The RFS Reset and Corn Ethanol Production

Prepared for

Growth Energy

By

Stillwater Associates LLC

Irvine, California, USA

July 17, 2018

Stillwater Associates

3 Rainstar Irvine, CA 92614 – Tel (888) 643 0197 – www.stillwaterassociates.com

Disclaimer

Stillwater Associates LLC prepared this report for the sole benefit of Growth Energy. Growth Energy may submit this report to the U.S. Environmental Protection Agency in connection with any proposed rulemaking or other agency action.

Stillwater Associates LLC conducted the analysis and prepared this report using reasonable care and skill in applying methods of analysis consistent with normal industry practice. All results are based on information available at the time of presentation. Changes in factors upon which the report is based could affect the results. Forecasts are inherently uncertain because of events that cannot be foreseen, including the actions of governments, individuals, third parties and competitors. NO IMPLIED WARRANTY OF MERCHANTABILITY SHALL APPLY.

Table of Contents

List of Tables

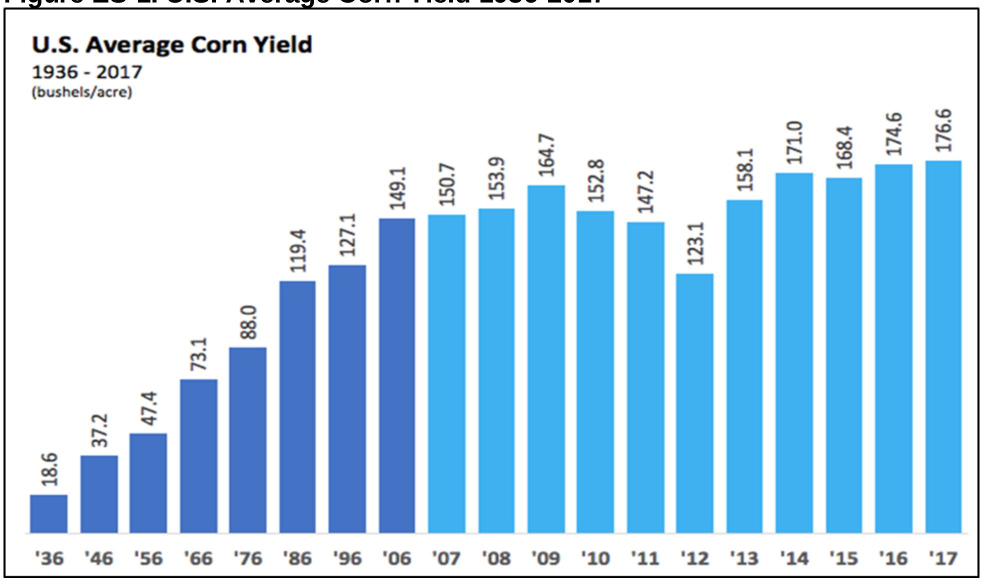
Table of Figures

Executive Summary

This report examines how much additional corn and ethanol could be produced if the historic trends for corn production and ethanol processing continue through 2022. The analysis allows the food and other non-ethanol portions of the corn crop to continue to grow in a manner that would not increase concerns about the availability of corn for the world's food supply.

Stillwater examined historic trends for U.S. farm acres planted in corn and harvested plus the volume of corn produced. While there is variability in the data, over the past 12 years, corn production has increased at an average rate of 2.3 bushels per acre per year. That rate closely aligns with the rate of growth that has been maintained over the previous seven decades, and there continue to be new technologies introduced enabling this rate of growth to continue. Figure ES-1 demonstrates this historic growth in corn yields per acre.

Figure ES-1. U.S. Average Corn Yield 1936-2017[1]



Ethanol production from corn also has maintained a steady rate of increase over the last three to four decades (the period for which data are available), and new developments in ethanol production technology should allow ethanol production efficiency to continue its rate of increase of 0.01gallons of ethanol produced per bushel of corn per year into the future.

[1] National Corn Growers Association. U.S. Average Corn Yield 1937-2017. January 12, 2018. http://www.worldofcorn.com/#us-average-corn-yield

Figure ES-2. Ethanol Refinery Conversion Efficiency[2]

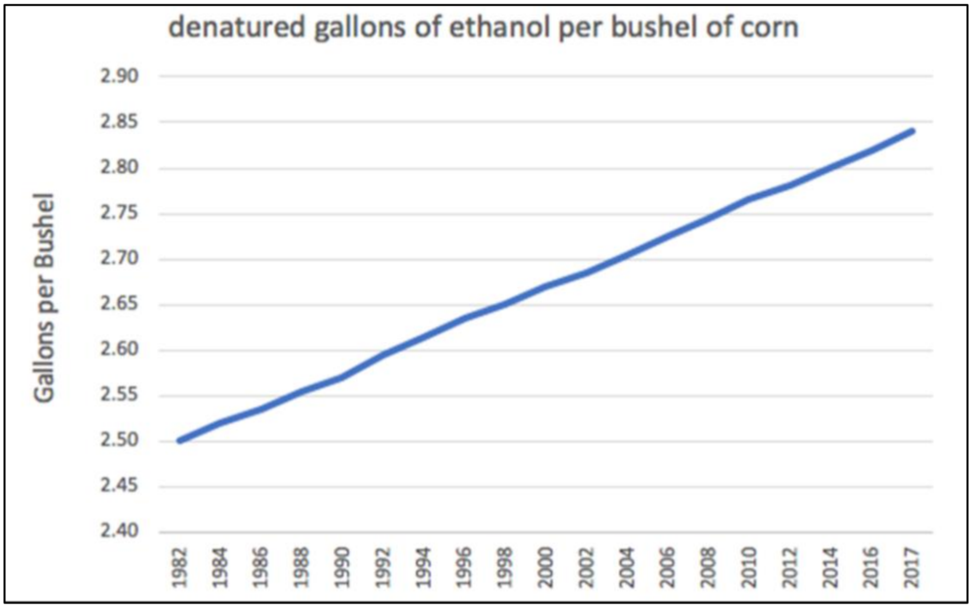


Table ES-1. Projected Ethanol Production 2016-2023

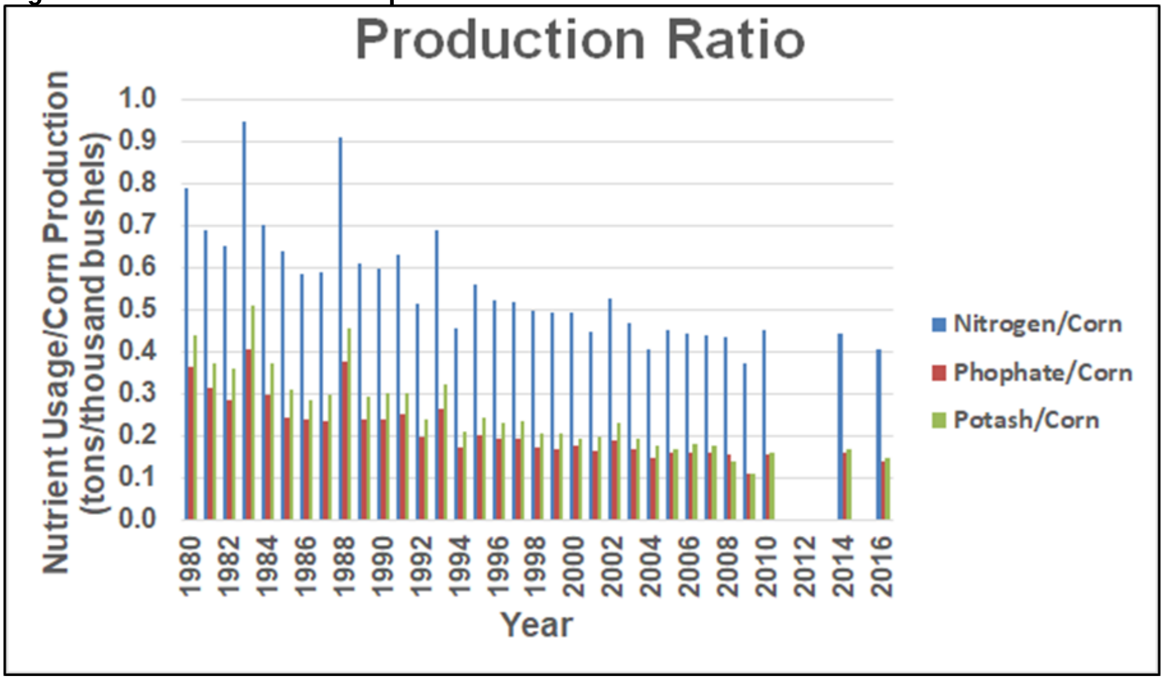
	2016	2017	2018	2019	2020	2021	2022	2023
Corn Acres Harvested (millions)	86.7	82.7	86.7	86.7	86.7	86.7	86.7	86.7
Corn Yield (bushels/acre)	174.6	176.6	179	181.3	183.7	186.0	188.4	190.7
Corn Harvested (billion bushels)	15.2	14.6	15.5	15.7	15.9	16.1	16.3	16.5
Corn Used for Non-Ethanol Purposes (billion bushels)	9.7	9.0	9.6	9.7	9.8	9.9	10.0	10.1
Corn Used for Ethanol Production (billion bushels)	5.5	5.6	5.9	6.0	6.1	6.2	6.3	6.4
Ethanol Plant Efficiency (gallons/bushel)	2.82	2.82	2.85	2.86	2.87	2.88	2.89	2.90
Ethanol Production (billion gallons)	15.4	15.9	16.9	17.2	17.6	18.0	18.3	18.7
Ethanol Production above 2018 (billion gallons)	-	-	-	0.4	0.7	1.1	1.5	1.8

Table ES-1 shows that the 2.3 bushels of corn per acre per year increase corresponds to a growth in corn harvested from 15.5 in 2018 to 16.3 in 2022. Of this roughly 0.8 billion bushels of corn increase, the food and other non-ethanol corn volume was allowed to grow by 0.4 billion bushels from 2018 through 2022, or roughly 1% per year, matching the rate of population growth projected by the U.S. Department of Agriculture (USDA) for the same period. The remaining corn produced, about 0.4 billion bushels, can be directed to new ethanol production of around 1.5 billion gallons.

Since this 1.5 billion gallons per year (bgy) of new ethanol can be produced with no new acreage required and with the volume of corn available for food and other non-ethanol purposes allowed to grow to match the population growth, any concerns about indirect land use and the sufficiency of corn available for world food resulting from such an increase in ethanol production should be negligible.

[2] United States Department of Agriculture. Economic Research Service. U.S. Bioenergy Statistics. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/

Figure ES-3. Corn Nutrient Requirements Per Bushel



This report also examines the nutrients required to produce 0.8 billion bushels of new corn and finds that the total nutrient requirements are relatively unchanged, and on a per-bushel basis – as depicted in Figure ES-3 – the nutrient requirements are dropping.

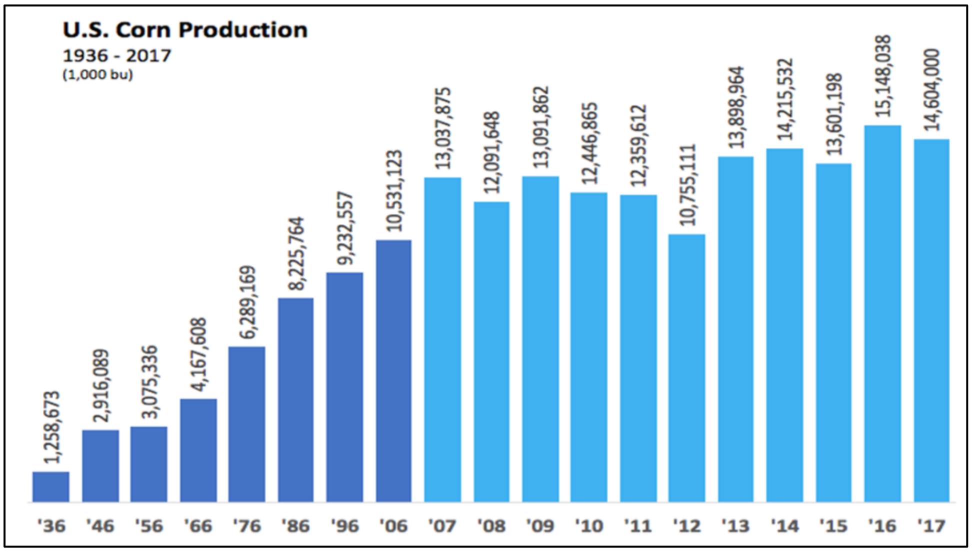
1 The Ethanol Industry's Production Capabilities

This report provides insights into the capability of U.S. agriculturalists to produce additional ethanol for transportation fuel in the future. This analysis is conducted keeping corn acres harvested constant for future years at 86.5 million acres – the acreage harvested in 2007. For the purposes of this analysis, non-ethanol corn usage has been allowed to increase each year at the same rate as the world population is projected to grow. These two steps should minimize environmental and food concerns.

1.1 The History of U.S. Ethanol Production

The RFS has provided a significant incentive for increased U.S. ethanol production, increased production of corn, and the increased allocation of farmland to corn production. Looking back 50 to 80 years, however, there was a steady increase in U.S. corn production on a relatively steady number of farm acres dedicated to corn. Figure 1 shows 80 years of corn production, ending with 14.6 billion bushels of corn in 2017. Figure 2 shows 80 years of the farm acres planted in corn, while Figure 3 shows the actual acres of corn harvested in the same time period.

Figure 1. U.S. Corn Production 1936-2017[3]



The increased corn production shown in Figure 1 has come from relatively the same number of planted acres, as shown in Figure 2. Meanwhile, the number of acres planted in corn in 2017 is actually lower than the number in 2007 and significantly lower than the number in 1936. Figure 3 shows the corn acreage harvested. The ratio of acres harvested to acres planted has increased over this time. This represents one element in the overall increases in corn productivity.

[3] National Corn Growers Association. U.S. Corn Production 1936-2017. January 12, 2018. http://www.worldofcorn.com/#us-corn-production

Figure 2. U.S. Corn Acres Planted 1936-2017[4]

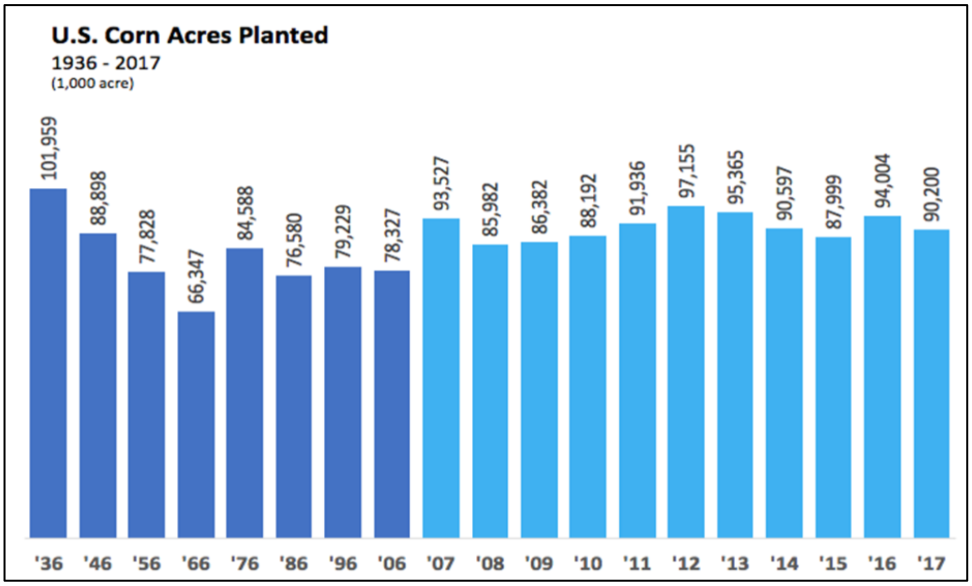
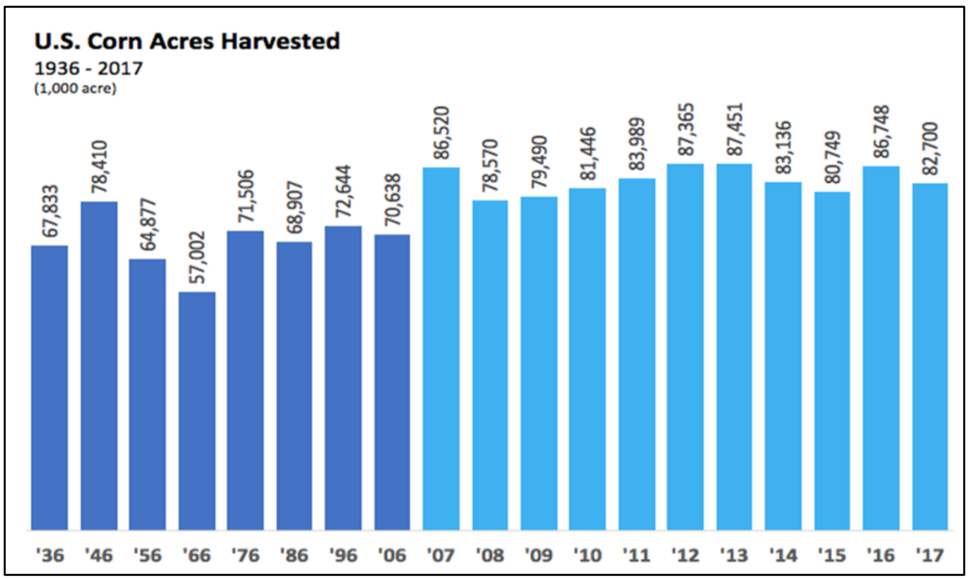


Figure 3. U.S. Corn Acres Harvested 1936-2017[5]



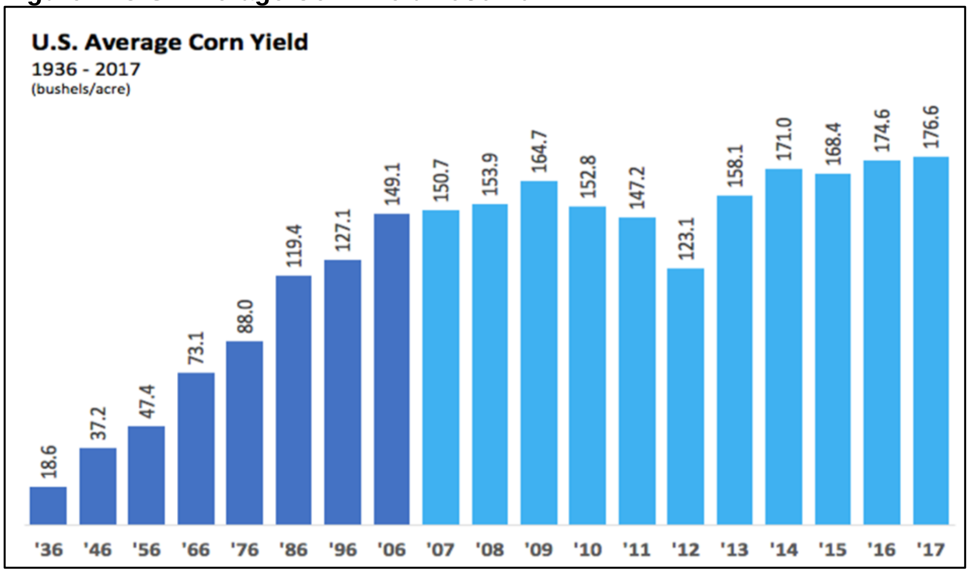
In looking at Figures 2 and 3 from 2007 forward (the beginning of the RFS) a nearly level pattern of acres planted and acres harvested is apparent. While there is some variability in the data, it would be difficult to characterize the light blue bars as representing an increasing or decreasing farm land use for corn over this period. Yet EPA, in their June 29, 2018 Biofuels 204 Report to Congress, found that: "It is likely that the Section 204 impacts associated with land use change are, at least in part, due to increased biofuel production and use associated with the RFS." Our analysis finds that while corn yields and production have increased as shown in Figures 1 and 4, land use for corn crops has remained relatively stable from 2007 to 2017.

[4] National Corn Growers Association. U.S. Corn Acres Planted 1937-2017. January 12, 2018. http://www.worldofcorn.com/#us-corn-acres-planted

[5] National Corn Growers Association. U.S. Corn Acres Harvested 1937-2017. January 12, 2018. http://www.worldofcorn.com/#us-corn-acres-harvested

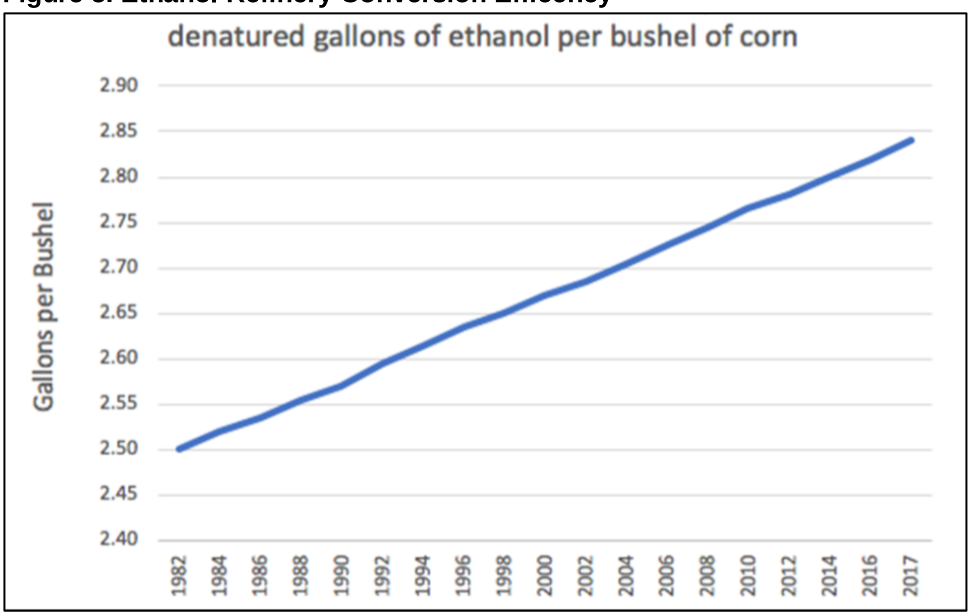
One of the largest keys to increased corn production is the increase in corn yield per acre, which is shown in Figure 4 and Table 1. The overall rate of increase is mainly steady over the past 80 years, with a slightly higher rate of increase in the past ten years on average. These improvements are due to new higher-yield varieties of corn with improved drought- and pest-resistance. The 176.6 bushels of corn produced per acre of farm land in 2017 represents an all-time high for the U.S.

Figure 4. U.S. Average Corn Yield 1936-2017[6]



While the number of bushels of corn produced per acre in the U.S. has steadily increased, the productivity of ethanol refineries in turning corn to ethanol has also improved to the point at which 2.82 and 2.84 gallons of undenatured ethanol were produced per bushel of corn in 2016 and 2017 respectively. This increased productivity is shown in Figure 5.

Figure 5. Ethanol Refinery Conversion Efficency[7]



[6] National Corn Growers Association. U.S. Average Corn Yield 1937-2016. January 12, 2018. http://www.worldofcorn.com/#us-average-corn-yield

[7] United States Department of Agriculture. Economic Research Service. U.S. Bioenergy Statistics. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/

1.2 Modeling Future Ethanol Production

Three main factors must be included in any model of future ethanol production: acreage harvested, rate of increase in corn yields per acre, and rate of increase in ethanol refinery productivity. While it is possible to represent the two rates by higher-order regression equations, a conservative approach – which simply represents these variables as straight lines with constant slopes – is typically the best way to project these variables into the future. Quadratic and higher-order equations tend to become infeasible when used to depict values outside of the original data set or when extended for 20 years or more.

1.2.1 Corn Acreage Harvested

For the initial phase of this analysis, we assumed that for the future years modeled, the harvested corn acreage would remain constant at 86.5 million acres – the acreage that was harvested in 2007.

1.2.2 Increased Corn Yields

For the past 12 years, corn yields have improved at an average of 2.3 bushels per acre per year. This increase is shown in Table 1 and is used in our model. While there is some variability in the year-to-year corn production data, the overall trend in corn yield has increased. Of course, there is no guarantee that this rate of increase will continue; it is possible that yields could plateau at 2017 levels, though we have no particular basis to believe that will happen. On the contrary, about 33% of the total corn production in 2017 came from Illinois and Iowa where statewide yields were above 200 bushels per acre. This bodes well for maintaining the rate of increases used in this analysis. New developments, such as precision agriculture,[8] GPS planting, improved seeds, and planting narrower rows should enable these rates of increase in corn yields to continue.

Table 1. Corn Yield Increases

For the past:	Average Increases per Year (bushels per year per acre)
12 years	2.3
22 years	2.3
32 years	1.
82 years	1.9

1.2.3 Increased Ethanol Refinery Productivity

Figure 5 shows increasing ethanol plant efficiency from 2.5 gallons of ethanol for every bushel of corn feedstock in 1982 to 2.84 gallons of ethanol per bushel of corn in 2017. This represents a relatively constant increase of 0.01 gallons of ethanol per bushel of corn over this 35-year period. We use this value in our analysis.

While some parties may question whether the increases in ethanol refinery productivity can continue into the future, the historic data tracks well. Future increases based on the implementation of technology improvements in ethanol plants – corn kernel fiber to ethanol, fiber separation to ethanol, improved selective milling processes – will contribute to improve productivity. There are already many refineries achieving higher than 2.84-gallons-per-bushel productivity currently, and most ethanol refineries should be able to achieve similar future gains. Some new refinery designs are projecting 3.1 gallons per bushel.[9]

[8] Schimmelpfennig, D., and R. Ebel. On the Doorstep of the Information Age: Recent Adoption of Precision Agriculture. U.S. Department of Agriculture, Economic Research Service. 2011.
[9] Scharping, Jeff. ICM, Inc. and The Andersons, Inc. Revolutionize the Ethanol Industry with ELEMENT. ICM, Inc. March 6, 2018. http://www.icminc.com/icm-media/whats-new-at-icm/23-press-releases/271-icm-inc-and-the-andersons-inc-revolutionize-the-ethanol-industry-with-element1.html

1.2.4 Ethanol Production Modeling Results

Future ethanol production rates can be projected when all of the variables mentioned above are modeled together. In 2017, 38% of all corn produced – 5.6 billion bushels out of the total corn production of 14.6 billion bushels – was used for ethanol production. For 2019 and beyond, the model allows non-ethanol corn production to grow by 1% per year, matching the growth rate of the world's population projected by the U.S. Department of Agriculture[10] for the same period. This growth in non-ethanol corn use should allow the U.S. corn contribution to world food and other non-ethanol uses to continue to meet the demands in these areas. Given these assumptions, new ethanol above the 2018 levels is projected to increase by 1.5 billion gallons per year (bgy) – from 16.9 to 18.3 bgy – in 2022.

Table 2. Projected Ethanol Production 2016-2023

	2016	2017	2018	2019	2020	2021	2022	2023
Corn Acres Harvested (millions)	86.7	82.7	86.7	86.7	86.7	86.7	86.7	86.7
Corn Yield (bushels/acre)	174.6	176.6	179.0	181.3	183.7	186.0	188.4	190.7
Corn Harvested (billion bushels)	15.2	14.6	15.5	15.7	15.9	16.1	16.3	16.5
Corn Used for Non-Ethanol Purposes (billion bushels)	9.7	9.0	9.6	9.7	9.8	9.9	10.0	10.1
Corn Used for Ethanol Production (billion bushels)	5.5	5.6	5.9	6.0	6.1	6.2	6.3	6.4
Ethanol Plant Efficiency (gallons/bushel)	2.82	2.82	2.85	2.86	2.87	2.88	2.89	2.90
Ethanol Production (billion gallons)	15.4	15.9	16.9	17.2	17.6	18.0	18.3	18.6
Ethanol Production above 2018 (billion gallons)	-	-	-	0.4	0.7	1.1	1.5	1.8

2 Environmental Impacts

There are several environmental concerns involved with the continued increasing growth of corn and production of ethanol. These concerns principally include greenhouse gas (GHG) lifecycle emissions, water usage, over-usage of agricultural land, runoff and drainage issues, and increased nitrogen oxides (NOx) emissions. However, many of these concerns assume that additional acreage is required to grow more corn and produce more ethanol. As this analysis demonstrates, a considerable increase in corn and ethanol production can occur over time without the need to plant more acreage in corn.

From 15.4 bgy of ethanol in 2016 to 18.3 bgy in 2022 is about a 19% increase in ethanol production, while total corn production increases from 15.2 to 16.5 billion bushels – or almost a 9% increase – in a seven-year period with no additional acres of farmland being used. With no additional U.S. farmland required, there is no additional indirect land use to consider as part of the GHG lifecycle emissions. Indirect land use concerns are predicated on the assumption that more land will be required to grow more of a particular crop. If more of a crop can be grown over the years with no need for increased farm land, then the indirect land use impacts should be minimal or non-existent. If the GHG benefits of growing corn remain constant on a per corn bushel basis, there would be a 9% improvement in the GHG reduction benefits per acre of corn grown. The growth of 9% more corn per acre enables the production of 1.5 bgy of ethanol and the benefits of this versus the petroleum-based gasoline which it could replace.

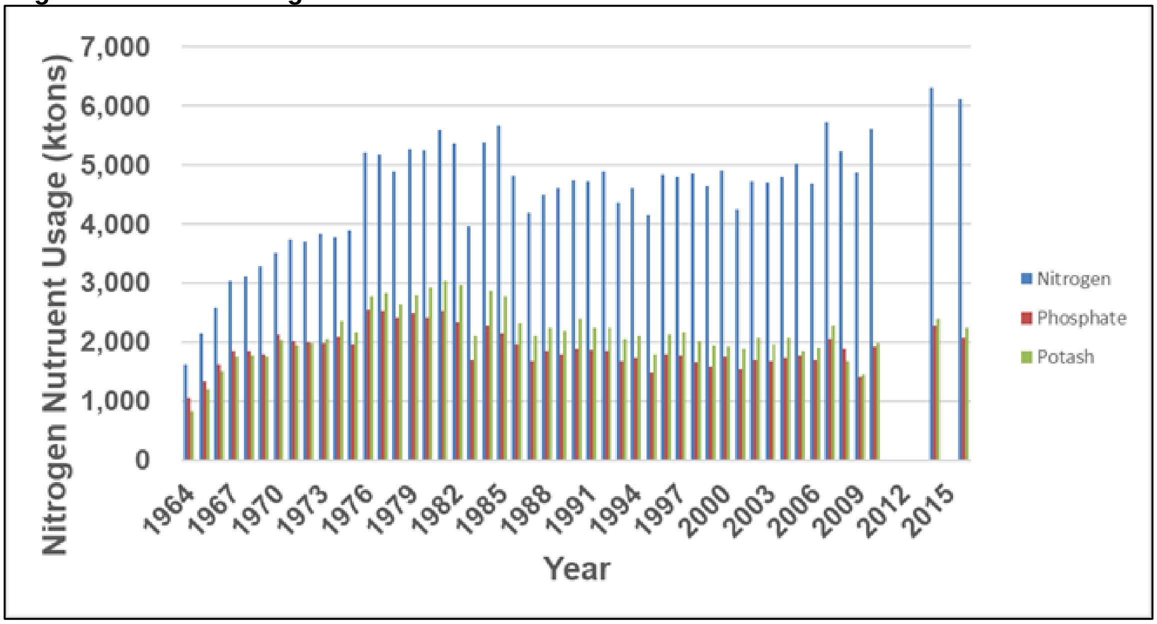
Likewise, concerns about increased runoff, drainage issues, and overuse of agricultural land are eliminated as all of these are based on the use of new acreage, which would not occur in this scenario. In addition to the removal of indirect land use concerns, recent improvements in farming technology and techniques promise a reduction in future NOx emissions and the use of nutrients in the growth of corn. NOx emissions can be decreased by 20-60%[11,12] through the application of NOx inhibitors. Fertilizer use can be reduced through the use of precision agriculture, variable-rate application, and GPS- and sensor-based mapping[13] which restrict the addition of fertilizer to the area immediately around the plant. Seed improvements have produced plants with improved

[10] ICF. A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol. January 12, 2017. https://www.usda.gov/oce/climate_change/mitigation_technologies/USDAEthanolReport_20170107.pdf
[11] Halvorson, A.D., 2014. Nitrogen Fertilizer Source and Management Effects on Nitrous Oxide Emissions. 16th World Fertilizer Congress of CIEC, Rio de Janeiro, Brazil, 20-24 October 2014, p. 68-71.
[12] Thapa et al., 2015. Stabilized Nitrogen Fertilizers and Application Rate Influence Nitrogen Losses under Rainfed Spring Wheat. Agronomy Journal, 107(5): 1885-1894.
[13] The Fertilizer Institute. Fertilizer Use. 2016. https://www.tfi.org/statistics/fertilizer-use

efficiency at utilizing available nitrogen, thus lowering fertilizer application requirements. These techniques offer the ability to reduce NOx and fertilizer requirements per acre even while bushels per acre increase. While these developments will not eliminate environmental concerns, they should prevent these problems from becoming any worse and may help to reduce the size of these problems in the future.

Another environmental challenge with U.S. corn production has been eutrophication – oxygen depletion in water bodies caused by excessive algae growth absorbing the oxygen content in water which can lead to the death of aquatic life. This excessive algae growth is stimulated by high levels of phosphates and nitrates from water from agricultural runoff. While corn yields and corn production continue to increase, more efficient methods of nutrient application have either flattened or reduced nutrient growth in corn production as shown in the figure below. While more progress needs to be made on nutrient efficiency and runoff, it appears the problem is not getting worse with higher levels of corn production. Figure 6 shows nutrient usage in corn production as relatively constant over time with a slight uptick in recent years. When the data is examined on a per-bushel basis, as in Figure 7, however, it can be seen that nutrient requirements are trending down on a per-bushel basis.

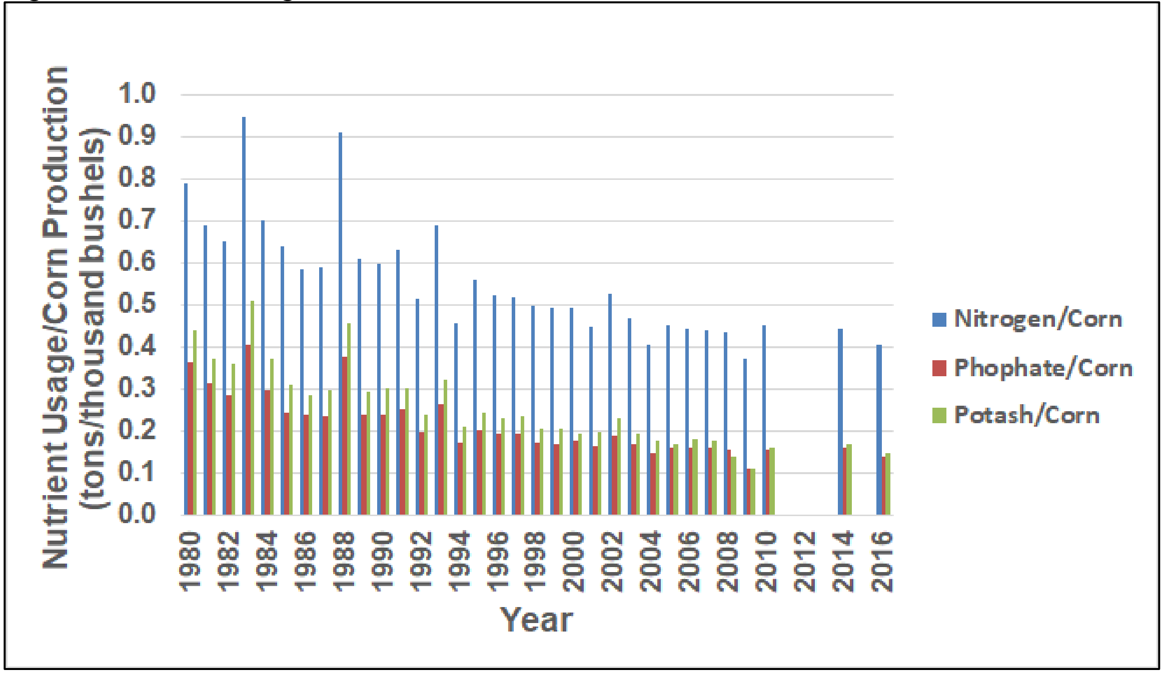
Figure 6. Nutrient Usage in U.S. Corn Production



Source: USDA

Projecting out over the next 5 years, continued improvements in farming techniques such as precision farming, variable-rate application, and GPS- and sensor-based mapping will lead to reductions in fertilizer usage while there is continued growth in corn yields per acre. The net results will be relatively level amounts of nitrogen and phosphates on a per-acre basis but a decrease in these nutrients on a per-bushel basis. In addition to growing more corn per acre, the productivity of ethanol refineries will also increase in terms of ethanol produced per bushel of corn. Both of these types of improvements will take place on a farm-by-farm and plant-by-plant basis to continue the historic trend of increases that has taken place for the past 50-80 years in the production of corn and ethanol.

Figure 7. Nutrient Usage in Corn Production on a Per-Bushel Basis



3 Conclusions

The farm land acreage devoted to corn production for the past 11 years since the beginning of the RFS (2007-2017) has been constant while corn yields have increased 12% from 13.0 to 14.6 billion bushels per year and conversion efficiencies at biorefineries have increased. Specifically, the 2017 USDA study documents that corn planted acreage has remained fairly constant (varying between ~86 and 97 million acres) between 2007 and 2017, while average crop yield, as measured in bushels/acre, has trended upward from 150.7 to 176.6. The study anticipates that corn crop yields will continue to increase through 2022. Additionally, the USDA analysis found that ethanol conversion (the amount of ethanol produced from a bushel of corn) has increased from 2.73 gallons/bushel to 2.84 gallons/bushel over 2007-2017 timeframe.

This analysis has examined the continuation of these trends and found that from 2018 to 2022 an additional 0.8 billion bushels of corn can be produced on the same number of acres that was used in 2007. Of these 0.8 billion bushels, the corn available for food and other non-ethanol purposes will be able to grow at the same rate as the world's population is projected to grow over this period. The remaining 0.4 billion bushels of new corn not used for food and other non-ethanol purposes can produce 1.5 bgy of new ethanol.

Since this 1.5 bgy of new ethanol can be produced with no new farm land needed and while continuing to grow sufficient corn for food and other non-ethanol needs, there should be minimal concerns about additional indirect land use or new corn for food needs. It also appears that the nutrients needed for this new corn are fewer on a per-bushel basis than the nutrients required prior to 2000.