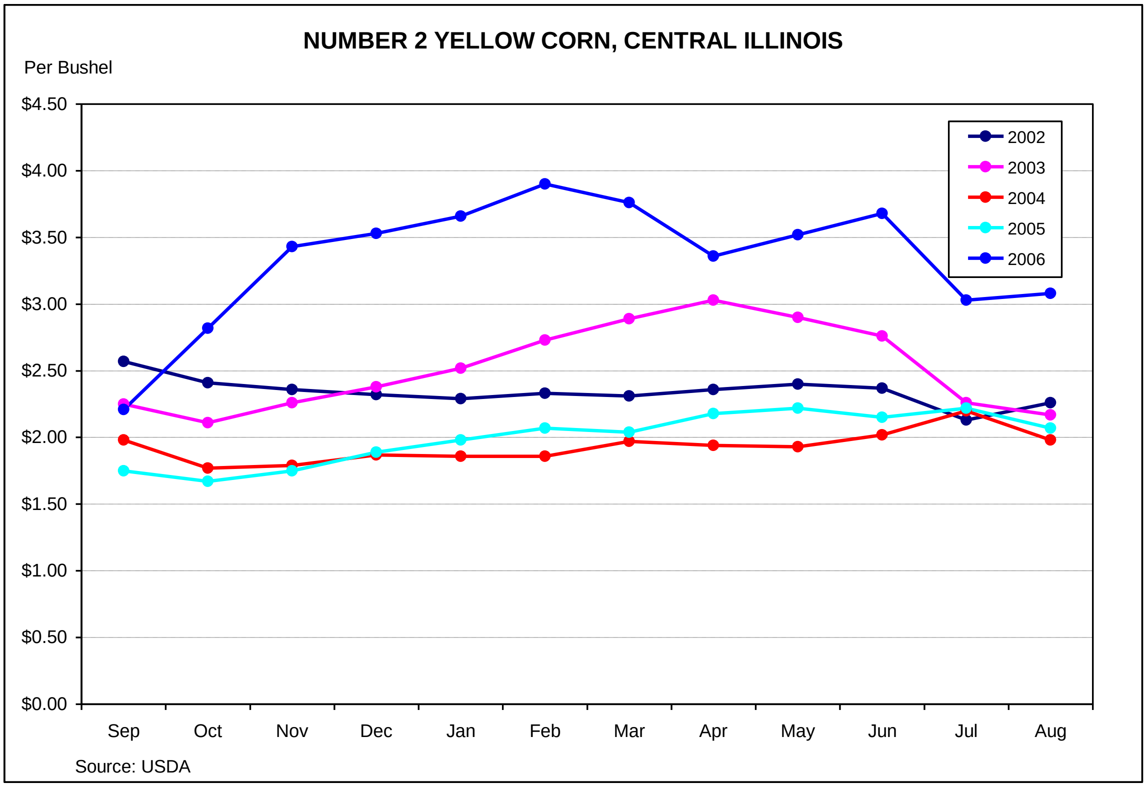
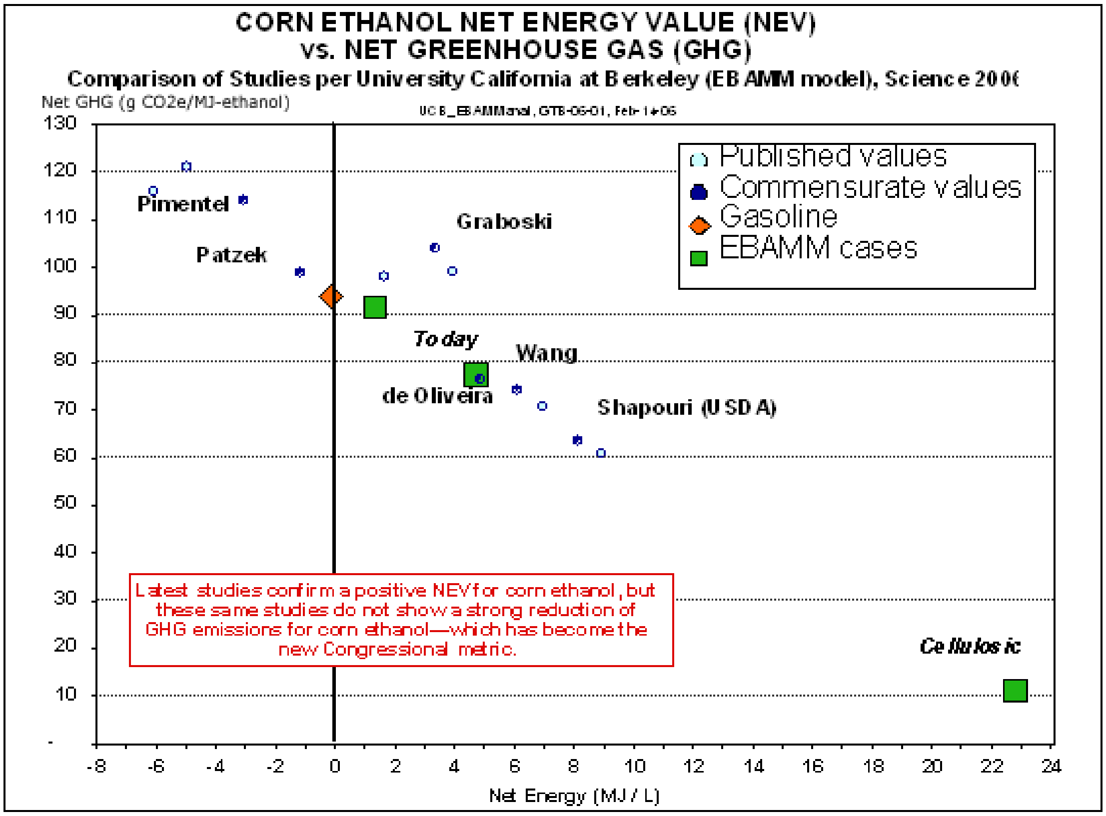


Figure 4



The role biofuels can play in the economic and political strategy of the United States was highlighted by President Bush in the last two State of the Union addresses. In 2006 President Bush outlined the Advanced Energy Initiative to replace 30 percent of the nation's current gasoline use by 2030. That would require roughly 60 billion gallons per year of ethanol. In January of this year President Bush accelerated the speed of the transition to biofuels by announcing his Twenty in Ten program of reducing gasoline usage by 20 percent by 2017 through a combination of reduced consumption and increased use of renewable fuels and alternative fuels. Alternative fuels include fuels like coal-to-liquid. Under the program, an alternative fuel standard would require 35 billion gallon of renewable and alternative fuels in 2017. While corn ethanol production is expected to be at least 15 billion gallons by 2015, it can also play an important role after 2015 in achieving the 35 billion gallons goal in 2017 and 60 billion gallons by 2030.

Purpose of This Analysis

The purpose of this analysis is to explore the potential for corn ethanol production in 2016-2030. Corn production is expected to continue to increase after 2015 while reducing its impact on the environment on a per bushel produced basis. The same is true for corn starch ethanol on a per gallon basis.

All facets of corn ethanol production will change from now to 2030, but three factors standout above the rest. First, corn yields will continue to increase.

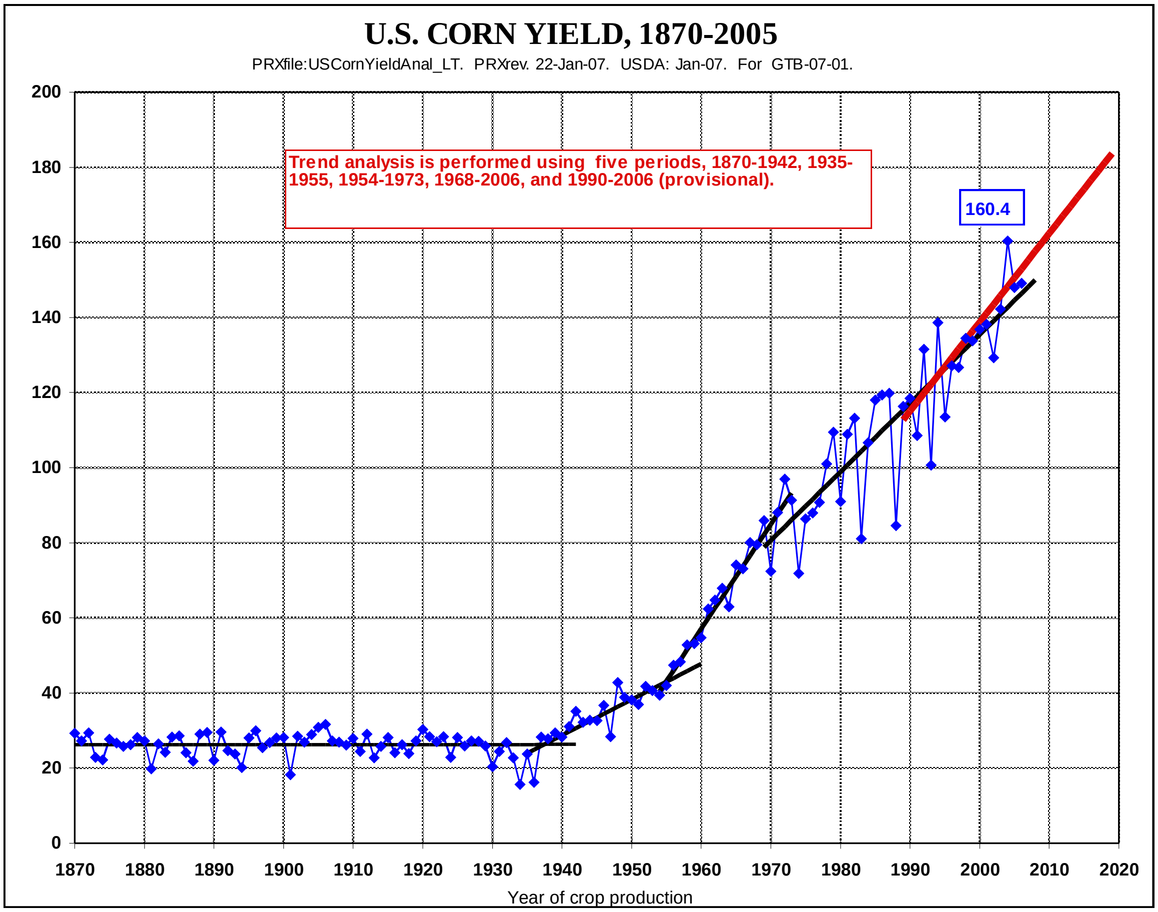
This will decrease the amount of fossil fuels used to produce each bushel of corn and gallon of ethanol. Second, while corn yield per acre increases, the amount of nitrogen used per bushel of corn produced is expected to continue to decline. Nitrous oxide, N_2O, is a greenhouse gas that is formed when nitrogen fertilizer is applied to the soil and the lower amount of nitrogen applied per bushel of corn produced will lower GHG emissions per bushel of corn. Third, ethanol plants will continue to improve efficiencies and reduce the amount of fossil fuels used per gallon of ethanol produced.

This analysis assumes that the price of petroleum through 2030 will remain at historically high levels so that consumers seek out alternative fuel sources for automobiles and trucks and national government officials consider petroleum supplies and use as economic and strategic policy issues. As the National Petroleum Council noted in a July 18, 2007 report to U.S. Secretary of Energy Samuel Bodman, "Facing the Hard Truths about Energy: A Comprehensive View to 2030 of Global Oil and Natural Gas," there are significant challenges to meeting projected energy demand. This will require the expansion of all economic energy sources, including renewable energy.

Corn Yield per Acre

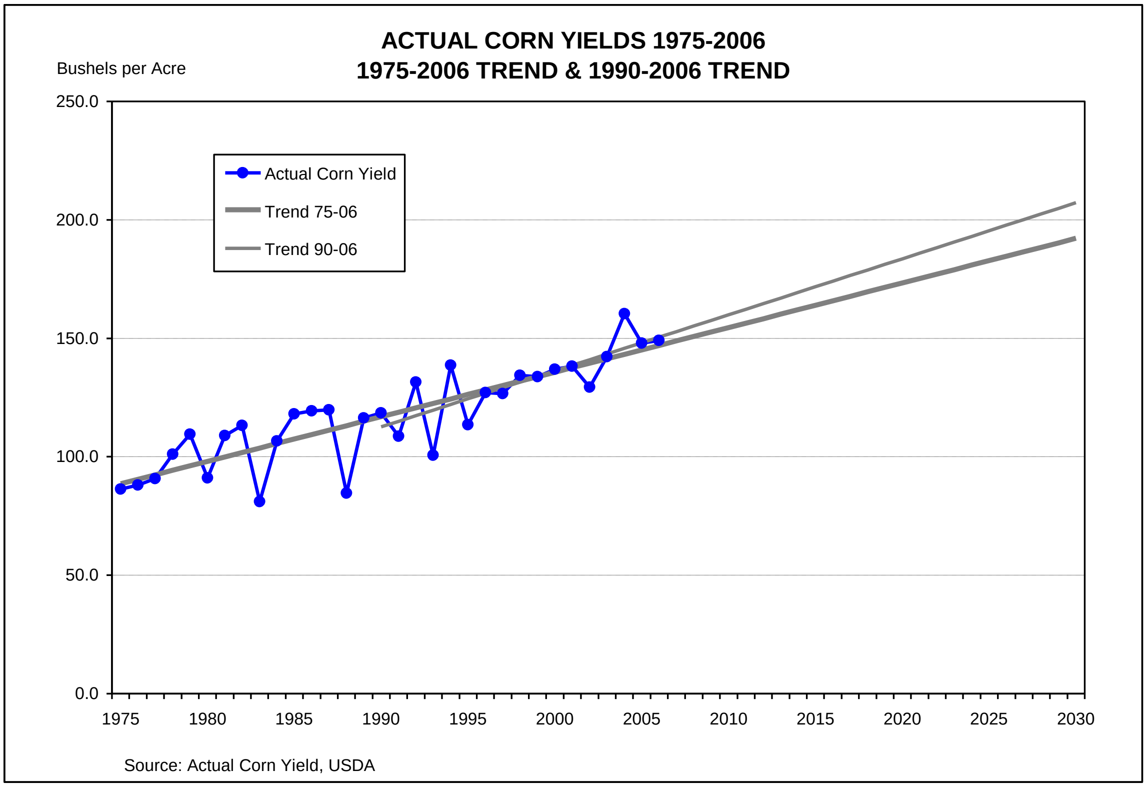
Increasing corn yield per acre of corn grown is not a new development. Since the wide adoption of hybrid seed corn in the 1940s corn yields have been increasing. That technological breakthrough was followed by increased use of commercial fertilizers in the 1950s and 1960s and by the use of herbicides and insecticides in the 1960s and 1970s. The last half of the 1990s and the current decade have seed corn enhanced through biotechnology.

Figure 5



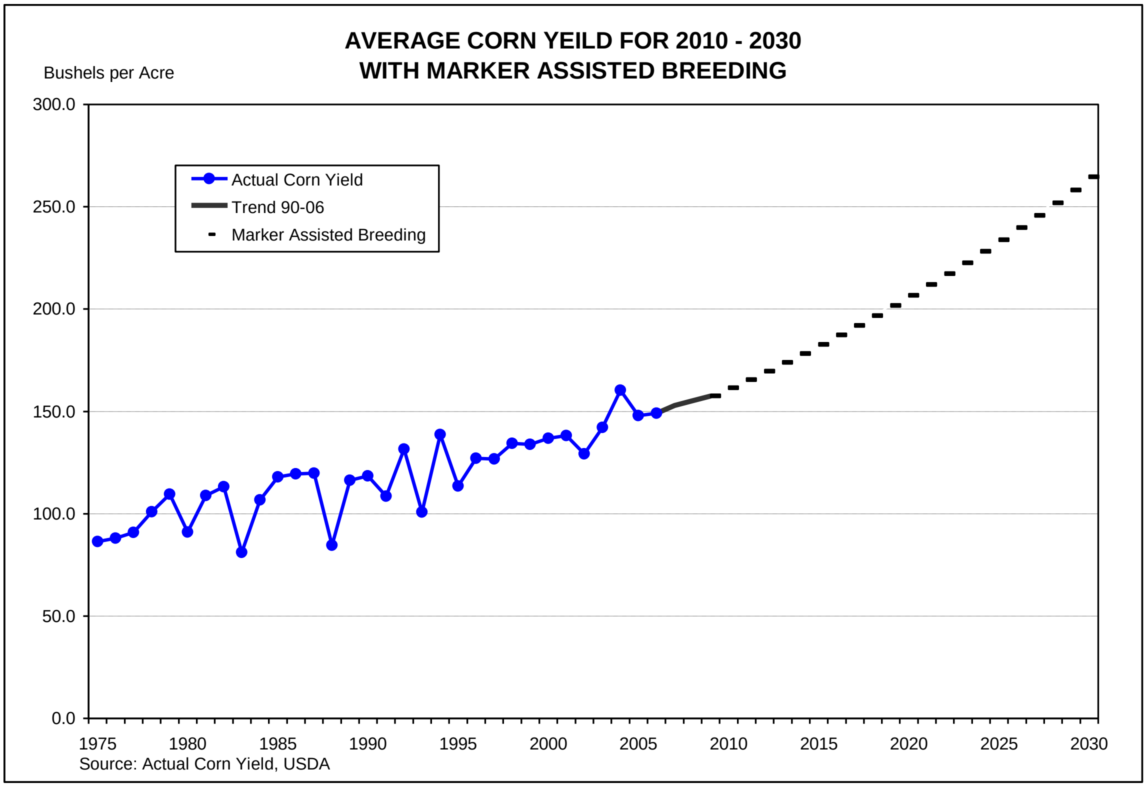
The potential for corn yields to continue to increase can be thought of in three increments. The first one is the continuation of the yield increases that have been evident from 1975 to 2006 or the slightly steeper trend from 1990 to 2006. Using the 1990-2006 trend, the average yield would be 172 bushels by 2015 and 207 bushels by 2030. With the same corn acres harvested as expected in 2007, 85 million acres, production would be 14.6 billion bushels in 2015 and 17.6 billion bushels in 2030. The 2007 corn crop is estimated by USDA at 13.168 billion bushels.

Figure 6



The trend yields in Figure 6 provide for a constant increase in per bushel yield, but as yields increase each year the percentage increase in yield declines because each year is starting from a higher base yield than the previous year. The use of marker assisted breeding and other procedures now allows plant breeders to more quickly identify and locate the presence of a specific desired trait. This is allowing corn plant breeders to make substantially faster progress in increasing corn yields and yields will increase at a greater absolute amount each year. Yield increases are expected to average 2.5 percent year over year throughout the 2010-2030 period. Yield per acre would increase to 183 bushels in 2015 and 265 bushels per acre by 2030 as shown in Figure 7. With the same harvested acres in 2015 and 2030 as in 2007, total production would be 15.6 billion bushels and 22.5 billion bushels, respectively.

Figure 7



The 2.5 percent per year increases for 2010-2030 facilitated by marker assisted breeding will be further enhanced by "bumps" in yields that will occur between 2015 and 2020 from transgenic yield enhancements that are in the early stages of development at commercial seed corn companies. The bumps will be associated with genetically engineered traits for cold tolerance, drought tolerance, increased nitrogen efficiency and pest control. Other yield enhancements may come after 2020, but those are not now in the development stage and cannot be identified.

Those yield "bumps" are modeled in this analysis by increasing yearly corn yields by 4.0 percent per year for 2015 through 2020. The per year yield increases for 2010 to 2014 and for 2021 to 2030 are assumed to remain at 2.5 percent per year based on marker assisted breeding.

The enhanced yields from marker assisted breeding combined with the "bumps" in yields from seed corn technology breakthroughs could increase yield per acre to 185 bushels per acre in 2015, 226 bushels per acre in 2020, 255 bushels per acre in 2025 and 289 bushels per acre in 2030. Using the expected harvested acres for 2007 of 85 million acres, total corn production would be 15.7 billion bushels in 2015, 19.2 billion bushels in 2020, 21.7 billion bushels in 2025 and 24.6 billion bushels in 2030.

Just how fast yields increase will partly be a function of the economic incentives to continue to increase yields. The increased demand for corn for

Figure 8

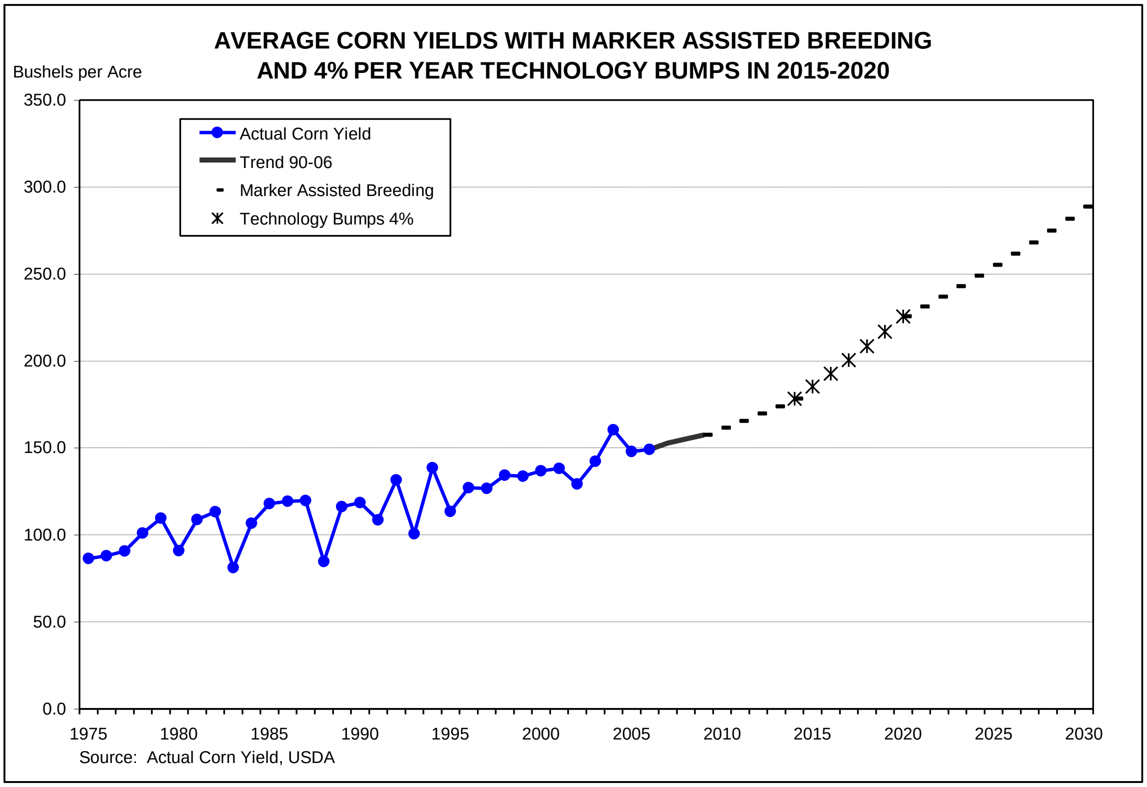
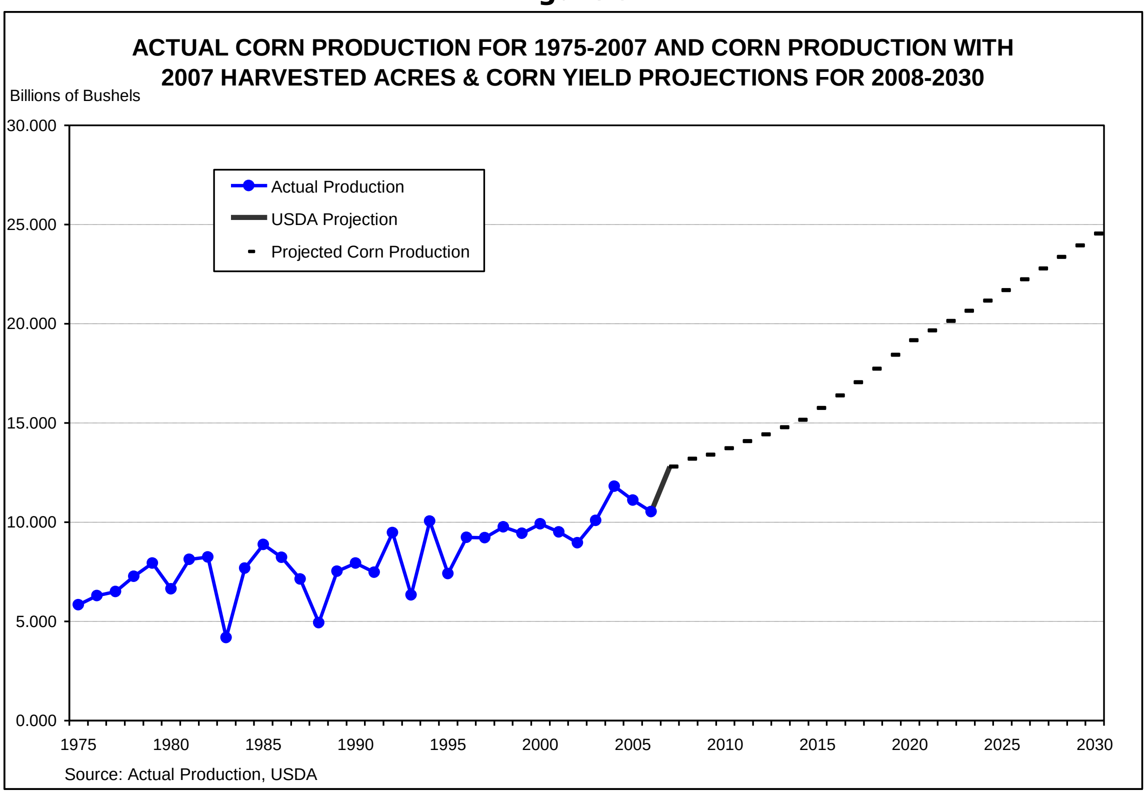

AVERAGE CORN YIELDS WITH MARKER ASSISTED BREEDING
AND 4% PER YEAR TECHNOLOGY BUMPS IN 2015-2020
Bushels per Acre
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Actual Corn Yield
Trend 90-06
Marker Assisted Breeding
Technology Bumps 4%
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Source: Actual Corn Yield, USDA

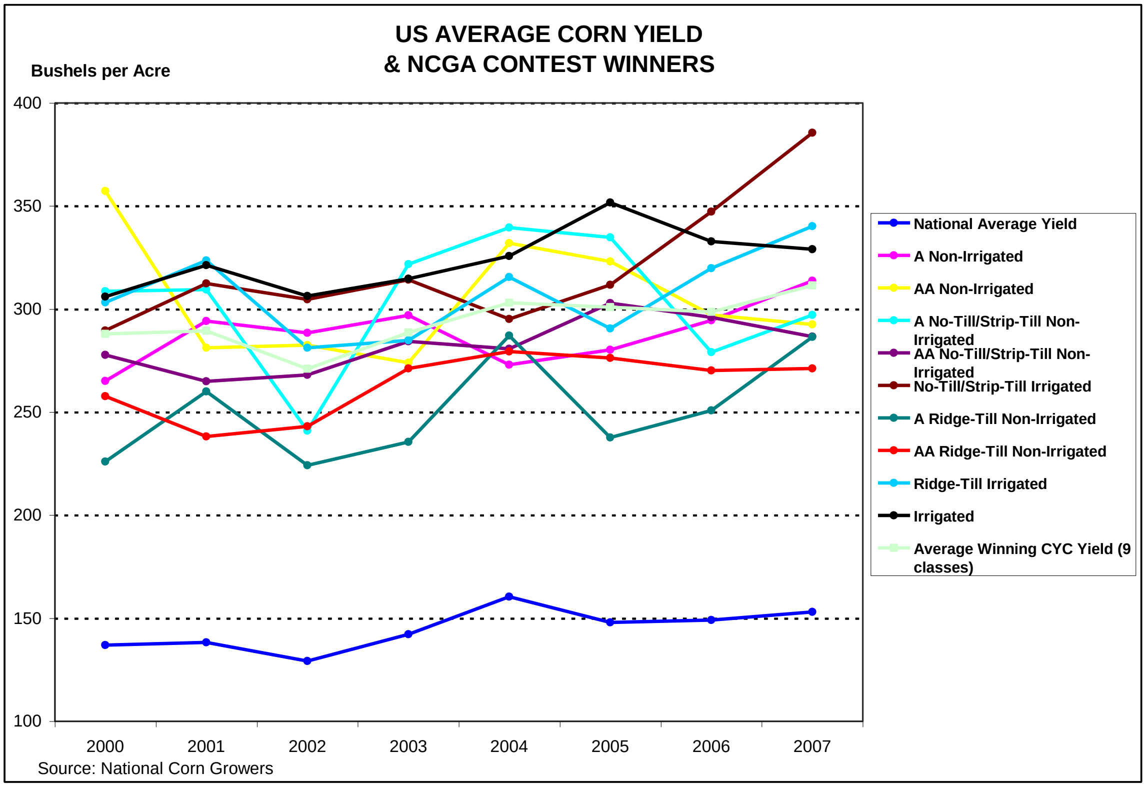
Figure 9


ACTUAL CORN PRODUCTION FOR 1975-2007 AND CORN PRODUCTION WITH
2007 HARVESTED ACRES & CORN YIELD PROJECTIONS FOR 2008-2030
Billions of Bushels
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Actual Production
USDA Projection
Projected Corn Production
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Source: Actual Production, USDA

ethanol production is providing incentives for commercial seed corn companies to invest in research to develop technological breakthroughs and for corn producers to use the technology to achieve higher yields in response to higher market prices. As long as those incentives remain in place, yields will continue to increase.

While the projected yield increases are large compared to national average corn yields in recent years, the yields are not large in relation to yields being achieved under the best of conditions using existing corn production technology. In the National Corn Growers Association (NCGA) national corn yield contest, most of the winners in recent years in the non-irrigated categories had yields of 240-295 bushels per acre. The winners in the irrigated categories had yields of 285-345 bushels per acres. Soil capabilities and rainfall patterns are available to support much higher yields than the average yields of today. Technology is now being developed to achieve those higher yields on a more consistent and wide-spread basis.

Figure 10



Uses of Corn

Increased use of corn for ethanol production has caused traditional users of corn to be concerned about the availability of corn supplies. Uses of corn are generally broken into four primary categories: industrial uses (including corn processed for food), ethanol, exports and livestock feed and residual. The first three categories are directly estimated by USDA and other sources and the fourth is a residual calculation based on beginning corn supplies, production, estimated uses and ending supplies.

For this analysis corn used for livestock feed and residual is tied to changes in Grain Consuming Animal Units (GCAU). The "residual" portion of feed and residual generally shrinks in short production years and grows in high production years. Since trend yields are used in this analysis, fluctuations in residual are not included. For the decade of 1976-1985, a period of relatively high market prices for corn and uncertainties of supply because of growing export markets, GCAU grew an average of 0.06 percent year over year. For 1986-1995 when corn supplies were more abundant and market prices were lower, GCAU grew by 0.87 percent year over year. For 1996-2005 when corn prices were also relatively low, GCAU grew by 0.55 percent year over year. With the expectations of relatively higher market prices for corn due to demand from ethanol, the assumption is made that GCAU will grow by 0.1 percent per year for 2007-15. After 2015 higher corn yields should accommodate growth in GCAUs of 1.0 percent per year to meet domestic demand and continued growth in international market demand for U.S. livestock and poultry products. The assumption is also made that DDGS will continue to displace corn in livestock feed so that net corn feeding and residual continue to decline to 5.350 billion bushels by 2015. The feed market for DDGS will likely be maximized by 2015 and whole corn use for feed will increase after 2015.

Non-ethanol industrial use grew about 2.2 percent year over year from 1991-2000 and has slowed to about 1 percent for the last six years. With more interest in the use of renewable plastics and other items now made from petroleum based products, the assumption is that use may expand by 3 percent year over year for 2007-2030.

The largest corn export years were 1979, 1980 and 1989 at about 2.4 billion bushels per year. The next highest was 2.2 billion bushels in 1995 and the just ended 06-07 year. The current marketing year of 07-08 is expected to have record exports of 2.45 billion bushels. The assumption is that exports will be at 2.1 billion bushels per year for 2008-2015 and then increase by 100 million bushels each year so that exports would be 3.6 billion bushels per year by 2030. The results of these assumptions are summarized in Table 1.

With the assumptions outlined above, corn available for ethanol production increases from the 2,190 million bushels used for crop marketing year 2006 to 12,011 million bushels by 2030. If feed and residual, exports and non-ethanol industrial uses are a few hundred million bushels per year higher or lower than the assumptions, the outcome is not substantially different.

Since harvested acres are fixed at the projected 2007 acres harvested for grain, per acre yield is the determining factor for the amount of corn available for ethanol production over the next 23 years. Assuming that the corn acres harvested in 2007 would be maintained in future years is a reasonable expectation. The August 2007 Baseline Update for U.S. Agricultural Markets from the Food and Agricultural Policy Research Institute at the University of Missouri – Columbia projects a slight dip in corn harvested acres to 82 million acres for 2008 before increasing to 86 million acres for 2009-2012.

Table 1
Corn Production and Use by Crop Marketing Year
2006 USDA Estimate, 2010-2030 Projections
Million Bushels

Item/Year	2006	2010	2015	2020	2025	2030
Corn Production	10,535	13,727	15,758	19,172	21,691	24,565
Non-eth. Industrial	1,354	1,519	1,761	2,041	2,366	2,743
Exports	2,100	2,100	2,100	2,600	3,100	3,600
Feed & Residual	5,875	5,600	5,350	5,623	5,910	6,211
Corn for Ethanol	2,190	4,508	6,547	8,908	10,315	12,011

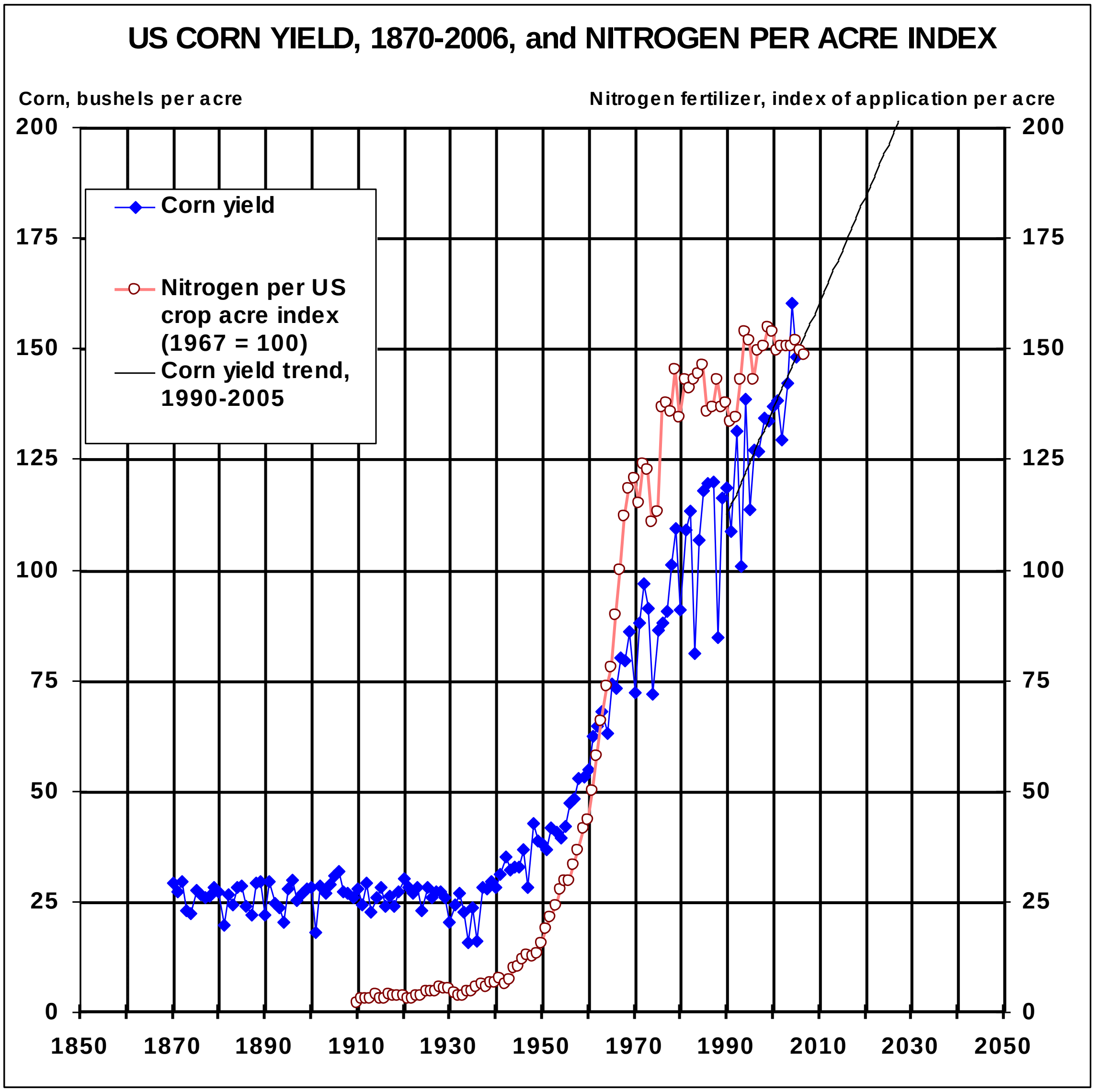
Nitrogen Fertilizer

Nitrogen is an essential macronutrient for corn production and is often the limiting nutrient for corn production. Corn producers apply commercial nitrogen fertilizer to supplement nitrogen available from precipitation, soil organic matter, previous crop residue and applied organic material. Nitrogen applications rates per bushel of corn produced have been declining in recent years and are expected to continue to decline.

Nitrous oxide (N2O) is a greenhouse gas that is estimated to be 300 times more potent on a per unit basis than CO2. Research has shown that N2O emissions are lower when nitrogen fertilizer application rates are not in excess of amounts needed to achieve optimal yields. The Intergovernmental Panel on Climate Change (IPPC) calculates direct N2O emissions as 1.25 percent of total nitrogen fertilizer applied. The GREET life cycle greenhouse gas emissions model from Argonne National Laboratory uses 2.0 percent.

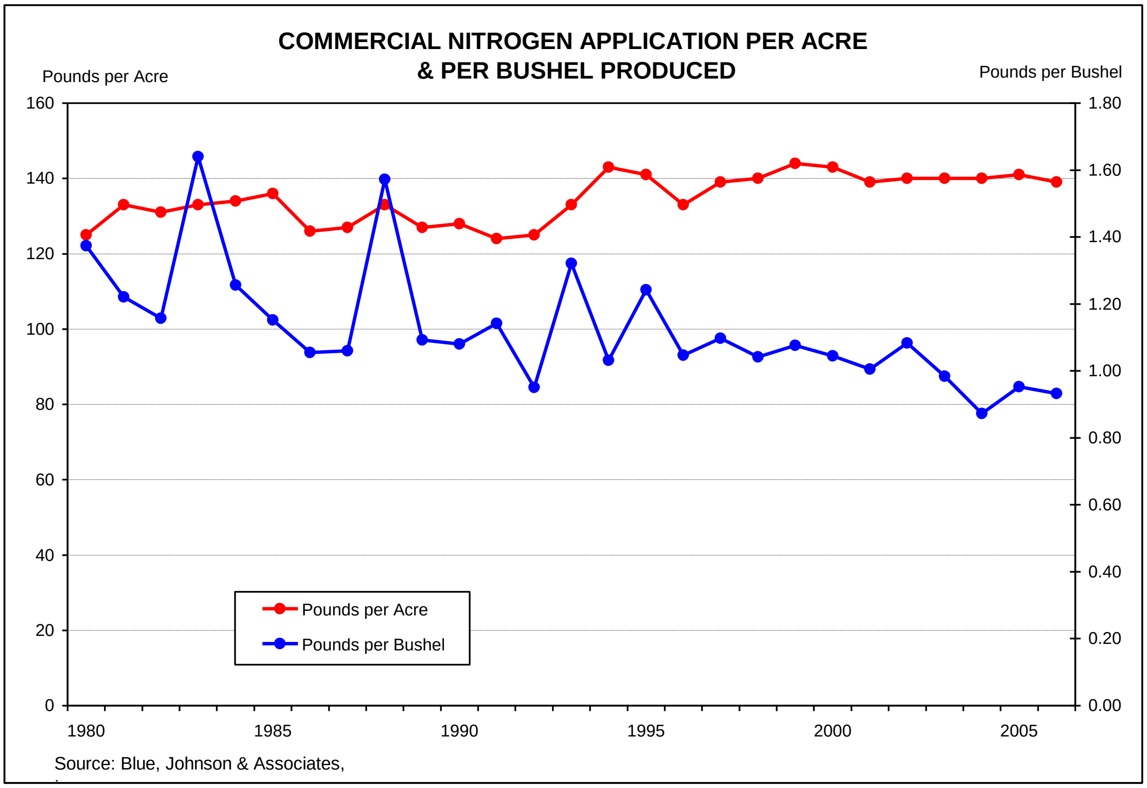
The application of commercial nitrogen fertilizer on corn land increased rapidly from an application per acre index of about 10 in 1950 (1967 = 100) to an index of about 145 in the early 1970s as shown in Figure 11. The application index then increased to just over 150 by the late 1990s. The application rate index has declined slightly since then.

Figure 11



Corn yields did not increase as rapidly as nitrogen application rates from 1950 to the early 1970s. As nitrogen applications increases moderated and then declined, corn yields per acre continued to increase.

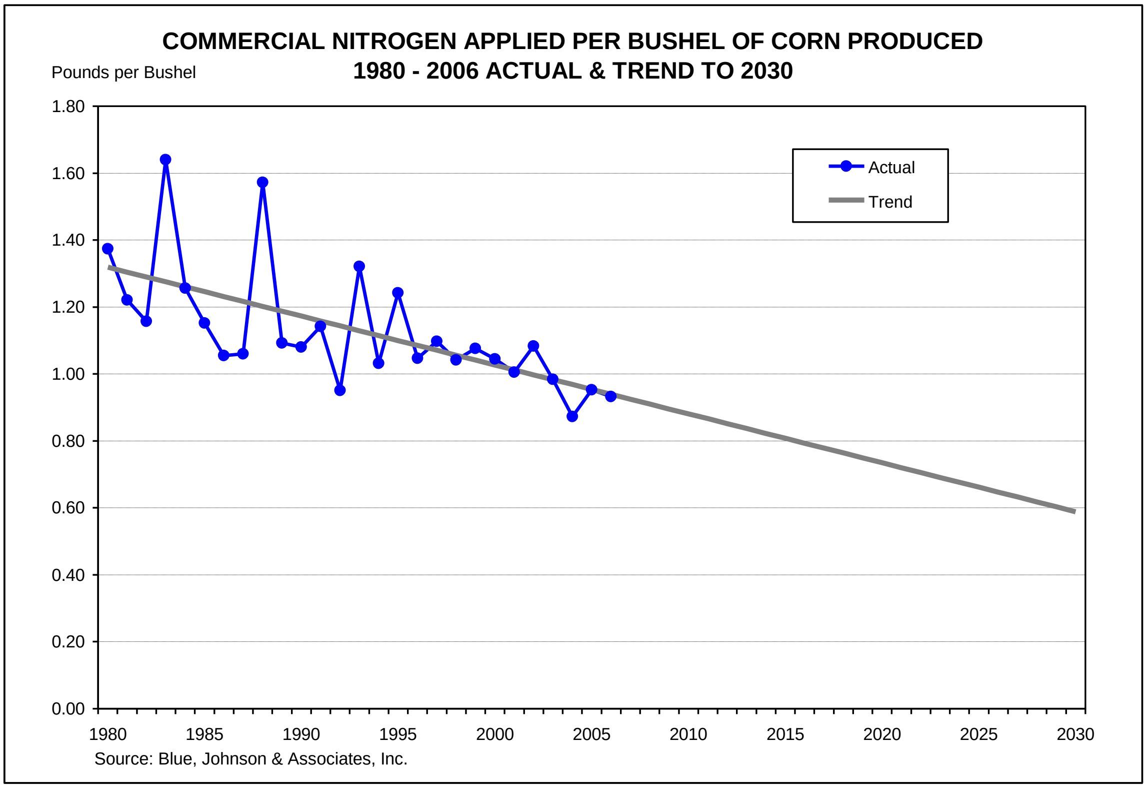
Figure 12



Nitrogen fertilizer application rates on a per acre basis went down slightly from the early 1980s to the early 1990s. Application rates then increased in the mid-1990s and have trended sideways since then. Application rates per bushel of corn produced have declined over the past 30 years from about 1.3 pounds per bushel produced to about 0.9 pounds per bushel, a 30 percent decline.

Nitrogen application rates per acre could remain stable in the immediate years ahead as increased utilization of existing nitrogen application allows corn yields per acre to continue to increase. If the yields per acre discussed earlier in this analysis are achieved, at some point applications per acre would likely increase. The actual applied rate will be influenced by a combination of the yield targets of producers and nitrogen use efficiency. As noted earlier, yields are expected to continue to increase between 2007 and 2030 because of improved genetic potential of corn plants and improved production practices. Precision application is expected to better match application rates with the yield potential of the soil. Multiple applications are also likely to more closely match nitrogen applications with plant uptake and increase uptake efficiency.

Figure 13



Based on the trend in Figure 13 on nitrogen application per bushel of corn produced, one possible outcome would be 0.6 pounds of nitrogen per bushel of corn produced in 2030 with continued increases in yield per acre. Corn agronomists are further researching the nitrogen cycle to better understand the natural sources of nitrogen and the timing and application rate of commercial nitrogen fertilizer to maximize corn production per bushel of corn produced and lessen the impact on water quality. Only 55-65 percent of the nitrogen fertilizer now applied is actually taken up by corn plants. Increasing that percentage could reduce the application rate per bushel of corn produced and reduce the loss of nitrogen as N20.

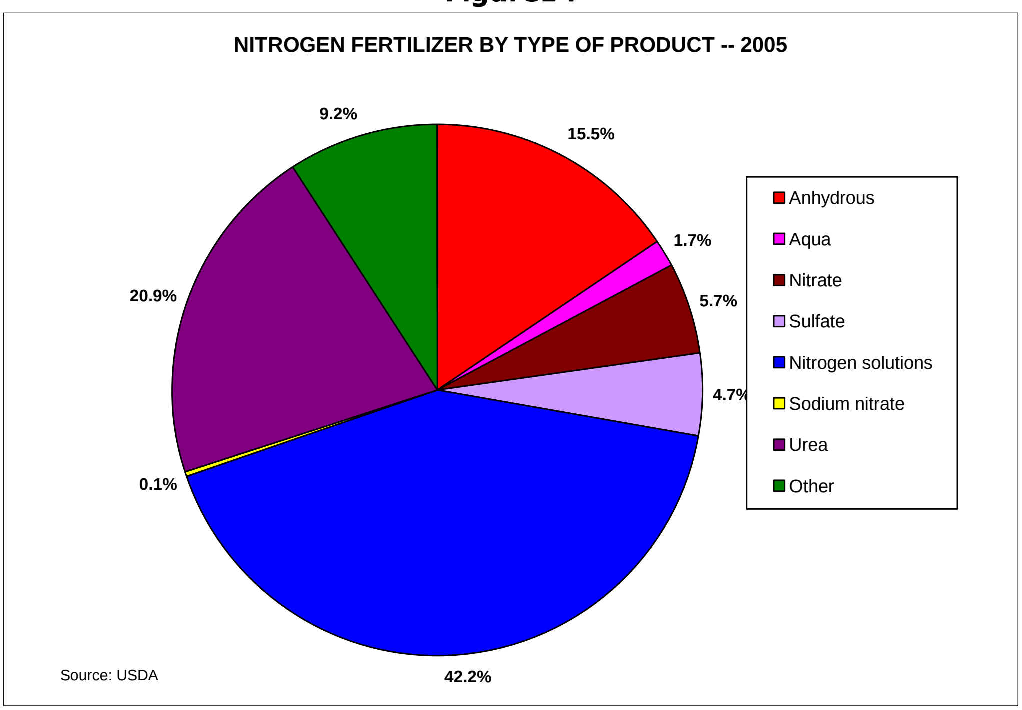
Seed corn companies are developing corn hybrids that are more efficient in the uptake of nitrogen and use of nitrogen by the plants to produce grain. This is one of the technology bumps in yield expected in the 2015-2020 time period. In the past corn breeders have focused on corn varieties that yielded well with high rates of applied nitrogen. Now more attention is being given to varieties that better utilize all sources of nitrogen in the soil. Producers' responses to the yield potential from nitrogen efficient corn varieties could range from producing the same yield with less nitrogen fertilizer to applying the same amount of nitrogen and attempting to increase yields. The approach chosen by individual producers will be driven by the agronomic characteristics of soils and the relative prices of inputs to market prices for corn. If market prices for corn remain strong because of demands for biofuels, a reasonable assumption is that the incentives will be tipped toward achieving higher yields. The higher corn prices will likely be somewhat offset by high prices for nitrogen and other fertilizers and encourage producers to conserve on fertilizer inputs.

Corn at 200 bushels per acre accumulates about 275 pounds of nitrogen, 140-150 pounds in the grain and the remaining in the stalks. Unless the stalks are removed, the nitrogen in the stalks can be available for the next crop.

Timing of fertilizer applications to the needs of the growing crop will continue to be an issue. About 60-70 percent of the total nitrogen uptake occurs in the six weeks from the four leaf stage to tasseling. Fertilizer companies are aggressively pursuing the development of slow release nitrogen fertilizers that will better match the nutrient requirements of the corm plant. Soil scientists continue to study how nitrogen is mineralized by the soil and taken up by corn plants. The goal is to match up as closely as possible nitrogen fertilizer application with the amount of nitrogen available in the soil and the needs of the corn plant.

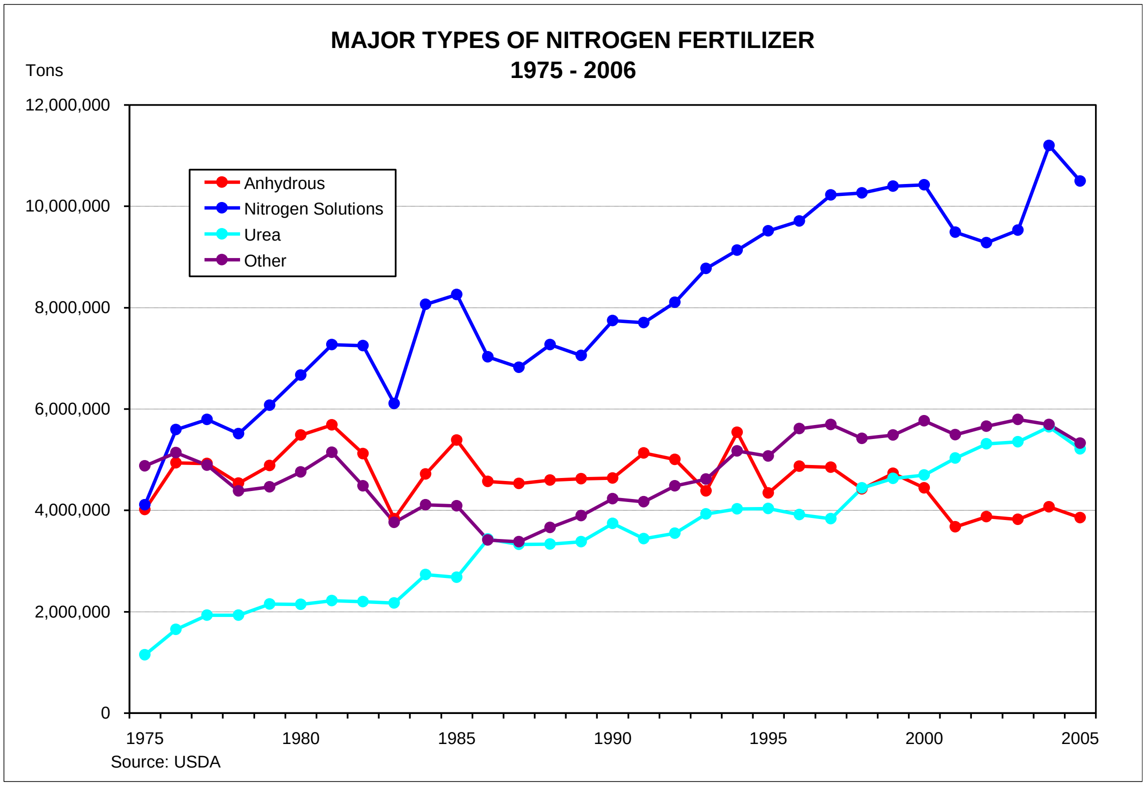
The most common nitrogen fertilizers used in the U.S. are nitrogen solutions, urea and anhydrous ammonia.

Figure14



Anhydrous ammonia is the only nitrogen fertilizer that has on average N2O emissions higher than the 1.25 percent of applied nitrogen fertilizer used by IPPC as a baseline number. Anhydrous ammonia use has been declining in both absolute terms and as a percent of the total nitrogen fertilizers applied in the U.S.

Figure15

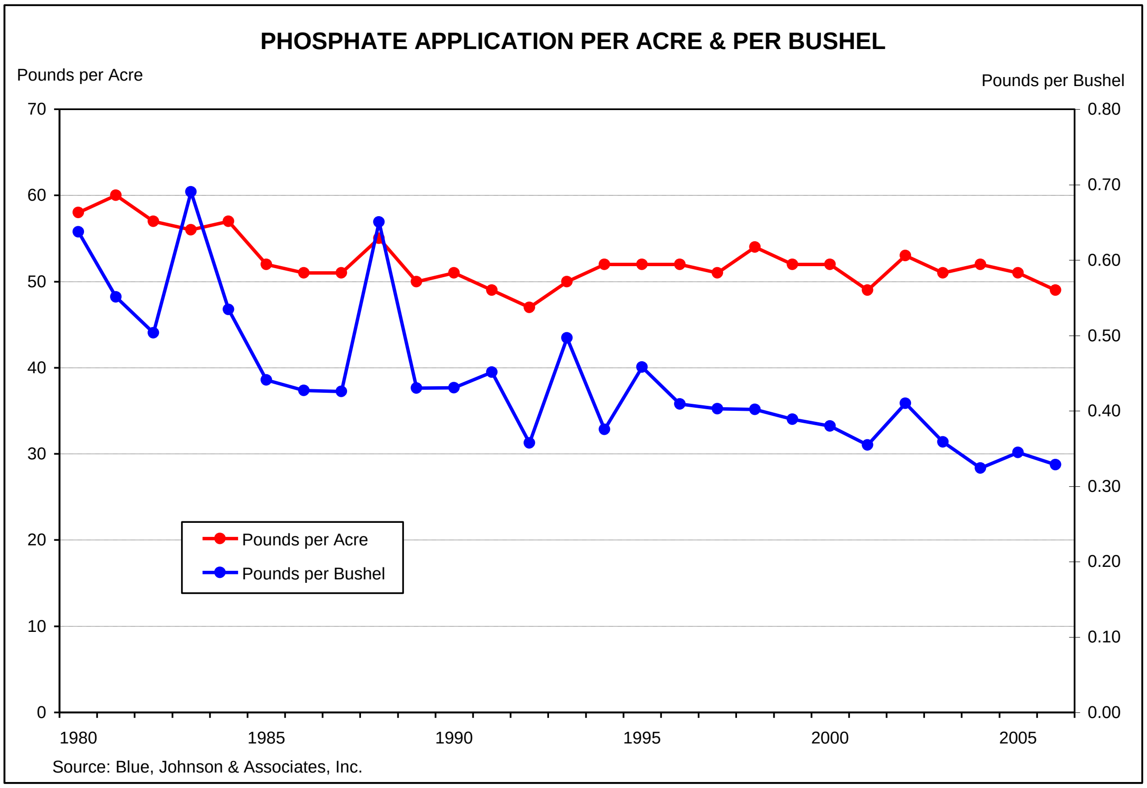


Nitrogen fertilizer should continue to be less of a concern for N20 emissions. The amount of nitrogen fertilizer applied per bushel of corn produced will likely continue to decline and corn producers are shifting away from anhydrous ammonia as a source of nitrogen. Economics and effectiveness of use will remain critical factors in determining which forms of nitrogen will be used.

Application of Phosphate and Potash Fertilizers

Application of phosphate fertilizer per acre of corn planted declined about 10 pounds from the early 1980s to about 50 pounds today, a 16 percent decline, with rates over the last ten years relatively flat. On a per bushel produced basis and ignoring the drought years of 1983 and 1988 the decline was about one-third from near 0.5 pounds per bushel to just over 0.3 pounds per bushel.

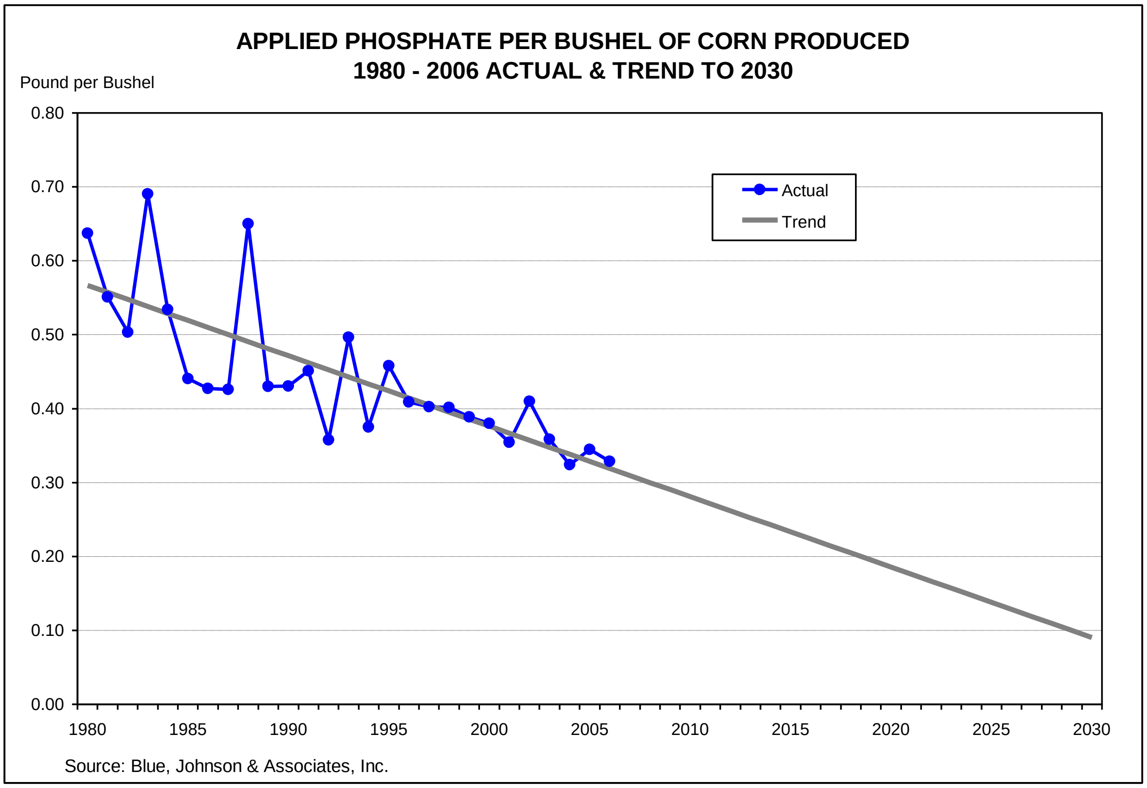
Figure 16



With continued increases in yields as discussed earlier and stable application rates per acre, applications of phosphate per bushel produced are likely to continue to decline. At some point the application rate per bushel produced will stop declining. That will partly be a function of improved application processes and more efficient uptake of nutrients by the corn plants.

Growing environmental concerns about excess phosphate in soil and water may result in efforts to increase regulations of application of phosphate fertilizers including livestock manure. This could require adjustments in phosphate applications and the development of corn varieties that are more efficient at drawing phosphate from the soil.

Figure 17



Potash application rates per acre have followed a similar pattern as phosphate with an overall decline and with much of the decline in the 1980s and early 1990s and a slower decline in the last 10 years. The overall decline was about 30 percent from just over 70 pounds per acre to less than 50 pounds per acre. On a per bushel produced basis the decline was from about 0.7 pound to 0.4 pounds, a 40 percent decline.

As with phosphate, application rates of potash per bushel of corn produced are not likely to hold to the trend line to 2030. Precision farming and increased nutrient uptake by the corn plants will continue to improve the efficiency of use of potash.

Figure 18

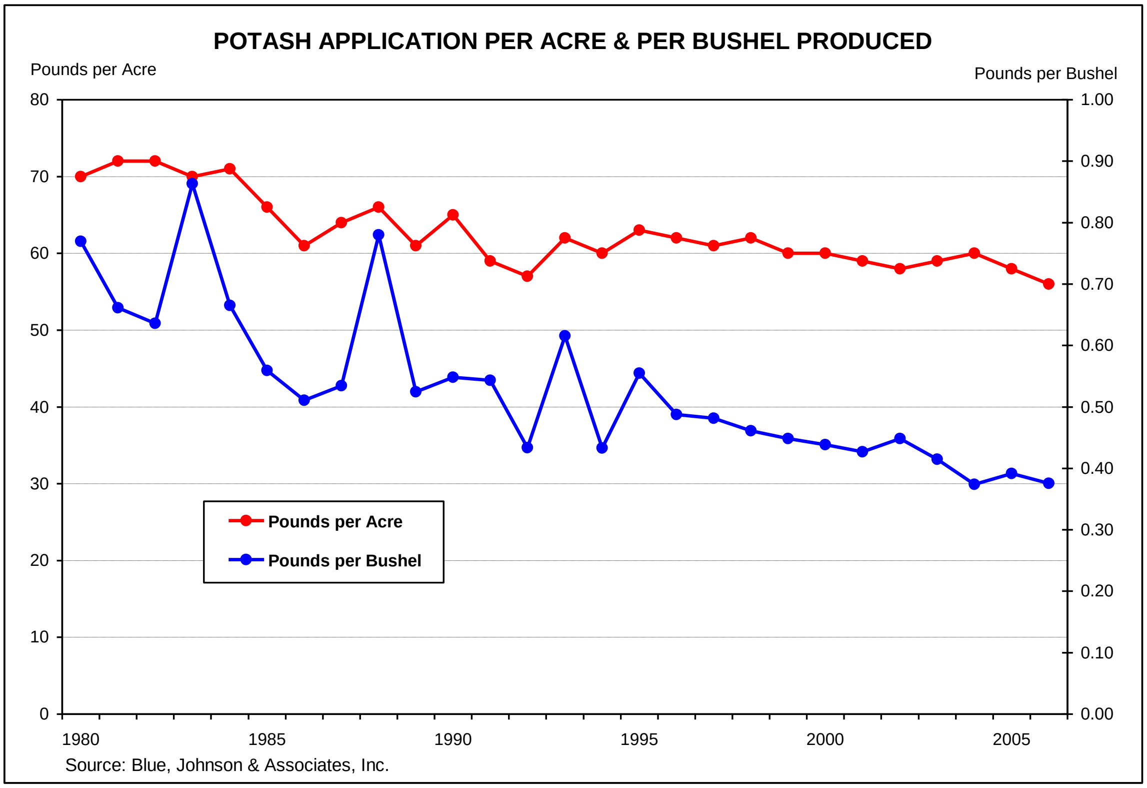
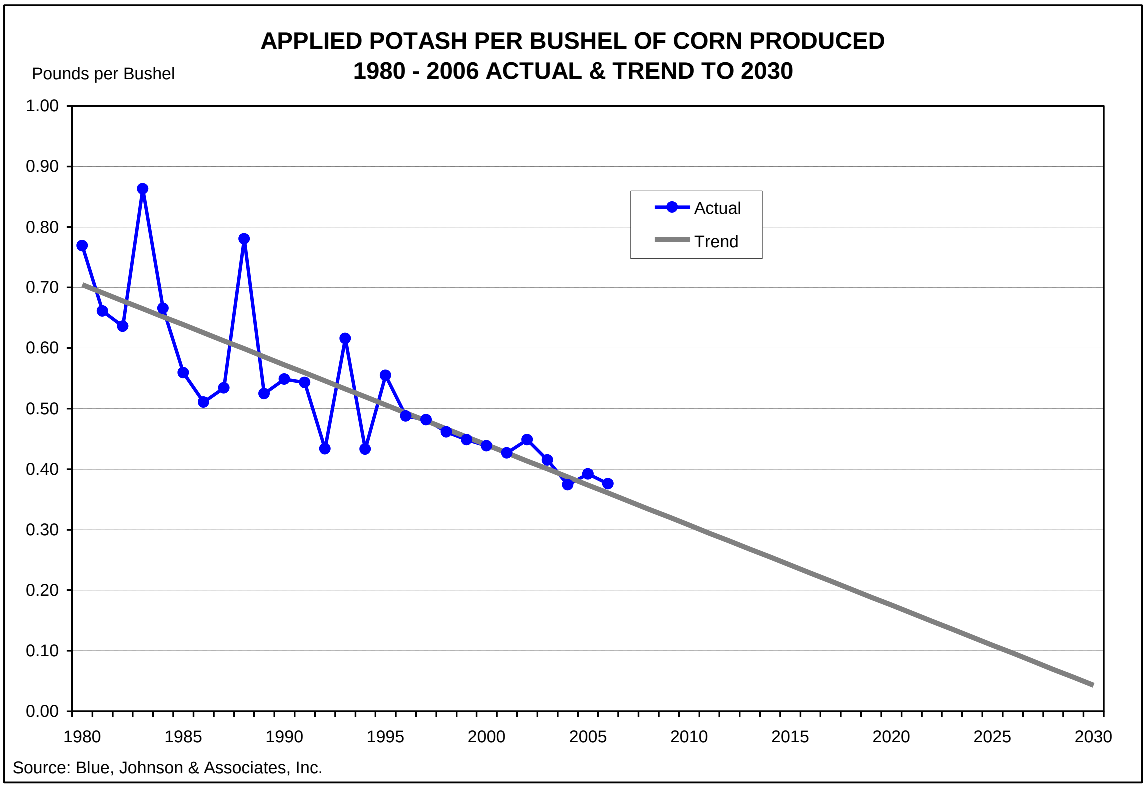


Figure 19

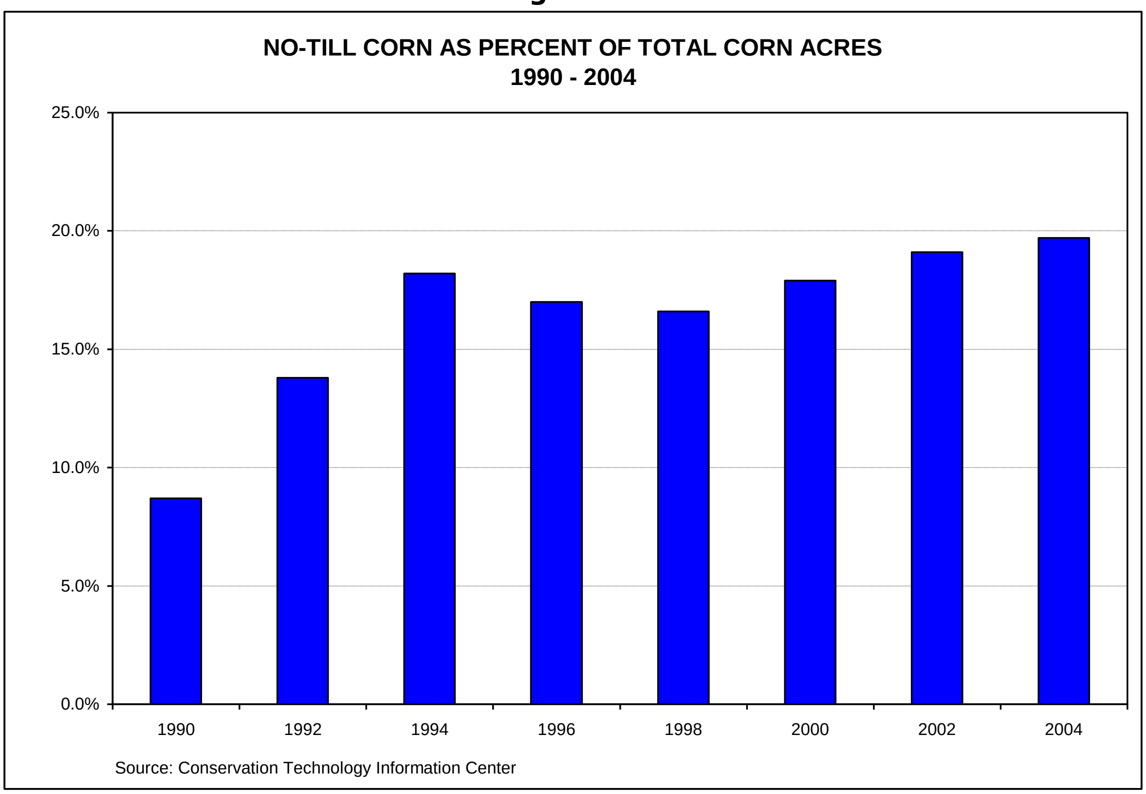


No-till & Reduced-Tillage Corn and CO_2

One way to reduce the amount of CO_2 released into the atmosphere during corn production is to use a farming practice called "no-till." Rather than traditional tillage practices of moldboard or chisel plowing, disking, field cultivating and similar soil preparation, the seed is directly planted into the stubble of the previous crop. According to an analysis by Kim and Dale at Michigan State University, in a tillage system that included plowing GHG emissions associated with 1 kg of corn production were 244g CO2 equivalent. In no-till corn the GHG emissions were -40 grams per 1 kg of corn mainly due to differences in soil organic carbon levels. No-till corn can be a carbon sink in that it ties up more carbon in the soil than the amount released in corn production. Analysts have targeted this issue for increased research to measure the carbon impact of no-till corn including different soil types, climate, crop rotations and different depths in the soil.

No-till corn has become an increasingly common practice. Nationwide data from the Conservation Technology Information Center at Purdue University show that no-till increased from 8.7 percent of total corn acres in 1990 to 19.7 percent in 2004. Most of the increase occurred in the early 1990s.

Figure 20



Data from the USDA Economic Research Service's Agricultural Resource Management Survey (ARMS) for states with no-till corn data show that 24 percent of the corn acres were no-tilled in 2005 compared to 19 percent in

2001 and 18 percent in 1996. According to USDA estimates, a corn producer can save 3.5 gallons of fuel per acre by adopting no-till.

Soil scientists, agronomists and corn producers are on a steep learning curve to increase adoption of no-till corn. Some producers face a reduction in yield when first adopting no-till corn production practices, but that may dissipate over time. Fertilizer applications and other variations in production practices are being explored to reduce the yield reduction in the first years of adopting no-till corn production.

Much of the current no-till corn is planted into soybean stubble from the previous crop year. With more interest in growing corn after corn, farmers and researchers have a new set of problems in planting in the increased ground cover of the corn stalks from the previous corn crop, providing timely application of fertilizer and managing insect pests. Precision guidance technology will play a key role in planting corn in heavy ground cover.

The many types of reduced tillage programs will likely become more important in dealing with residue in corn-on-corn programs. A recent analysis by Dobermann, et al from the University of Nebraska indicates that chisel plowing in a corn-on-corn system may also result in substantial reductions in carbon release compared to traditional tillage systems. Higher crop productivity for corn-on-corn was generally associated with increased soil carbon sequestration.

Soil Productivity and Use of Corn Stover

As the ethanol industry has explored ways to increase ethanol production and reduce the carbon intensity of ethanol on a life cycle basis, researchers have focused on corn stover as a cellulosic ethanol feedstock or a boiler fuel for a corn starch ethanol plant. Questions have been raised about how much stover can be removed without reducing soil productivity.

The Agricultural Research Service (ARS) of USDA in 2006 began a five-year systematic study of the issue. The Renewable Energy Assessment Project (REAP) has four objectives:

- Determine the amount of crop residues (e.g., corn stover, cover crop) that must remain on the land to maintain soil organic carbon and sustain production.
- Estimate the trade-off between the short-term economic return to growers who harvest crop residues as biofuel or biomass product feedstock versus the long-term benefits to soil, water, and air resources associated with retaining crop residues to build soil organic matter and sequester carbon.
- Develop robust algorithms to guide the amount of crop residue that can be sustainably harvested as feedstock for biomass ethanol and bio-based products without degrading the soil resource, environmental quality, or productivity.

> Develop management strategies (e.g., no tillage) supporting sustainable harvest of residue. Modify existing or devise new management practices that allow harvest of stover but maintain production level and soil organic carbon through use of cover crops, organic amendment, or other techniques.

An article by Jane M-F Johnson et al from the USDA's North Central Soil Conservation Research Laboratory in Morris, MN titled "A Matter of Balance: Conservation and Renewable Energy" appeared in the August 2006 Journal of the Soil and Water Conservation Society. The article reviewed existing literature on crop biomass removal and maintaining soil productivity. Their preliminary assessment on maintaining soil organic matter and "safely" or "sustainably" removing biomass is that it depends on specific soils, yield, tillage, and cropping systems. An underlying assumption was that corn and other crop residues should not be removed from highly erodible lands even if erosion and soil organic carbon needs are met.

The authors concluded that continuous corn with 156 bushels per acre yield would have 3.3 tons of stover and one ton could be removed if the land was chisel plowed or no-tilled. None could be removed if moldboard plowed. Continuous corn with a 200 bushels yield would have 4.5 tons of stover, and 2.1 tons could be removed if no-tilled or chisel plowed and 1.1 tons if moldboard plowed. In a corn-soybean rotation, a 200 bushels corn yield would allow only 0.9 tons of stover to be removed in a chisel plow or no-till system and none for moldboard plow tillage. The REAP effort will yield additional information as on-the-ground research results are analyzed.

The shift to more corn on corn will allow more stover to be removed while maintaining soil productivity. The trend of higher yields each year and sharply higher yields over five or ten years should increase the amount of stalks and cobs. Increases in no-till will also increase the amount of stover that can be removed. As noted by the ARS researchers, the amount of stover removed will still be site specific. It may be helpful in some cases to avoid tying up too many nutrients in the soil.

These preliminary results fit with the Poet company plan of only using the corn cobs for cellulosic ethanol. The cobs account for one ton or less of stover per acre except for high yield situations.

Irrigated Corn Production

Based on the USDA National Agricultural Statistics Service (NASS) 2002 Census of Agricultural and the 2003 NASS Irrigation Survey, about 14 percent of the corn land area harvested for grain is irrigated. Because irrigated land has a higher average yield per acre of corn, the irrigated acres account for about 20 percent of the nation's corn production.

Total acres of irrigated cropland in the U.S. declined to 55.3 million acres in the 2002 Census from 56.3 million acres in the 1997 Census of Agriculture. Irrigated corn acres declined from 10.8 million acres in 1997 to 9.7 million acres in 2002.

Increases in corn acres in 2007 have occurred in both irrigated and non-irrigated corn growing areas. A reasonable assumption would be that irrigated corn acres would have increased at least as much as non-irrigated corn acres. If that is true, the percent of the corn crop produced on irrigated land in 2007 may increase a percentage point or two from the 20 percent for 2002.

As with most inputs of production agriculture, irrigation has become more efficient. Shifting from flood irrigation to mechanized systems like center pivots can reduce water usage by up to 50 percent. Most new irrigation systems have computer designed application systems that match the unique needs of the buyer.

Researchers are working on timing of water application to conserve water while still achieving high yields. This usually involves installation and use of soil moisture monitoring equipment, delaying beginning watering until soil moisture levels indicate plants need additional water, keeping records by individual field on rain fall and irrigation, and reducing the amount of water provided after the grain enters the dough stage of maturity. This approach has shown to maintain yields while reducing water usage by 15 percent.

Irrigation systems of the future will be even more efficient. Scientists at USDA’s Agricultural Research Service are developing a state-of-the-art irrigation system that uses the latest in wireless technology for "communicating" with crops through Bluetooth technology, sensors, weather stations and traditional irrigation equipment. The system is designed with two goals: increase crop survivability and save water and fertilizer. Scattered across a field are sensors that constantly take the temperature of the plants and soil around them. Bluetooth enables the sensors to transmit data to the base station, which then instructs individual sprinkler heads how much water to release. Variations in soil types can be accommodated to eliminate underwatering or overwatering scenario. Fields are treated as collections of smaller, individual plots, each with its own specific needs.

Ethanol from Corn Kernel Fiber and Stover

Corn ethanol producers are exploring ways to increase the amount of ethanol produced per bushel of corn and per acre of corn. Poet, the ethanol plant builder and producer of ethanol from Sioux Falls, South Dakota, is retrofitting an existing ethanol plant in Emmetsburg, Iowa with partial funding by the U.S. Department of Energy that will use the fiber from corn kernels and corn cobs to produce ethanol. According to information on Poet’s website, the fiber from corn kernels will be extracted through Poet’s BFRAC fractionation process and account for 40 percent of the fiber used in the plant. That fiber will have no additional harvesting, storage or transportation costs because it is already coming into the ethanol plant and leaving as part of the DDGS. The other 60 percent of the fiber will come from corn cobs from corn fields. The corn cobs account for about 18 percent of the carbohydrates in the stover left on corn fields after harvest. Corn cobs have more carbohydrate content than the rest of the corn plant and a higher bulk density making them more efficient to haul than the remaining stover. About three-fourths to one ton of cobs will be removed per acre.

When the plant is fully operational at 125 million gallons per year, 25 million gallons of the ethanol will be cellulosic. The plant will produce 11 percent more ethanol from a bushel of corn (increasing from 2.8 gallons to 3.1 gallons), produce 27 percent more ethanol from an acre of corn, use 83 percent less fossil fuel than a conventional ethanol plant and reduce water use by 24 percent. They anticipate paying farmers $30-60 per ton for the cobs depending on logistics and storage.

Distillers Dried Grains with Solubles

Distillers dried grains with solubles (DDGS) are a co-product of ethanol production and have traditionally been used primarily for livestock feed, either wet or dry. Wet distillers grains with solubles (WDGS) is not economical to ship more than 50 miles and cannot be stored for more than 5-7 days, but reduces by about one-third the amount of thermal heat used in ethanol production. DDGS dried to 10 percent moisture can be stored and shipped across the country and into export markets.

While DDGS started as a by-product sold at whatever price possible, it has now become a co-product. Ethanol plants want to provide a consistent product that is mixed into livestock rations on a continuing basis. With the development of fractionation and extraction processes that remove corn oil and other products at the beginning or end of the production process, feed co-products are becoming increasingly heterogeneous and marketed to meet different needs.

A bushel of corn processed by a dry mill produces 17.5 pounds of DDGS. Some mills have experimented with removing corn oil from thin stillage after fermentation to use as a feedstock to produce biodiesel. That reduces the amount of DDGS per bushel to about 16 pounds and reduces the fat content. Fractionation before fermentation enables a dry mill to convert 4 pounds of pericarp and the starch for ethanol, capture the oil for biodiesel or other uses, and produce about 11.9 pounds of higher protein feed. Some dry mills are experimenting with burning the thin stillage, or the distillers grains, or both to provide process heat in ethanol plants. Other dry mills are working with gasification of the fiber and/or other low valued products to produce syngas either to substitute for natural gas in fueling the plant or for use as a feedstock to produce more ethanol. Other proposed uses of DDGS include wallboard and other construction materials and as a fertilizer.

Given that the DDGS are located at the ethanol plant and natural gas is the second highest cost after corn for a dry mill ethanol plant, combustion and production of syngas could provide a floor for DDGS prices. This would also reduce the amount of fossil fuel used to produce ethanol and lower the carbon content of the ethanol on a life cycle basis. How much DDGS are used as a boiler fuel will be determined partially by the regulatory and market pressures to lower the life cycle carbon content of ethanol.

While the use of feed co-products for combustion in ethanol plants will create a floor price, the upside potential for prices is yet to be fully explored. The protein and vegetable oil markets will create opportunities for feed co-products and set market prices in most years. The upside price potential will be determined by the ability to find uses for co-products that replace higher cost inputs in other industries.

The ethanol industry will go through periods of excess supply of DDGS during rapid ethanol expansion, but the resulting lower prices will expand uses and demand for DDGS in the long run.

Dry Mill Ethanol Plant Improvements

A separate report titled An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2015-2030) prepared by Steffen Mueller, Ph.D, of the Energy Resources Center University of Illinois at Chicago considered likely changes in primary energy feedstocks and energy system configurations for dry mill ethanol plants in five year increments from 2007 to 2030.

Table 2 shows the projected changes to the primary energy feedstock and energy system configurations at ethanol plants. Standard natural gas plants are expected to decline in use as more efficient combined heat and power plants are used and biomass and biogas become more important as energy feedstocks.

Table 2
Projected Diffusion of Primary Energy Feedstocks
And Energy System Configurations

	2007	2010	2015	2020	2025	2030
Natural Gas Boiler	88%	77%	65%	54%	42%	31%
Natural Gas CHP	4%	6%	8%	11%	13%	15%
Coal Boiler	0%	0%	0%	0%	0%	0%
Coal CHP	4%	4%	4%	4%	4%	4%
Biomass Boiler*	2%	5%	7%	10%	12%	15%
Biomass CHP*	1%	4%	7%	9%	12%	15%
Integ. Biogas Energy System	1%	5%	9%	12%	16%	20%
Sum:	100%	100%	100%	100%	100%	100%

The analysis considered changes in energy use with corn oil extraction after ethanol distillation, raw starch hydrolysis (also know as cold cooking or cold hydrolysis) and dry mill corn fractionation where the germ and oil are removed before ethanol production. Corn kernel fiber to ethanol was also considered, but no energy savings are expected from it use. Table 3 shows the expected energy savings.

Table 3
Projected Adoption Rates and Energy Savings
From Ethanol Process Improvements

Percent of all plants	**2007**	**2010**	**2015**	**2020**	**2025**	**2030**
Corn Oil Extraction	5%	10%	15%	20%	25%	30%
Raw Starch Hydrolysis	5%	10%	15%	20%	25%	30%
Dry Mill Corn Fractionation	1%	7%	13%	18%	24%	30%
Energy Reduction from Base Process						
Thermal	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Corn Oil Extraction	4%	4%	4%	4%	5%	5%
Raw Starch Hydrolysis	16%	16%	16%	16%	17%	17%
Dry Mill Corn Fractionation	31%	31%	31%	31%	31%	32%
Weighted Average Savings from Process Adjustments						
	1.3%	4.1%	6.9%	9.7%	13.1%	16.2%
Energy Reduction from Base Process						
Electric	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Corn Oil Extraction	-9%	-9%	-9%	-9%	-8%	-8%
Raw Starch Hydrolysis	0%	0%	0%	0%	0%	0%
Dry Mill Corn Fractionation	-10%	-10%	-9%	-9%	-8%	-8%
Weighted Average Savings from Process Adjustments						
	-0.6%	-1.6%	-2.5%	-3.5%	-3.9%	-4.8%

Note: Negative numbers indicate increased energy consumption

The rate of adoption of dry mill fractionation will have the greatest impact on thermal energy savings on a weighted average plant basis. Corn oil extraction and dry mill fractionation use more electricity, but that is more than overset by lower thermal energy costs.

Table 4 shows the expected decrease of ethanol plant energy consumption due to both improvements to current energy equipment and adjustments to the current dry mill process. The weighted average adjusts the conversion efficiency improvements by the diffusion rate of each plant type listed in Table 2. By 2030, on average, an ethanol plant will consume about 23,652 Btu/gal of thermal energy, a 27 percent decrease, and 0.37 kWh/gal of electricity, a 46 percent reduction, taking into account:

a) Adjustment based on ethanol plants choosing different primary energy feedstocks (coal, natural gas, biomass) and energy system configurations (adoption of combined heat and power technologies),
b) Expected improvements to energy equipment (more efficient boilers, motors, etc.), and
c) Adjustments to the current dry mill processes (adoption of corn fractionation, cold cook, etc.).

Table 4
Projected Conversion Efficiencies with Efficiency Gains From Energy Equipment Improvements and Dry Mill Process Improvements

	2007	2010	2015	2020	2025	2030
Thermal	Btu/gal	Btu/gal	Btu/gal	Btu/gal	Btu/gal	Btu/gal
Natural Gas Boiler	31,581	30,316	28,395	26,326	24,272	23,393
Natural Gas CHP	34,048	32,684	30,614	28,383	26,168	25,220
Coal Boiler	39,476	37,895	35,494	32,908	30,340	29,241
Coal CHP	43,424	41,684	39,044	36,199	33,374	32,165
Biomass Boiler*	39,476	37,895	35,494	32,908	30,340	29,241
Biomass CHP*	43,424	41,684	39,044	36,199	33,374	32,165
Integ. Biogas Energy System	14,310	13,737	12,867	11,929	10,998	10,600
Weighted Average Efficiency	32,257	30,902	28,886	26,727	24,591	23,652
Electric	kWh/gal	kWh/gal	kWh/gal	kWh/gal	kWh/gal	kWh/gal
Natural Gas Boiler	0.75	0.73	0.71	0.68	0.67	0.68
Natural Gas CHP	0.17	0.17	0.16	0.16	0.15	0.15
Coal Boiler	0.90	0.88	0.85	0.82	0.81	0.81
Coal CHP	0.06	0.06	0.06	0.06	0.06	0.06
Biomass Boiler*	0.90	0.88	0.85	0.82	0.81	0.81
Biomass CHP*	0.06	0.06	0.06	0.06	0.06	0.06
Integ. Biogas Energy System	0.06	0.06	0.06	0.06	0.06	0.06
Weighted Average Efficiency	0.69	0.61	0.54	0.47	0.41	0.37

Global Warming Impact Analysis

A separate report titled An Analysis of the Projected Global Warming Impact of Corn Ethanol Production (Years 2010-2030), prepared by Steffen Mueller of the University of Illinois at Chicago Energy Resources Center (UIC-ERC) and Stefan Unnasch with Life Cycle Associates analyzed the global warming impact (GWI) of corn ethanol produced in dry mill corn ethanol plants operating between the years 2010 and 2030. The analysis is based on the definition of GWI as the sum of the global warming potentials of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emitted on a life cycle basis, including corn production, corn transport, ethanol production, and ethanol distribution. The overall GWI is the sum of the emissions of these gases over the life cycle, weighted by the global warming potential of each gas as defined by the Intergovernmental Panel on Climate Change.

The study utilized a modified version of Argonne National Laboratory's GREET 1.7 model and the Biofuels Emissions and Cost Connection Model (BEACCON) developed by Life Cycle Associates. These modifications tailored the GREET model to the agricultural practices provided by the ProExporter Network and the ethanol plant conversion efficiencies projected for 2010 through 2030 as estimated in Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2015-2030) prepared by Steffen Mueller.

Table 5 shows the agricultural efficiency assumption supplied by the ProExporter Network. The agricultural efficiency assumptions for corn yield and nitrogen applied were used directly as input variables into the GREET model. The increase in irrigation efficiencies and the increase in no-till practices were adjusted for GREET modeling purposes.

Table 5
Agricultural Efficiency Assumptions

	2007	2010	2015	2020	2025	2030
Corn Yield (bushels/acre)	153	162	185	226	255	289
Nitrogen applied (lbs/bushel)	0.92	0.88	0.81	0.73	0.66	0.59
No-till Practices (%)	20	20	27	35	43	50
5-Year Intervals Irrigation Efficiency Improvement (%)		3	3	3	3	3

Table 6 lists the on farm energy use adjusted for increased irrigation efficiencies and increased no-till practices.

Table 6
Summary of Adjustments

	2007	2010	2015	2020	2025	2030
Current GREET on Farm Energy Use (Btu/bu)	22,800	22,500	22,500	22,500	22,500	22,500
Net Irrigation Savings (Btu/bu)		65	127	188	247	304
Net No-Till Savings (Btu/bu)		0	306	655	1,004	1,309
Btu/bu with Irrigation and No Till Improvements		22,435	22,067	21,657	21,249	20,886

Besides energy savings, certain agricultural practices (reduced tillage, crop rotations) may also increase soil carbon sequestration. The sequestered amount depends on various factors including climate and this topic is the subject of currently diverging studies. As a conservative study assumption, this study does not consider soil carbon sequestration.

GREET 1.7 allows for time series analyses through 2020. For the purpose of this study, the time series was expanded through 2030 in conjunction with the GREET 2020 inputs. Therefore, petroleum refining, natural gas and coal production, and power generation inputs were consistent with the 2020 assumptions for GREET. The GREET 1.7 default input values were replaced by the data listed in Tables 4, 5 and 6.

The GWI contributions from several corn ethanol production stages were extracted from the various GREET spreadsheet vectors. These individual phases are:

<u>Ag Phase:</u> the GWI contribution from farm operations including energy use in tractors, irrigation equipment, chemicals, etc.
<u>Combustion:</u> the GWI contribution from ethanol plant energy systems including the upstream emissions from the fuel feedstock (coal mining, natural gas drilling, biomass procurement).
<u>Imported Electricity:</u> the GWI contribution from the electricity purchased by an ethanol plant. This includes emissions from

centralized electricity power plants and upstream emissions from fuel feedstocks to the power plants.
<u>Ethanol Distribution:</u> the distribution of ethanol to the blending terminal and the gas stations.
<u>Gasoline/Denaturant:</u> Since ethanol is blended with a denaturant by about 4.5% by volume (6.6% by energy) with gasoline, this phase includes emissions from gasoline production.

Table 7 shows the GWI (in g CO2eq/MMBtu, lower heating value) for each ethanol plant type by phase of the ethanol production process and year.

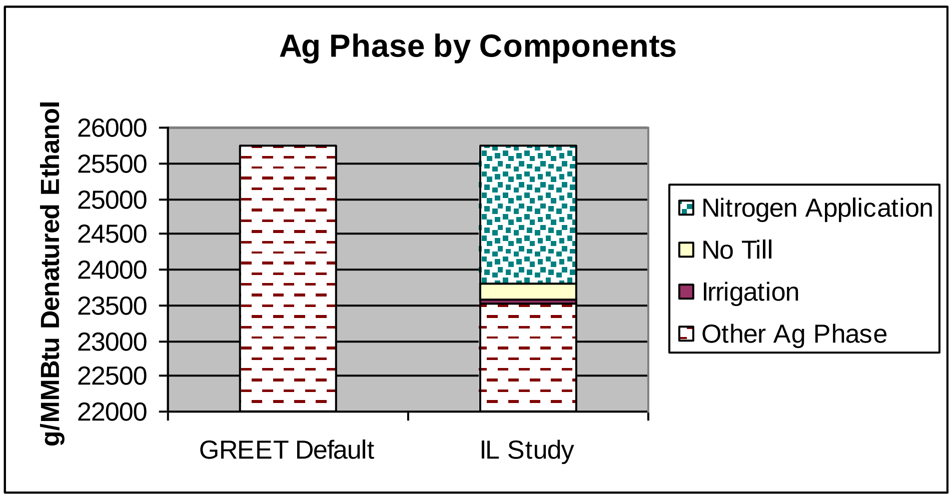
Table 7
Projected GWI of Future Corn Ethanol Plants

WTT Results, Denatured Ethanol (g/MMBtu), LHV											
Year	Phase	NG Boiler, GREET Default	Natural Gas Boiler	Natural Gas CHP	Coal Boiler	Coal CHP	Biomass Boiler*	Biomass CHP*	Integ. Biogas Energy System*	Weighted Average	Federal RFG
2010	Ag Phase	27,469	26,610	26,610	26,610	26,610	26,610	26,610	26,610	26,610	
2010	Combustion	28,425	24,154	26,041	51,971	57,168	1,682	1,850	15,962	23,317	
2010	Imported Power	10,496	7,261	1,646	8,714	610	8,714	610	610	6,142	
2010	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2010	Gasoline/Denaturant	6,399	6,399	6,399	6,399	6,399	6,399	6,399	6,399	6,399	97,651
	Total	74,280	65,916	62,187	95,185	92,278	44,896	36,960	51,072	63,959	
2015	Ag Phase	26,563	25,158	25,158	25,158	25,158	25,158	25,158	25,158	25,158	
2015	Combustion	28,424	22,623	24,391	48,677	53,545	1,526	1,679	15,962	20,534	
2015	Imported Power	10,386	6,953	1,576	8,344	584	8,344	584	584	5,379	
2015	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2015	Gasoline	6,398	6,398	6,398	6,398	6,398	6,398	6,398	6,398	6,398	97,623
	Total	73,261	62,622	59,013	90,067	87,175	42,916	35,309	49,592	58,959	
2020	Ag Phase	25,745	23,528	23,528	23,528	23,528	23,528	23,528	23,528	23,528	
2020	Combustion	28,423	20,974	22,612	45,129	49,642	1,354	1,490	15,962	17,919	
2020	Imported Power	10,303	6,685	1,515	8,022	562	8,022	562	562	4,688	
2020	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2020	Gasoline	6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total	72,392	59,109	55,577	84,601	81,653	40,826	33,501	47,973	54,056	
2025	Ag Phase		22,134	22,134	22,134	22,134	22,134	22,134	22,134	22,134	
2025	Combustion		19,337	20,848	41,607	45,768	1,221	1,343	15,962	15,599	
2025	Imported Power		6,575	1,490	7,890	552	7,890	552	552	4,136	
2025	Ethanol Distribution		1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2025	Gasoline		6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total		55,968	52,394	79,553	76,376	39,166	31,950	46,570	49,791	
2030	Ag Phase		20,755	20,755	20,755	20,755	20,755	20,755	20,755	20,755	
2030	Combustion		18,637	20,093	40,100	44,110	1,153	1,269	15,962	14,111	
2030	Imported Power		6,630	1,503	7,956	557	7,956	557	557	3,691	
2030	Ethanol Distribution		1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2030	Gasoline		6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total		53,943	50,272	76,732	73,343	37,785	30,502	45,195	46,479	

**The GREET default DDGS co-product credit was added to the combustion phase.*

Based on the data presented in Table 7, the GWI contribution from corn agriculture (on farm energy use for agricultural practices) is projected to decline by 22% from 26,610 gCO2eq/MMBtu to 20,755 gCO2eq/MMBtu by 2030. For reference purposes, this is 25% below the current GREET default value of 27,469 gCO2eq/MMBtu. Figure 21 shows the relative contribution of the various ag-phase components to the GWI (reference year 2020). As can be seen, among the factors varied for this study the nitrogen application rate has the biggest impact on GWI, followed by no-till practices and irrigation. The variation in the yield has a negligible effect: Most GREET agricultural inputs are on a per bushel basis, which means increased yield in bu/acre only affects certain agricultural efficiency parameters.

Figure 21
Ag Phase Component Contributions to GWI



The GWI of the average ethanol plant stock declines from 63,959 CO2eq/MMBtu to 46,479 gCO2eq/MMBtu by 2030, a 27% decline. More significantly, the GWI of ethanol produced from the averaged ethanol plant stock in place in 2030 may likely be half of the GWI of gasoline. The GWI of ethanol produced in a biomass fueled system may be less than 1/3rd of the GWI of gasoline (30,502 gCO2eq/MMBtu vs. 98,134 gCO2eq/MMBtu).

Increased efficiencies at the corn production level and at the ethanol production level will occur from 2010 to 2030. The greatest impact will occur in plants that use biomass and integrated biogas energy systems to fuel boilers and combined heat and power systems (CHP).

Figures 22 and 23 show that the agricultural production phase and the combustion phase are the two biggest sources of GWI in ethanol production and use. This analysis assumes that the corn used in all ethanol plants is the weighted average for the nation.

Figure 22

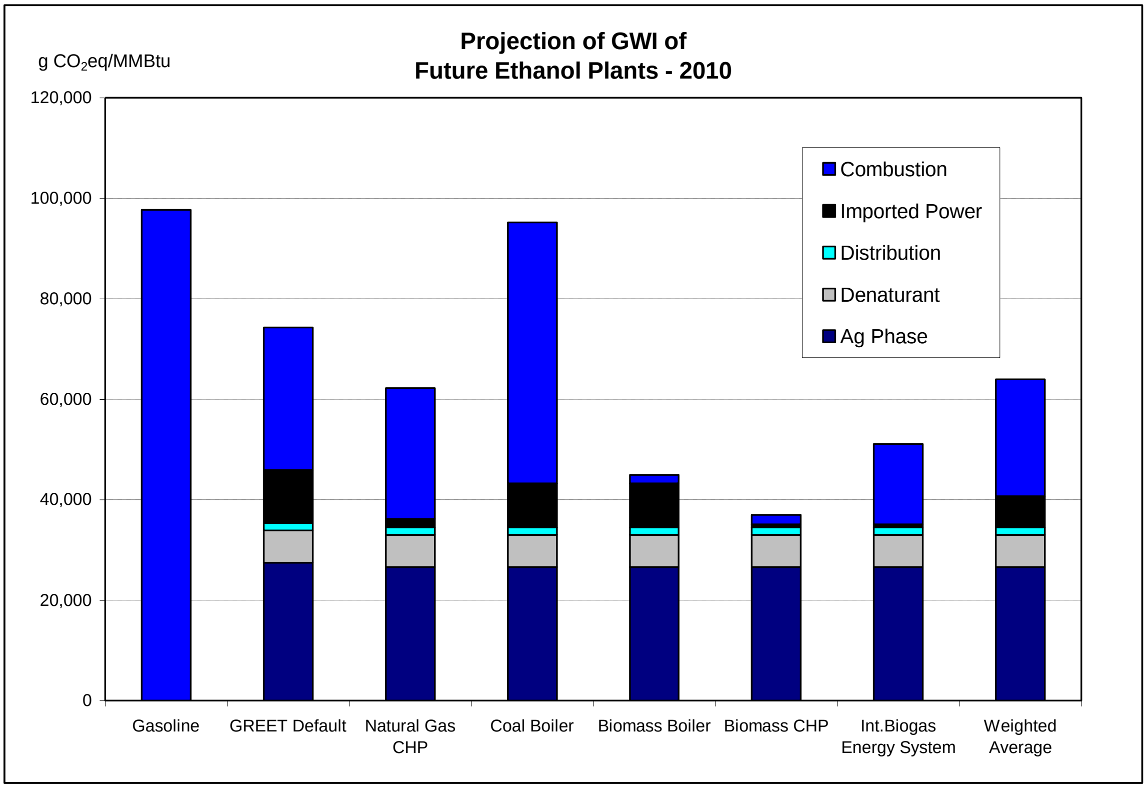
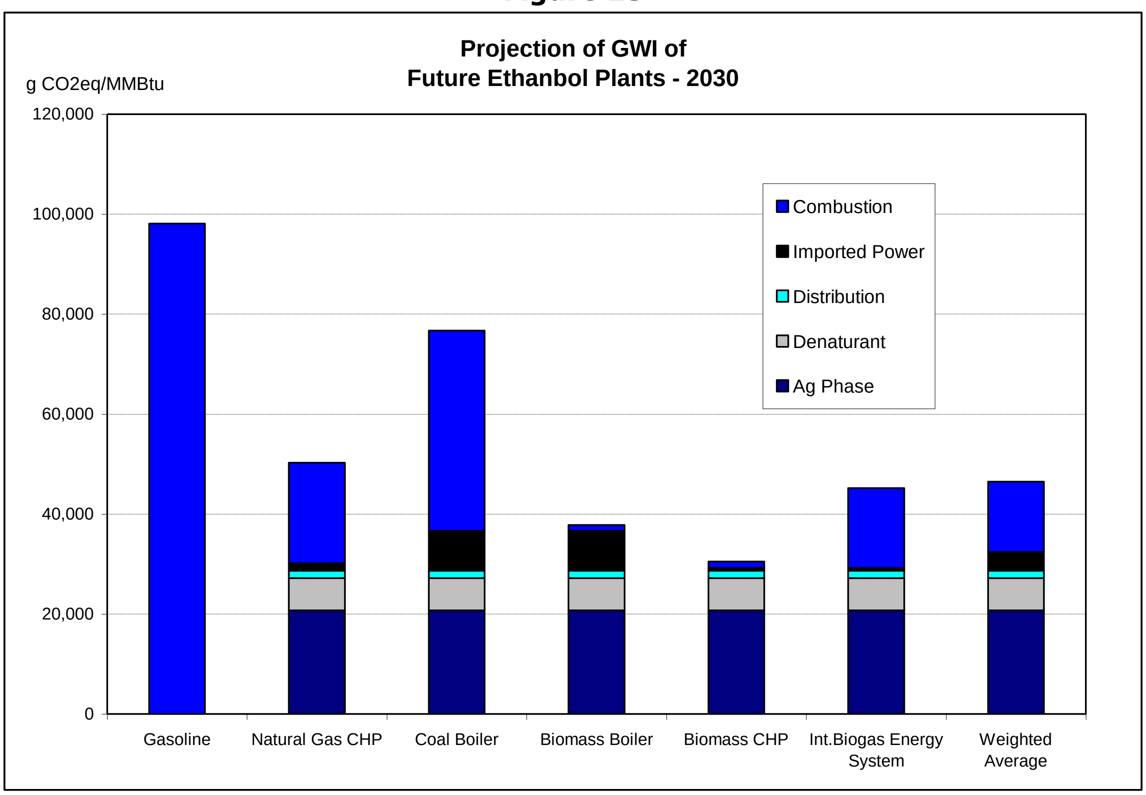


Figure 23



All ethanol plants are expected to be more efficient in fuel use and GWI in 2030 than in 2010. Those that use biomass as a boiler fuel or as a combined heat and power system (CHP) will have a clear advantage in 2010 and again in 2030. Integrated biogas energy systems have the next greatest reduction in GWI.

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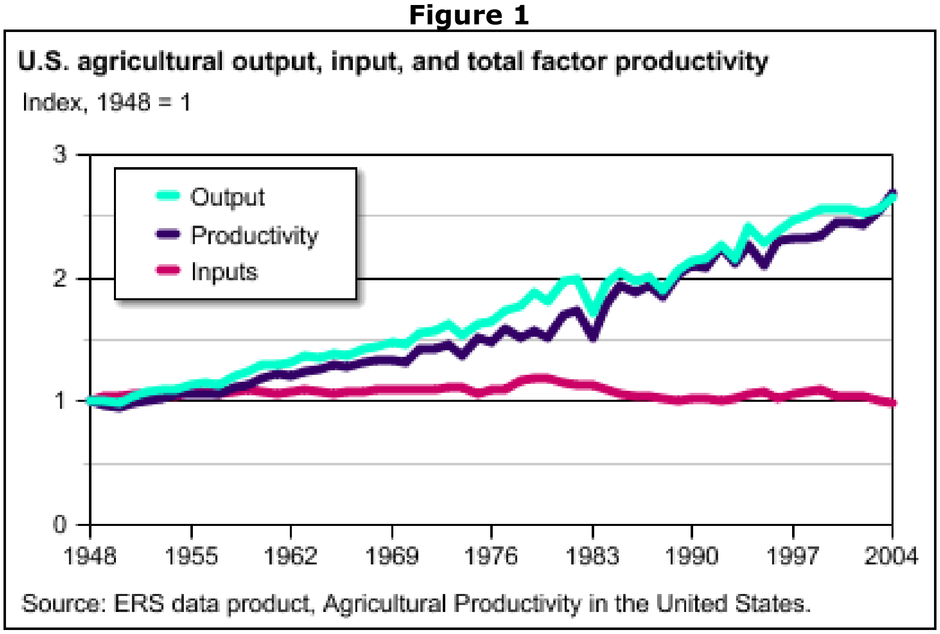
Agricultural Productivity
And U.S. Production of Corn for Ethanol

Ross Korves
Economic Policy Analyst
The ProExporter Network

October 2008

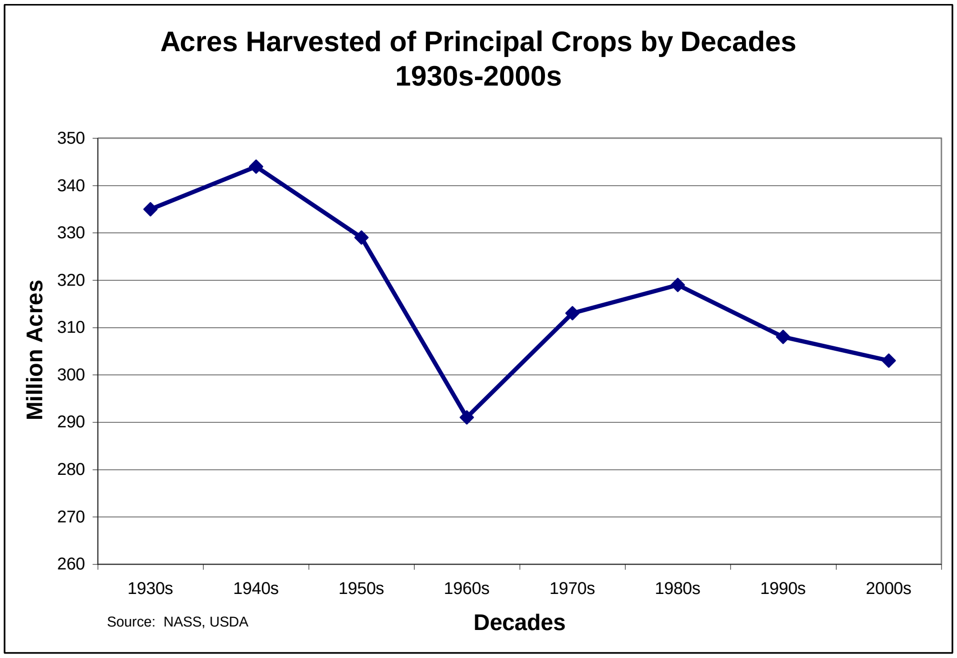
Since the end of the "land rush days" early in the 20th century, U.S. agriculture has been an increasingly science and technology driven industry. In the late 1940s, U.S. agriculture began rapidly shifting resources away from labor and toward capital and technology. Figure 1 from USDA shows that total resources in agriculture have remained roughly the same since the late 1940s while output has almost tripled as resources are used more efficiently.

Figure 1



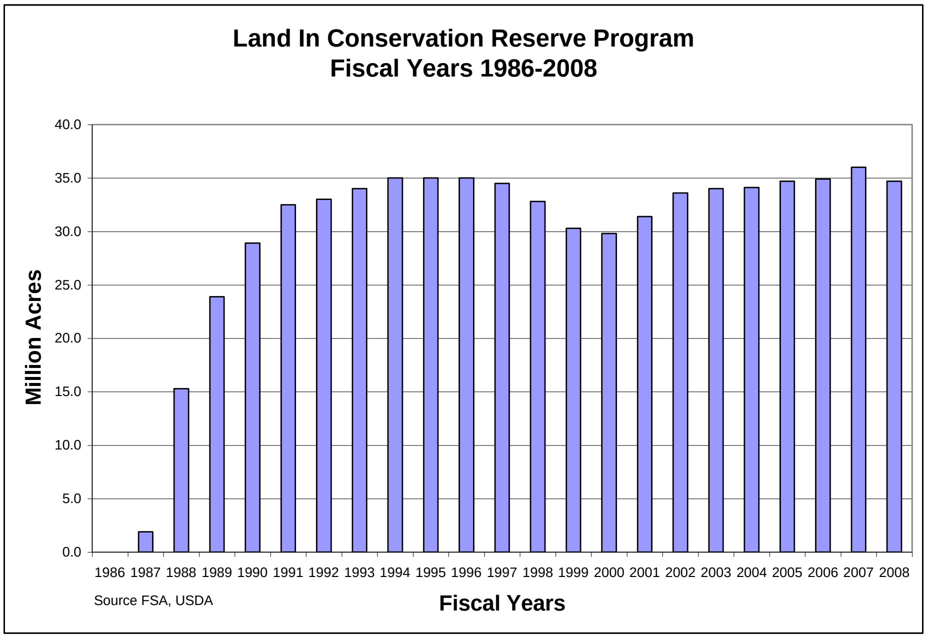
This trend will continue into the future and could accelerate at times as new technology becomes available. Increasing productivity was once seen as a problem for public policy as increased output resulted in downward pressure on market prices and farm incomes, but is now seen as an opportunity because it has eliminated the need to bring more land into production in the U.S. As can be seen in Figure 2, acres devoted to the major field crops have been declining since the 1940s.

Figure 2



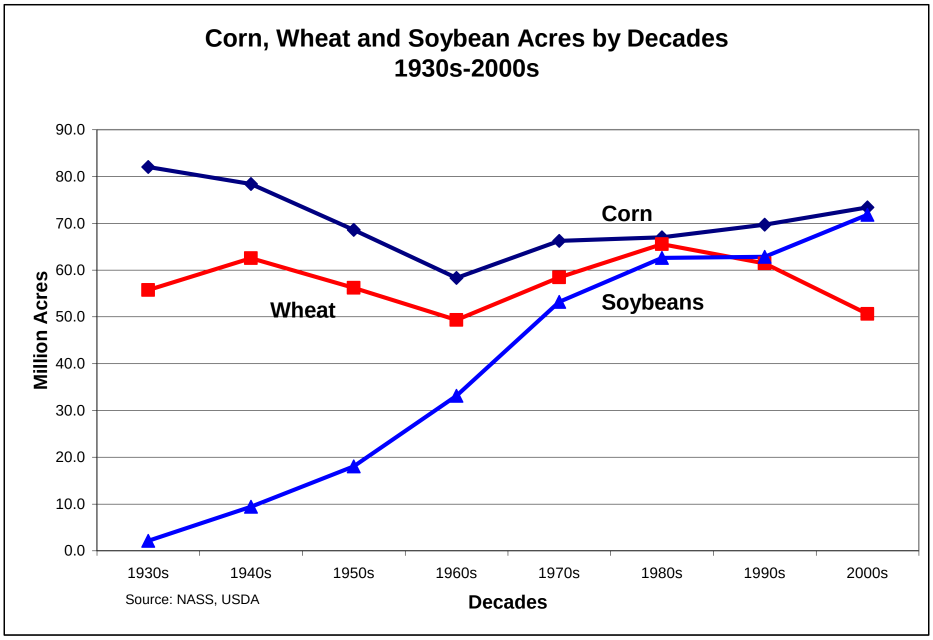
Cropland was so abundant in the 1980s that Congress created the Conservation Reserve Program (CRP) in 1985 to take 35 million acres of farmland out of production to support market prices and to achieve environmental policy goals rather than use the land for food production. See Figure 3. About three million acres have returned to production in recent years and another five million could return to production over the next few years, but the rest of the land is likely to remain in the CRP for the foreseeable future.

Figure 3



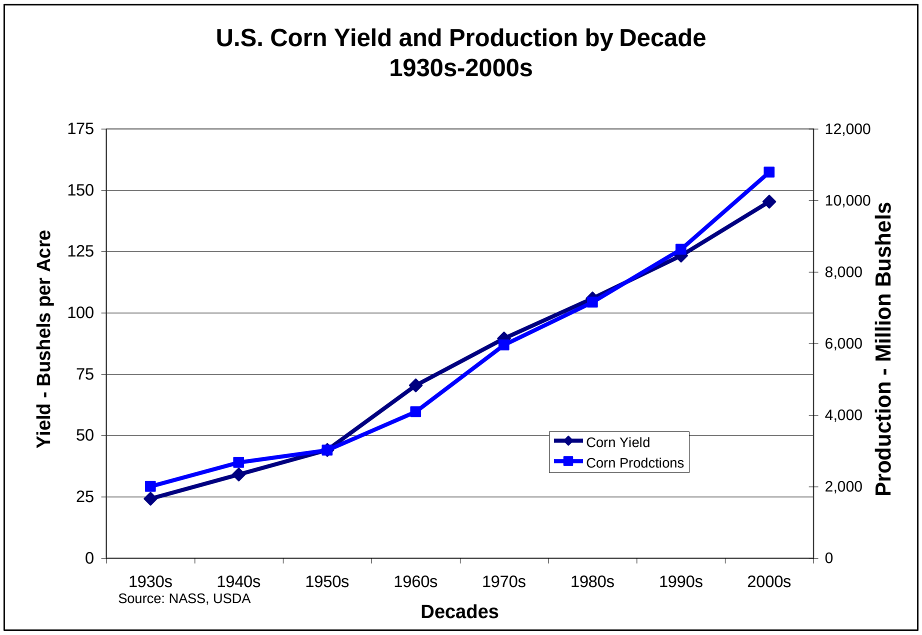
Changes over the last 70 years in harvested acres for the three principal crops in the U.S., corn, wheat and soybeans, are shown in Figure 4. Soybean acres have increased rapidly to challenge corn as the largest crop in acres while wheat acres have been declining after peaking in the 1980s.

Figure 4



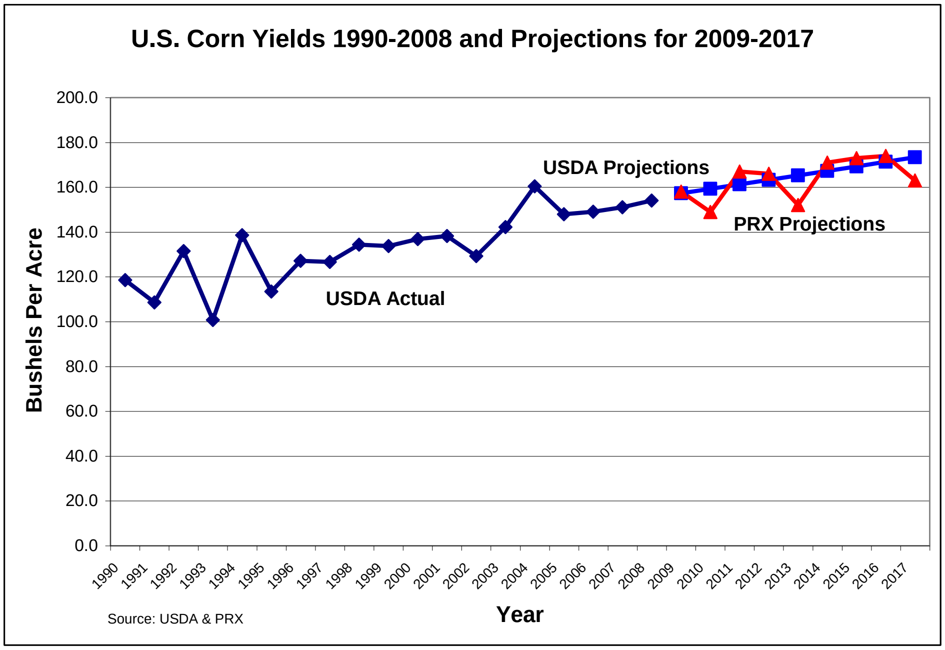
With corn acres relatively fixed, the real story in corn production for the past 70 years has been higher yields per acre. That can be seen in Figure 5 where production tracks closely with yield per acre total.

Figure 5



With corn acres harvested for grain not likely to increase beyond the recent 2007 high, the focus in coming years will be on increasing yields to increase total corn output for food, feed, fuel and other industrial uses. That is consistent with what has happen for the major field crops and corn specifically for the past 70 years. Figure 6 shows two possible scenarios of corn yield increases over the next decade. Major seed corn breeding and technology companies have made public statements that yields will increase more than shown here.

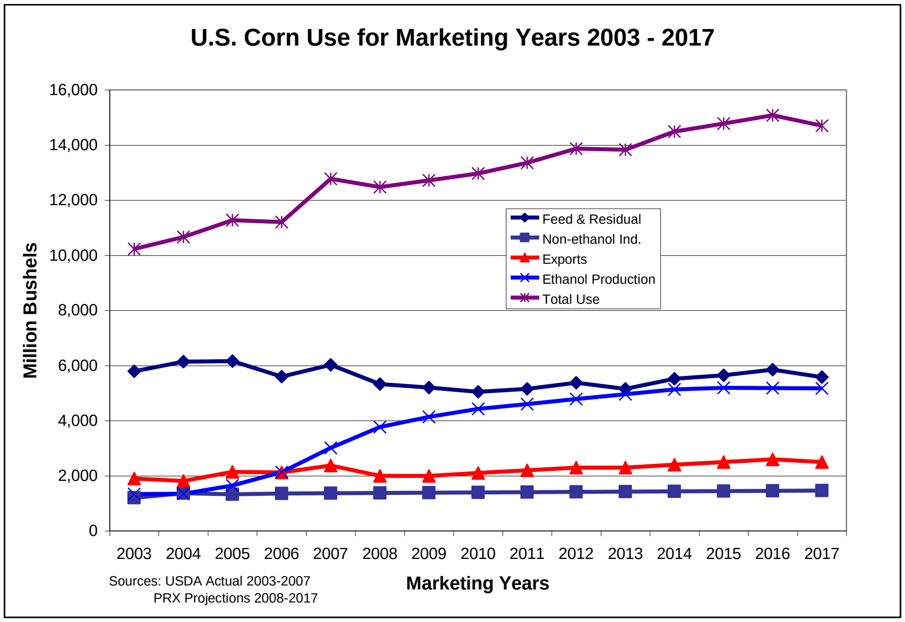
Figure 6



The USDA yield projections are from the 10-year baseline projections released in February of 2008 with yearly yield increases of 2.0 bushels per acre. The PRX (ProExporter Network) projections are from September 2008 and provide some variability of yearly yield increases since they seldom follow a straight line trend, but the trend is still for increasing yields. Virtually all private and public projections of corn yields show increases similar to these. As noted earlier, major corn breeding and technology companies believe yields will increase more rapidly as corn varieties currently in development are released for planting.

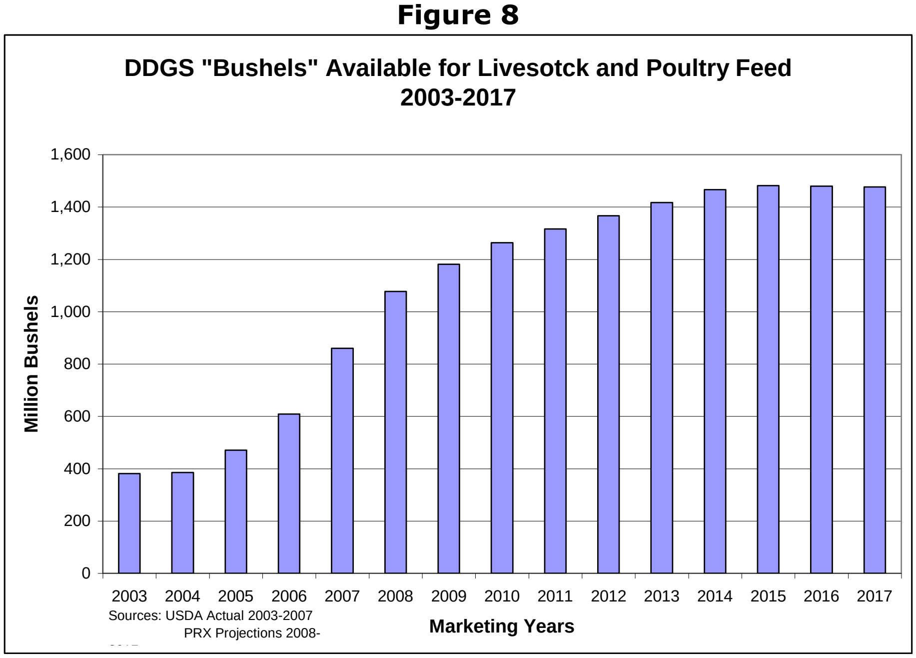
After a decline in corn acreage in 2008, the PRX projections show planted corn acreage increasing to the 2007 level over the next few years. That acreage level and the expected higher yields will produce enough corn to meet expected demand, including the higher Renewable Fuel Standard for corn ethanol. The increased demand for ethanol can be accommodated assuming modest per acre corn yield increases without decreasing other uses. Exports of corn are expected to decline in the short term because of larger supplies in the rest of the world, not because of a lack of supplies in the U.S.

Figure 7



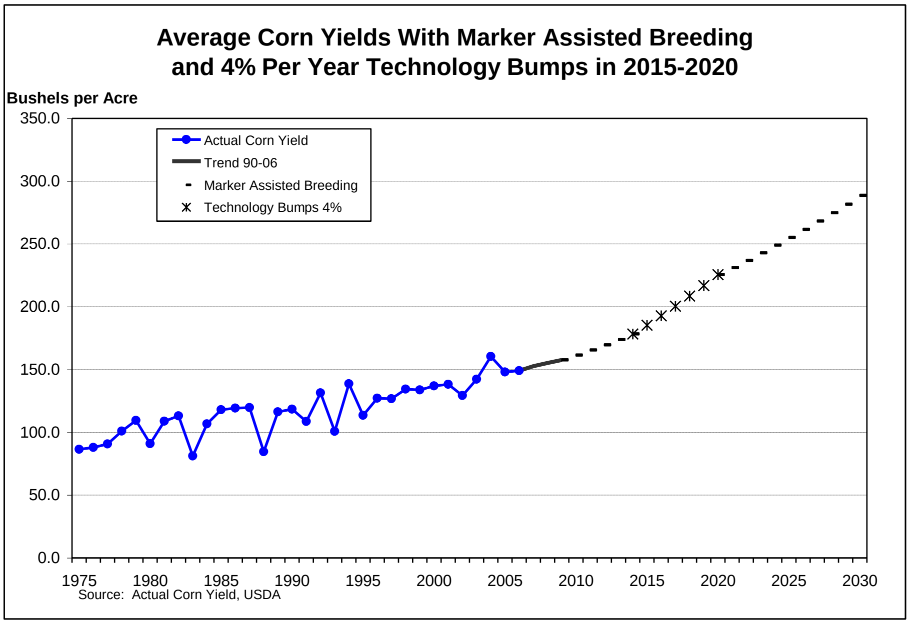
Feed supplies are even larger than shown in Figure 7. Distillers dried grains with soluble (DDGS) is a by-product of dry mill ethanol production. A bushel of corn (56 pounds) used to make ethanol has about 16 pounds of DDGS as a by-product. DDGS now produced are used for livestock and poultry feed, with about 10 percent moving into the export market. Figure 8 shows the bushel equivalents of DDGS that are expected to be produced through marketing year 2017. Market forces will determine whether that DDGS will be used for livestock and poultry feed in the U.S., exported to other markets or broken into component parts for a combination of feed and other uses.

Figure 8



Previous analysis has shown that beginning in 2010 corn yields could increase more rapidly than yields shown in Figure 6. Marker assisted breeding is allowing seed companies to search more rapidly for genes with specific characteristics that increase yields. The use of biotechnology to develop specific new characteristics is also expected to increase yields. Figure 9 shows one possible path for increases in U.S. national average corn yields to the year 2030.

Figure 9



The yield increases for 2010-2030 in Figure 9 show a faster growth trend than 1975-2010, but they are consistent the expectations of the major U.S. seed corn companies. If these yield increases are achieved, production will increase more rapidly than in the baseline projections and more corn will be available for all uses, including corn ethanol.

These higher yields would provide more corn for ethanol production and other uses. As can be seen in Figure 10, by 2017 an additional 2 billion bushels of corn could be available for use. If all that was used to produce ethanol, an additional 5.5 billion gallons of ethanol could be produced.

The story does not end in 2017. Assuming that corn acres do not increase, yield increases as shown in Figure 8 and increases in all the other corn use categories, corn available for ethanol production could increase to almost 11.9 billion bushels by 2030. At 2.75 gallons of ethanol per bushel of corn, the current conversion rate, total corn ethanol production would be 32.7 billion gallons compared to 10.5 billion gallons estimated for the 2008-09 marketing year that began on September 1, 2008.

Figure 10

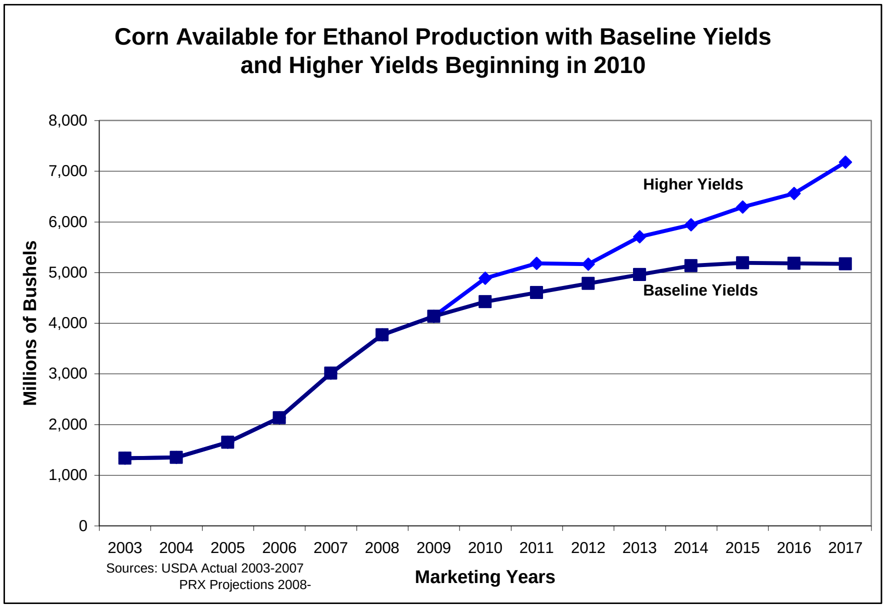
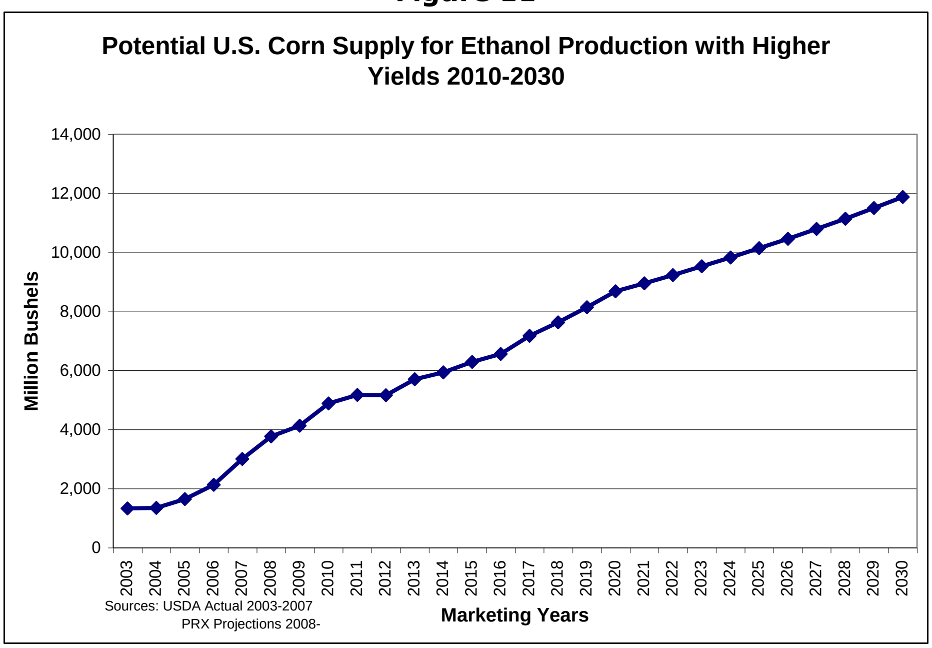


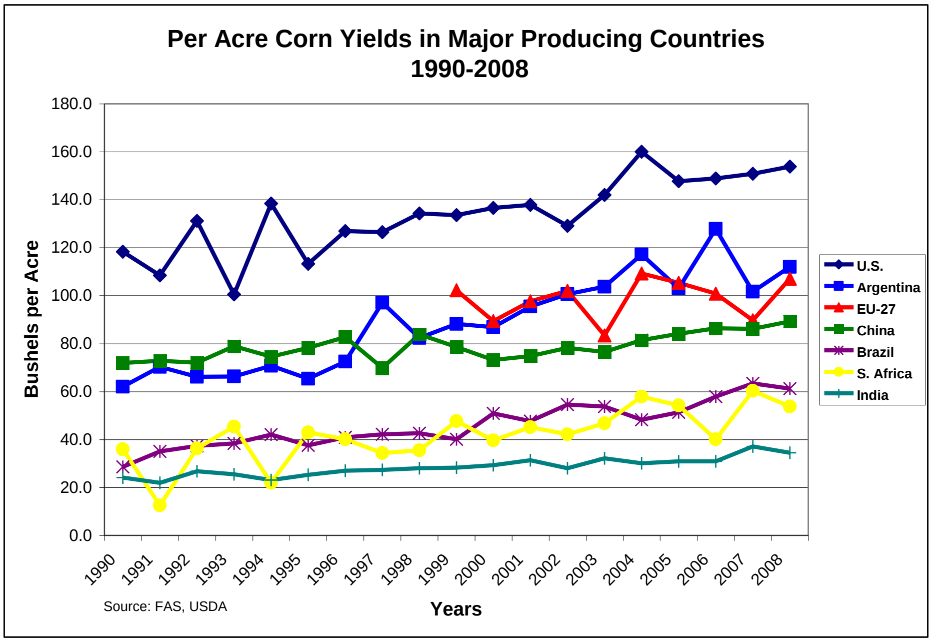
Figure 11



Corn production in the U.S. has a bright future because of higher yields per acre. Traditional domestic and export markets can be met while also increasing the production of ethanol from corn.

The technology for higher corn yields is not unique to the U.S., and the potential for yield increases in other countries is greater than in the U.S. because yields currently are lower.

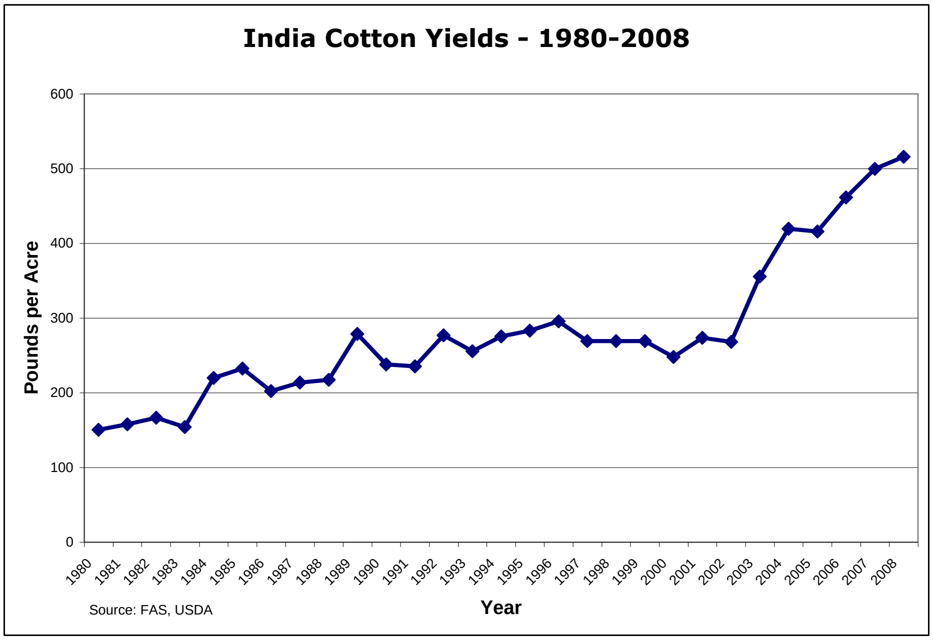
Figure 12

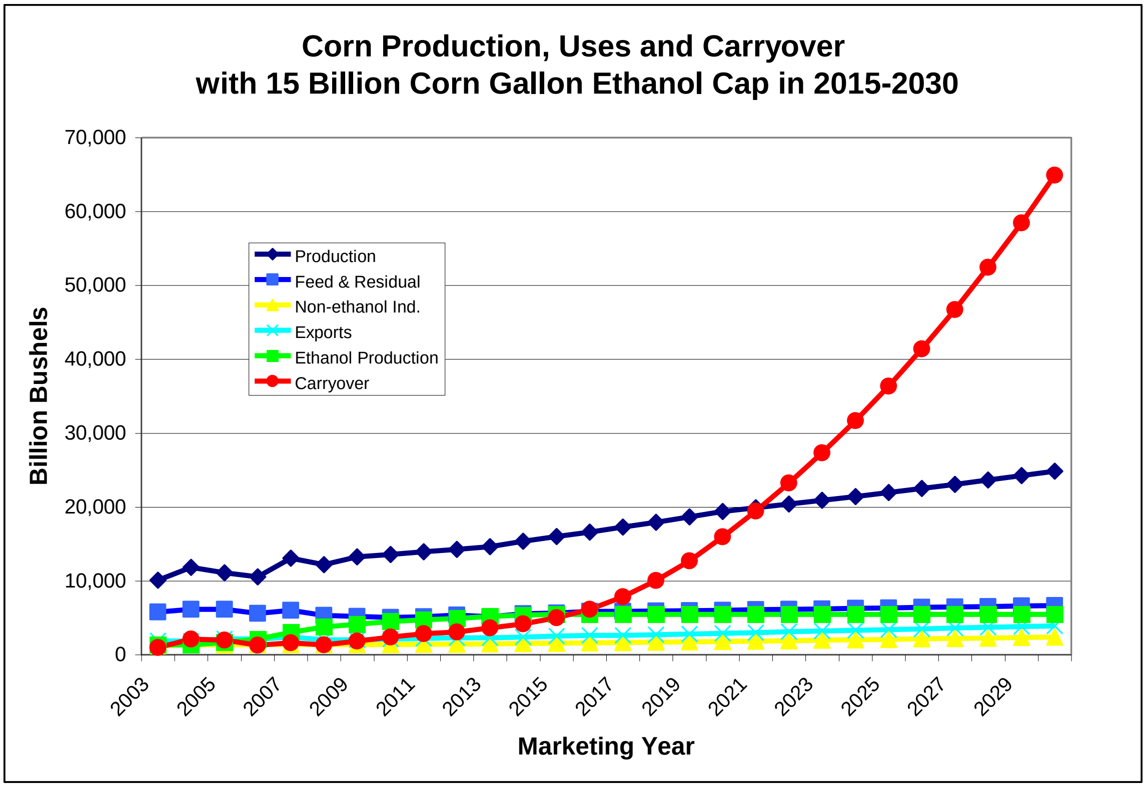


Argentina has some soils similar to the U.S. and has mostly hybrid seeds and herbicide tolerant corn, but does not have the latest insect tolerant seeds because of intellectual property protection issues. The EU-27 has a wide range of agricultural development among its countries, and only Spain has a significant amount of biotech corn. China has the second largest corn acreage after the U.S. and has invested heavily in biotech crops, but has only released biotech cotton. Corn yields have been growing slowly and have been outpaced by Argentina. Brazil will likely never have yields comparable to the U.S. because of soil types, hot summer weather and production of a lower yielding winter crop, but yields have doubled in the last 20 years with still one-fourth of the acreage in non-hybrid open-pollinated corn. Biotech corn will be planted this year. South Africa has a mixture of large and small farms and has had biotech corn for 10 years. India is just entering the hybrid/biotech era for corn.

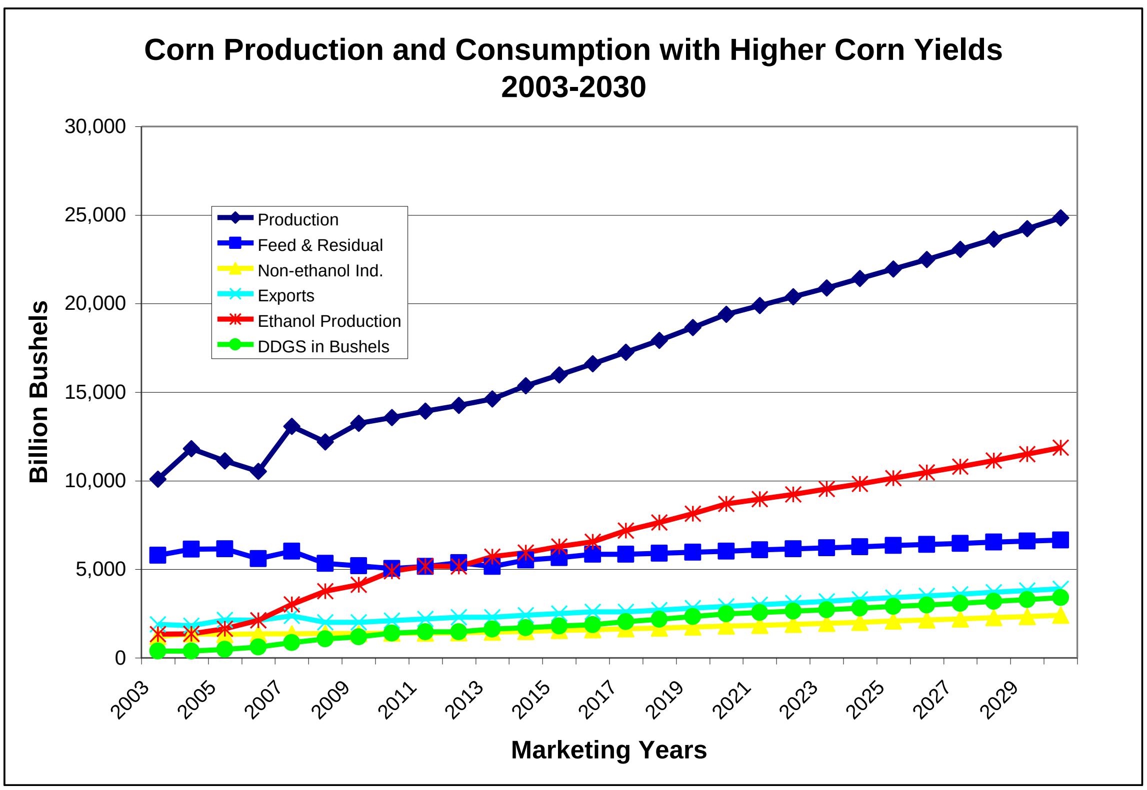
Indian cotton yields are an indication of what could happen with corn yields around the world in the next 10 years. Cotton yields had stagnated in the 1990s, but have been moving sharply higher in this decade as farmers adopted hybrids and biotech varieties. One difference for India compared to much of the rest of the world is that the Indian government heavily subsidizes the use of fertilizer so adequate nutrient supplies are available to maximize the production potential of the new seed.

Figure 13


India Cotton Yields - 1980-2008
Pounds per Acre
0
100
200
300
400
500
600
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Source: FAS, USDA



Corn Production, Uses and Carryover
with 15 Billion Corn Gallon Ethanol Cap in 2015-2030
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Billion Bushels
Production
Feed & Residual
Non-ethanol Ind.
Exports
Ethanol Production
Carryover
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
Marketing Year



Corn Production and Consumption with Higher Corn Yields
2003-2030
30,000
25,000
20,000
15,000
10,000
5,000
0
Billion Bushels
Production
Feed & Residual
Non-ethanol Ind.
Exports
Ethanol Production
DDGS in Bushels
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
Marketing Years