The RFS Reset: A Look at Corn Land Use and Conventional Ethanol Production

Prepared for

Growth Energy

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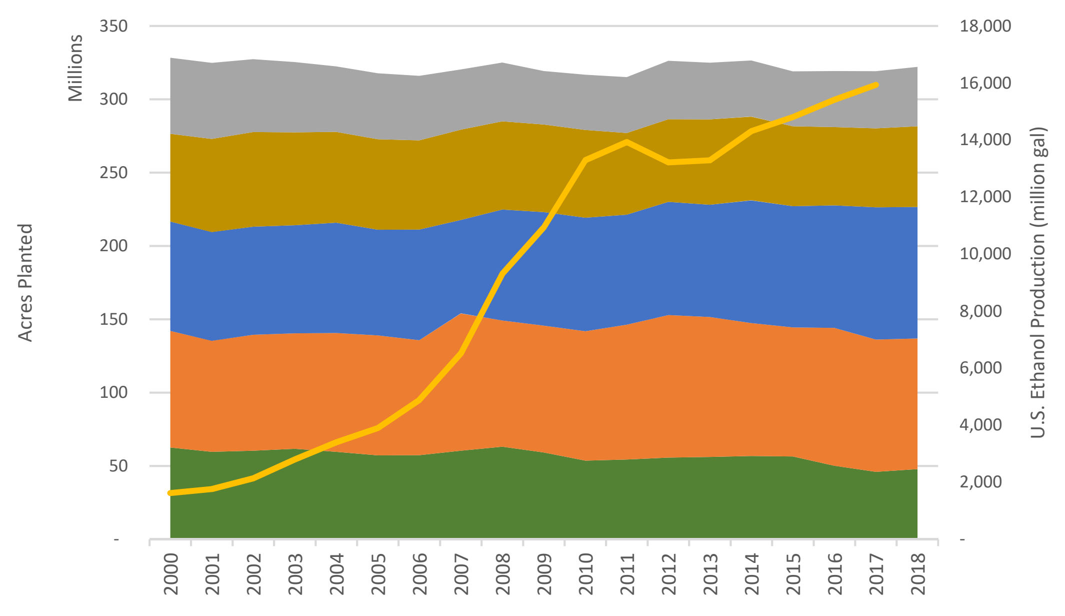
Executive Summary

This report examines U.S. agricultural land use and crop production. It also examines how much additional corn and conventional ethanol could be produced if the historic trends for corn production and ethanol processing continue through 2022. This report uses the term “ethanol” to refer to conventional ethanol. 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.

In many sources, including its Second Triennial Report to Congress, the U.S. Environmental Protection Agency (EPA) claims that biofuel growth driven by the renewable fuel standard (RFS) has resulted in increased U.S. agricultural land use. However, that is not the whole story. As can be seen in Figure ES-1, since about 2010 the crop acreage devoted to corn production has remained relatively constant while ethanol production has substantially increased. The land use increase determined by EPA appears to be dependent on the beginning and end points selected for the analysis. In addition, EPA’s Second Triennial Report looks at total biofuel land use, which combines both corn and soy. There is general agreement that soy land use has increased during the period since the RFS was implemented, but that does not mean that corn land use has also increased. Finally, EPA was unable to identify the corn land use increase specifically caused by the production of conventional ethanol under the RFS. EPA points out these errors and its inability to prove its contention in various parts of the report which are not highlighted or mentioned in its key findings. In fact, the conclusions that EPA reaches in the report are not fully supported by EPA’s own analysis or independent study of the data.

Figure ES-1. U.S. Crop Acreage and Ethanol Production

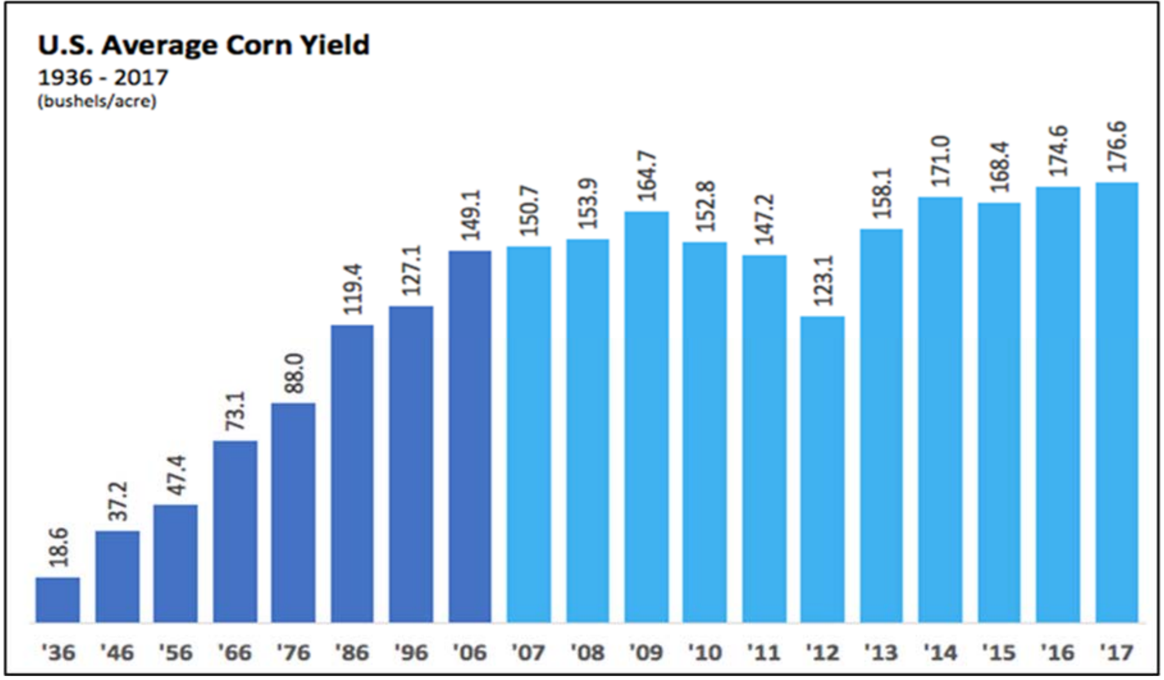


sources: *USDA, EIA*

In its Second Triennial Report, EPA fails to recognize that U.S. farmers choose the allocation of their crop acres to different crops based on a wide variety of market drivers including weather, world crop supply balances, U.S. and world inventories, and imports and exports worldwide. The RFS has a slight influence on some of these variables, but it is not the large driver that EPA seems to imply. Since the U.S. is currently exporting corn and soy beans plus ethanol and distiller's dried grains with solubles (DDGS) in amounts at or above pre-RFS levels, and imports of ethanol and biomass-based diesel (BBD) are currently minimal, there can be no indirect land use impacts from other countries for corn ethanol or BBD. Therefore, EPA's claim of increased indirect land use impacts from other countries is unsupported.

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 maintained over the previous seven decades, and there continue to be new technologies introduced enabling this rate of growth to continue. Figure ES-2 demonstrates this historic growth in corn yields per acre.

Figure ES-2. U.S. Average Corn Yield 1936-2017[1]



As shown in Figure ES-3, conventional ethanol production from corn has maintained a steady rate of increase over the last three to four decades (the period for which data are available). New developments in conventional ethanol production technology should allow conventional ethanol production efficiency to continue its historic rate of increase of 0.01 gallons of ethanol produced per bushel of corn per year into the future.

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[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-3. Conventional Ethanol Refinery Conversion Efficiency[2]

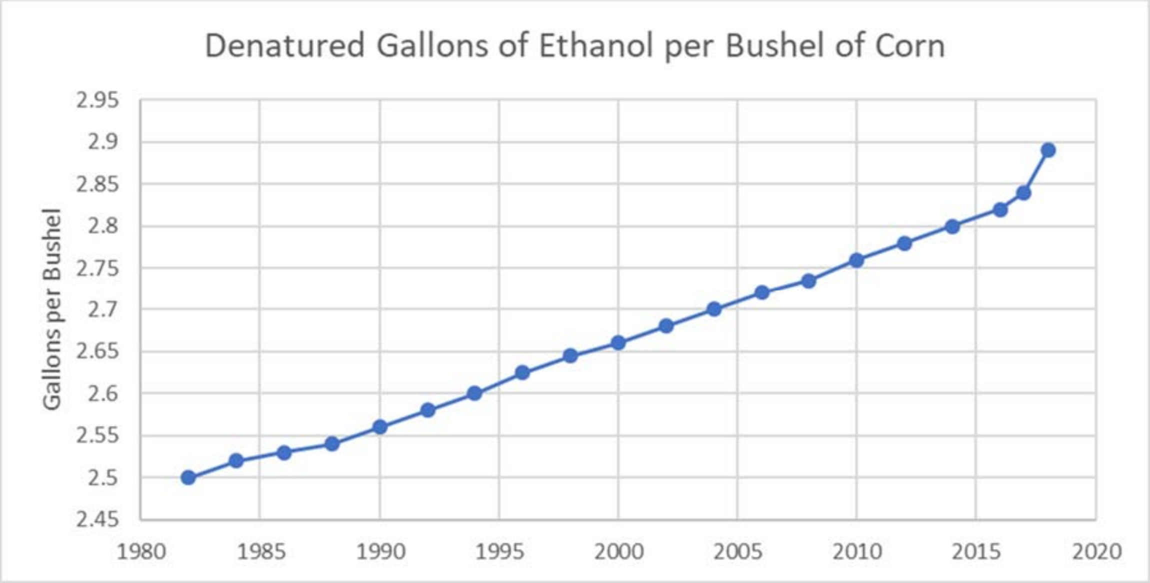

Table ES-1 shows that the 2.3 bushels of corn per acre per year increase corresponds to a growth in corn harvested from 14.4 billion bushels in 2018 to 16.1 billion bushels in 2022. If the food and other non-ethanol corn volume is allowed to grow at the rate of population growth projected by the U.S. Department of Agriculture (USDA) for the same period – 1% per year – about 0.3 of these additional 1.7 billion bushels of corn would be devoted to food and other non-ethanol corn uses. The remaining additional corn produced – about 1.2 billion bushels – can be directed to new ethanol production of around 4.0 billion gallons in 2022.

Table ES-1. Projected Conventional Ethanol Production 2018-2022*

	2016	2017	2018	2019	2020	2021	2022
Corn Acres Planted, million acres	94.2	89.9	89.1	94.0	94.0	94.0	94.0
Planted to Harvested Ratio	92%	92%	92%	92%	92%	92%	92%
Corn Acres Harvested, million acres	86.7	82.7	81.7	86.5	86.5	86.5	86.5
Corn Yield, bushels per acre	174.6	176.6	176.4	178.7	181.0	183.3	185.6
Corn harvested, billion bushels	15.1	14.6	14.4	15.5	15.7	15.9	16.1
Corn used for non-Ethanol Purposes	9.7	9.0	8.9	9.0	9.0	9.1	9.2
Corn Used for Ethanol Production, Billion Bushels	5.5	5.6	5.6	6.5	6.6	6.7	6.8
Ethanol Plant Efficiency, gallons per bushel	2.82	2.84	2.89	2.90	2.91	2.92	2.93
Ethanol Production, billion gallons	15.4	15.8	16.1	18.8	19.2	19.6	20.0
Ethanol Production above 2018, billion gallons				2.8	3.2	3.6	4.0

* The values for years 2016 and 2017 are actual values not projected values.

Since these additional gallons of ethanol could 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. This analysis also shows ethanol production could increase by about 0.4 bgy or 1.1 billion gallons (bg) every 3 years *without* increasing the number of corn acres planted and harvested.

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; while corn and ethanol production is increasing. In fact, on a per-bushel basis the nutrient requirements are dropping as depicted in Figure ES-4.

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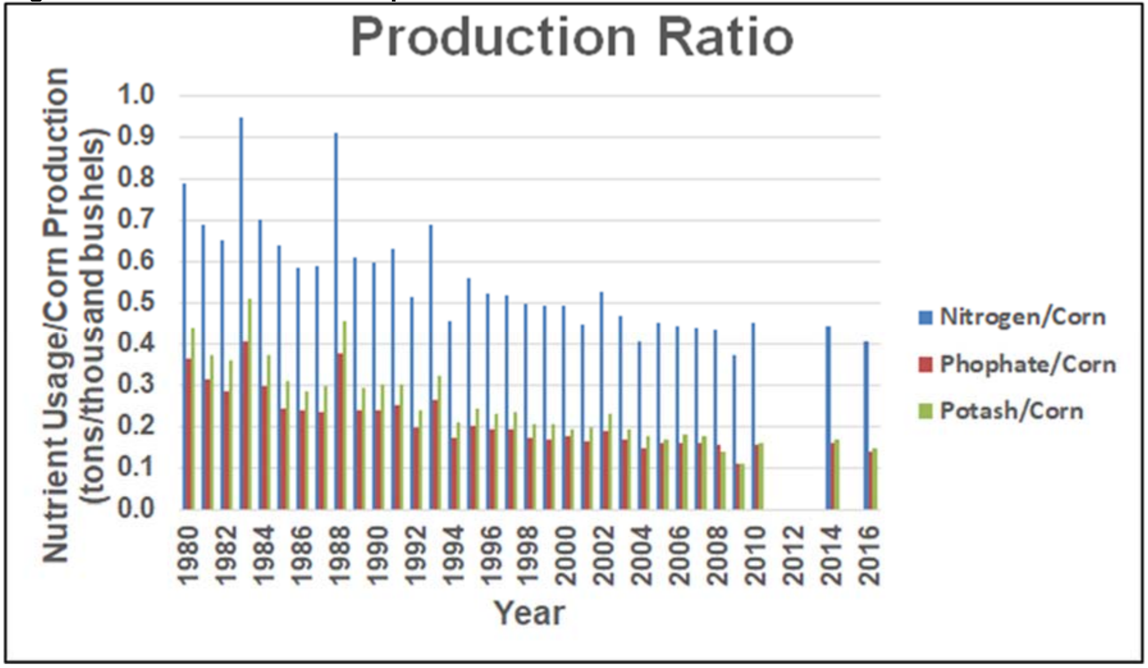
[2] United States Department of Agriculture. Economic Research Service. U.S. Bioenergy Statistics. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/

Figure ES-4. Corn Nutrient Requirements Per Bushel



This report is made up of two sections. The first section deals with the use of U.S. agricultural land for corn and conventional ethanol production. In this section we seek to demonstrate that even though crop acreage increased for soy beans and perhaps very slightly for corn during the time period of the RFS, there were many other factors at play in addition to the RFS. Also, these additional acres came from land previously used for other crops and not from the creation of new farm land. This section is also devoted to issues discussed in EPA’s Second Triennial Report. The second section of this report demonstrates that with continual improvements being made in growing corn and in conventional ethanol production, it is feasible to produce some limited additional volumes of corn and conventional ethanol without an associated increase in the crop acreage used by corn.

1 Review of U.S. Agricultural Land Use History Before and After the RFS

1.1 Overview

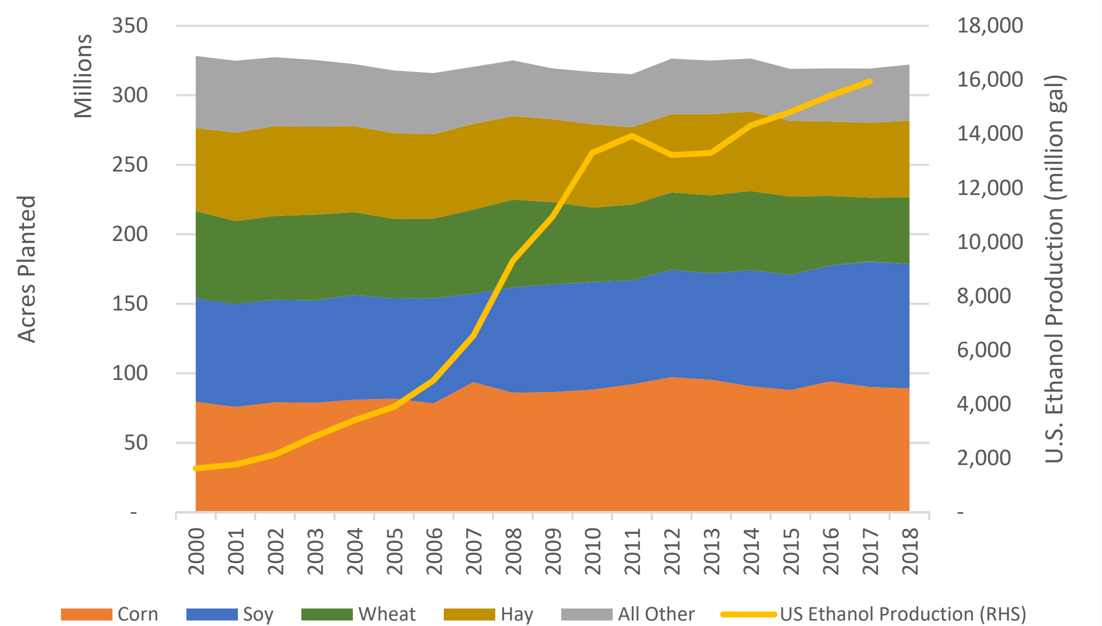
The use of land for agriculture in the U.S. and the disposition of the crops produced is monitored annually by the United States Department of Agriculture (USDA) through the National Agricultural Statistical Services (NASS). A detailed understanding of traditional trends in agricultural land and crop use is a prerequisite for assessing any impacts on land use which may or may not be attributable to the implementation of the RFS. To create the necessary foundation for assessing potential RFS impacts, this section begins by reviewing land use and crop use for U.S. agriculture over the years 2000 through 2018, with an emphasis on corn and soybean crops. This foundation provides context for reviewing the discussion on agricultural land and crop use contained in the U.S. Environmental Protection Agency's (EPA) Second Triennial Report to Congress (the "Triennial Report").[3]

1.2 Review of USDA Historical Land Use Data

As a first step in understanding the impact of the RFS on U.S. agriculture, it is important to review the overall landscape of how agricultural land use has changed over time. This section reviews and interprets USDA data on total U.S. crop acreage as well as a more detailed look into supply and demand for U.S. corn and soybeans acreage specifically. Analysis of these data is presented in order to provide insight into factors other than the RFS which may be influencing production and demand for corn and soybeans in the U.S.

Figure 1 illustrates annual planted acreage in the U.S. from 2000 through 2018 with a breakout of the four highest-acreage crops – corn, soybeans, wheat and hay.[4] These four crops comprise 85 to 90 percent of all planted acres. This chart is overlaid with annual U.S. ethanol production as found in USDA Quick Stats.[5]

Figure 1. U.S. Crop Acreage and Conventional Ethanol Production



sources: *USDA, Stillwater analysis*

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[3] U.S. Environmental Protection Agency. Biofuels and the Environment: The Second Triennial Report to Congress. June 29, 2018. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=IO&dirEntryId=341491

[4] Data drawn from the annual Acreage report published by USDA National Agricultural Statistical Service (NASS) every June. https://usda.library.cornell.edu/concern/publications/j098zb09z?locale=en. All acreage data used, with the exception of the 2018/2019 market year, are the final estimates as reported in the Acreage report published in the June following harvest. For the 2018/2019 market year, the June 2018 estimates have been used.

[5] USDA Quick Stats. Accessed January 10, 2019 https://quickstats.nass.usda.gov

In interpreting the USDA acreage data, it is important to recognize the level of accuracy achieved through the statistical sampling methods employed. In their annual Crop Production Summary report published in January 2018,[6] USDA reports cite reliability of their final (post-harvest) crop estimates in terms of 95 percent confidence limits for the national crop totals, indicating ± 2.2 percent for corn and ± 2.0 percent for soybeans. This corresponds to uncertainties of about ± 2 million acres for corn and ± 2 million acres for soy. Assuming similar uncertainty in the national total crop acreage would imply 95 percent confidence limits of ± 6 million acres. In many cases, the year-to-year variation in reported crop acreage is within the 95 percent confidence limits of USDA's estimates, and thus cannot be distinguished from measurement uncertainty.

The data displayed in Figure 1 reveal a number of key points about trends in U.S. agriculture from prior to enactment of RFS to the current date.

First, total annual planted acres averaged nearly 322 million over this timeframe but experienced an overall decline from 328 million in 2000 to 320 million in 2018. There is year-to-year variation, represented by a standard deviation of over four million acres; thus, comparisons taken between individual years can be misleading; it is necessary, therefore, to look at multi-year averages in order to identify any potential long-term trends. Total annual acreage in the pre-RFS period (2000-2007) averaged 323 million acres, declining to an average of 321 million acres since the start of RFS (2008-2018). The highest acreage year in that time interval was 2000 (pre-RFS) with 328 million acres planted; the lowest acreage year in that time interval was 315 million acres in 2011 (post-RFS). Thus, overall trends clearly indicate that total crop acreage declined during the years of the RFS.

These USDA annual acreage data, however, are aggregate figures and therefore do not indicate whether the same acres are put into or taken out of agricultural use each year. As agricultural acres are regularly converted to other uses (e.g., housing, industrial and recreational uses), new lands need to be cultivated each year if total planted acres are to remain constant. That influence on land cultivation is independent of the RFS. Thus, it is not accurate to designate RFS as the primary cause for any conversion of previously non-agricultural lands to crop production. In fact, these data demonstrate that, as the aggregate acreage has declined despite the growing feedstock requirements of the RFS, U.S. farmers did not replace all of the acres converted away from agriculture with newly-cropped acres.

Second, EPA's Second Triennial Report to Congress[7] examines the issue of land conversion. Citing work from Lark, et al,[8] based on interpretation of apparent land use changes derived from satellite photographs, the EPA review notes a net increase in U.S. cropland of three million acres between 2008 and 2012 and adds that gross land conversion was nearly four times greater than net land conversion (i.e., implying that nearly 12 million acres were newly cultivated while nearly nine million acres were removed from cultivation). The USDA annual acreage data, based primarily on farmer surveys, in comparison, shows a much smaller increase in planted acres, from 325.0 million acres in 2008 to 326.3 million acres in 2012 but, as just explained, does not indicate how many acres may have been newly cultivated. Yet, the Lark study is flawed because it took single-year snapshots; this fails to capture the extent of year-to-year variability in planted acres. Looking at the individual years around 2008 as reported by USDA in their annual acreage report, USDA reports total planted acres of 316.0 million in 2007, 325.0 million in 2008 and 319.3 million acres in 2009. Examining USDA's annual reports for individual years around 2012, finds total crop acres reported as 315.1 million acres in 2011, 326.3 million acres in 2012, and 324.9 million acres in 2013. Thus, one-year changes in their selection of comparison years could have greatly changed

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[6] USDA. Crop Production 2017 Summary. January 2018. https://downloads.usda.library.cornell.edu/usda-esmis/files/k3569432s/f4752k06n/th83m180b/CropProdSu-01-12-2018.pdf, See p127 for a discussion of Statistical Methodology

[7] U.S. Environmental Protection Agency. Biofuels and the Environment: The Second Triennial Report to Congress. June 29, 2018. pg. 34. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=IO&dirEntryId=341491

[8] Lark TJ, Salmon JM and Gibbs HK (2015). Cropland expansion outpaces agricultural and biofuel policies in the United States. Environmental Research Letters 10(4): 10.1088/1748- 9326/10/4/044003.

the conclusion – a decline of 0.9 million acres between 2007 and 2011, or an increase of 5.6 million acres between 2009 and 2013. This large year-to-year variability in acreage data means that long-term trends, such as any impact from RFS, can only be accurately discerned through analysis of multiple years, which the Lark study did not do.

Third, EPA's Second Triennial Report fails to mention that overall U.S. planted acres, as reported by USDA, have decreased since the start of the RFS program, even while corn and soybean acres have increased. This omission ignores the fact that increased corn and soybean acreage was predominantly realized through reduced plantings of other crops rather than through conversion of previously un-cropped land. Further, 2012 was the recent peak year for corn planting at 97 million acres and has since fallen to 90 million acres in 2017 and 89 million acres in 2018.[9] Soybean acres have continued to rise since 2012 but, as will be analyzed later in this report, this increase in soybean acres has been driven by rapidly growing exports and not RFS-driven demand for soybean oil. The Lark study also cites that the converted acres were planted 27% in corn, 25% in wheat, 20% in soybeans and 7% in alfalfa; this is lower in corn and soybean share than the overall U.S. crop distribution as reported by USDA – 30% corn, 24% soybeans, 17% wheat and 17% hay (roughly 30% of the total hay acres, corresponding to 5% of total acres are alfalfa)[10]. As the new acres claimed in the Lark study are not predominantly corn or soybeans, it is not reasonable to conclude that these new acres were put into production because of the RFS.

Fourth, in addition to the annual variation in total planted acres, the total acres planted for individual crops also varies significantly from year to year. After observing many years of USDA agricultural land use, Stillwater has found that these changes are observed in both pre- and post-RFS time periods and, thus, should not be attributed to the RFS but to changes in factors such as demand patterns, relative crop prices and global supply and demand.[11,12] For the pre-RFS years, corn acreage averaged 81 million acres with a standard deviation of over 5.4 million acres; in the RFS timeframe, the average increased to nearly 91 million acres with a standard deviation of 5.4 million acres. Soybean acres increased from 72 million acres with a standard deviation of 3.9 million acres pre-RFS to 81 million acres with a much larger 8.5-million-acre standard deviation in the RFS time frame.[13] As total planted acreage for all crops has not increased since RFS, these increases in corn and soybean plantings have been achieved through reduced plantings of other crops.

Fifth, on a national level, the diversity of U.S. agriculture has not materially changed under the RFS. During the pre-RFS years of 2000-2007, the four leading crops accounted for an average of over 85% of planted acres and increased slightly to 88% of planted acres since 2007. This concentration actually peaked at 88.6% in 2009 and has since fallen to 87.4% in 2018.[14]

For its part, USDA acreage estimates are based on a combination of surveys of farmers (current response rates to USDA surveys are about 60%), satellite imagery and comparison with data reported by farmers to the Farm Service Agency (required for participation in federal crop insurance programs). USDA collects data each year for its March report on planting intentions, its June report issued after most summer crops have been planted and its January report utilizing data acquired after the summer crops have been harvested. For this report, the post-harvest data are used for all

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[9] U.S. Department of Agriculture. National Agricultural Statistical Service (NASS) Annual Acreage Reports. https://usda.library.cornell.edu/concern/publications/j098zb09z?locale=en

[10] Calculations derived from USDA annual Acreage reports for years 2000 through 2018. https://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1000

[11] https://www.researchgate.net/profile/Daniel_De_La_Torre_Ugarte/publication/5146588_Bioenergy_Crop_Production_in_the_United_States_Potential_Quantities_Land_Use_Changes_and_Economic_Impacts_on_the_Agricultural_Sector/links/0c960524f4570b731e000000/Bioenergy-Crop-Production-in-the-United-States-Potential-Quantities-Land-Use-Changes-and-Economic-Impacts-on-the-Agricultural-Sector.pdf

[12] https://www.researchgate.net/profile/Milind_Kandlikar/publication/226200760_Scale_context_and_decision_making_in_agricultural_adaptation_to_climate_variability_and_change/links/0c9605376a89024091000000/Scale-context-and-decision-making-in-agricultural-adaptation-to-climate-variability-and-change.pdf

[13] U.S. Department of Agriculture. National Agricultural Statistical Service (NASS) Annual Acreage Reports. https://usda.library.cornell.edu/concern/publications/j098zb09z?locale=en.

[14] U.S. Department of Agriculture. National Agricultural Statistical Service (NASS) Annual Acreage Reports. https://usda.library.cornell.edu/concern/publications/j098zb09z?locale=en

years. Table 1 below summarizes the average planted areas for all U.S. crops and the four major individual crops for the pre-RFS (2000-2007) and RFS (2008-2018) periods. The standard deviations are provided as a measure of the year-to-year variability observed in each of the two time periods.

Table 1. Planted Acres Pre- and Post-RFS

	Averages		Standard Deviation	
	Pre RFS (2000-2007)	RFS (2008-2018)	Pre RFS (2000-2007)	RFS (2008-2018)
Total Planted Acres	**323 million**	**321 million**	**4.5 million**	**3.3 million**
Corn Acres Planted	81 million	91 million	5.4 million	5.4 million
Soy Acres Planted	73 million	81 million	3.9 million	8.5 million
Wheat Acres Planted	60 million	54 million	1.9 million	1.9 million
Hay Acres	62 million	57 million	1.5 million	1.1 million
Other Crop Acres	47 million	39 million	3.9 million	0.7 million
Top 4 Crops Share of Acres	85.4%	88.0%	1.1%	0.3%

While corn and soybean acreage have increased from the pre-RFS to the RFS timeframe (an average of ten million acres for corn and eight million acres for soybeans), it is necessary to examine how all uses of these crops have changed over this timeframe before attributing the reasons for these increases. Below, we review the uses of these two crops based on the World Agricultural Supply Demand Estimates (WASDE) report published by the USDA.[15]

1.3 The Evolution of Corn Supply and Demand

U.S. corn production has experienced a long trend of increasing production due to steadily increasing yields. The acreage planted each year is the collective result of individual land use allocation decisions made by the many thousands of farmers who plant corn each year. As corn is widely traded in global markets, it can be inferred that individual farmers will make their annual planting choices after assessing supply, demand and economics relative to other crop choices they have based on their experience with their land. Annual corn production averaged 10.6 billion bushels per year during the pre-RFS period (2000-2007). Average production since the start of the RFS in 2008 has been 13.3 billion bushels, an increase of about 2.7 billion bushels. Average yields during this timeframe increased from 143.8 bushels per acre pre-RFS to 160.6 bushels per acres since 2008. Accordingly, 1.2 billion of the 2.7 billion bushels per year increase can be attributed to improved yields with the remaining 1.5 billion bushels per year production attributable to increased acreage[16].

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[15] U.S. Department of Agriculture. World Agricultural Supply and Demand Estimates. August 12, 2019. https://usda.library.cornell.edu/concern/publications/3t945q76s?locale=en

[16] The 10.6 billion bushel average production (2000-2007) was achieved through harvesting an average of 73.6 million acres with an average yield of 143.8 bushels per acre. Increasing the average yield to the 160.6 bushels per acre average (2008-2018) while holding harvested acres constant, would produce 11.8 billion bushels (160.6 X 73.6/1000), an increase of 1.2 billion bushels per year. Applying the 161.0 bushel per acre average yield (2008-2018) to the 83.0 million acres harvested, on average for 2008 through 2018, results in an average production of 13.3 billion bushels, an average 1.5 billion bushel per year increase due to increased acreage.

In addition to production of conventional ethanol and co-products, the other primary use categories tracked by USDA for corn in the U.S. are Feed and Residual; Food, Seed and Industrial; and Exports. Proper allocation of annual corn acreage to the various demand categories requires two adjustments be made to the raw data:

1. **Inventory Change –** While inventory changes average out over periods of years, inventory builds or draws of hundreds of millions of bushels can occur in a given year.[17] For example, the 2004/2005 market year saw an inventory build of 1,155 million bushels and the 2006/2007 market year saw an inventory draw of 663 million bushels[18].
2. **Distiller's Dried Grains with Solubles (DDGS) Production** – DDGS is the primary co-product from dry mill ethanol plants. Conventional ethanol production consumes only the starch contained in the corn, while the remainder of the corn kernel comprising all the protein, fiber, and oil is sold as a high-protein animal feed which can replace a significant portion of the corn used to feed cattle and other livestock. Accordingly, it is appropriate to subtract DDGS production from the amount of corn used as ethanol plant feed and report the DDGS as an addition to the domestic feed and export categories based on USDA data on DDGS supply and demand.

Some key observations based on the WASDE data on U.S. corn and DDGS use –

1. **Ethanol** – While ethanol production grew steadily prior to implementation of the RFS, growth accelerated, as expected, once the RFS took effect. Corn grain demand for ethanol production grew from 1.43 billion bushels per year during the pre-RFS period (2000-2007) to 5.00 billion bushels per year since 2008. Proper perspective, however, requires that this gross corn grain use be offset by the co-production of DDGS which is available as a high-quality animal feed in both domestic and export markets. With the increase in ethanol production, DDGS production grew from 8.7 million metric tons (343 million bushels[19]) per year pre-RFS to 35.5 million metric tons (1,396 million bushels) per year since 2008. This adjustment for DDGS results in a net corn demand for ethanol production of 1,083 million bushels per year pre-RFS, increasing to 3,587 million bushels per year since 2008.
2. **Exports** – U.S. exports of corn grain have remained nearly constant since the start of the RFS. Exports averaged 1,985 million bushels per year during the pre-RFS (2000-2007) period and 1,860 million bushels per year since 2008, well within the standard deviation of 251 million bushels per year (pre-RFS). Accordingly, other countries have not been required to increase their corn production due to increased U.S. domestic corn demand for ethanol production. Further, while corn grain exports have held constant, DDGS exports have increased with growing ethanol production, increasing from 1.4 million metric tons (54.6 million bushels) per year pre-RFS to 9.7 million metric tons (381.6 million bushels) per year since 2008.
3. **Food, Seed and Industrial (other than ethanol)** – Demand for food use is expected to grow with U.S. population. Demand for seed is expected to grow with planted acres. Demand for Industrial uses, including high fructose corn syrup, cationic starch and renewable chemicals (such as bio-propanediol, PDO) is expected to increase with population and GDP. Estimated demand for corn in this category increased from 1,409 million bushels per year pre-RFS to 1,783 million bushels per year since 2008.
4. **Feed** – Use of corn grain has decreased from an average of 5,836 million bushels per year pre-RFS to an average 5,047 million bushels per year since the inception of the RFS in 2008. However, this loss is offset by increasing use of DDGS. DDGS used as feed in

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[17] USDA WASDE data are reported by market year. The market year begins on September 1st of the year indicated and runs through August 31st of the following year. As an example, the 2006 market year (often listed as 2006/2007) runs from September 1, 2006 through August 31, 2007. Thus, the bulk of the annual U.S. corn harvest is at the start of the market year and the end of the market year corresponds to nearly the low point of the annual inventory cycle.

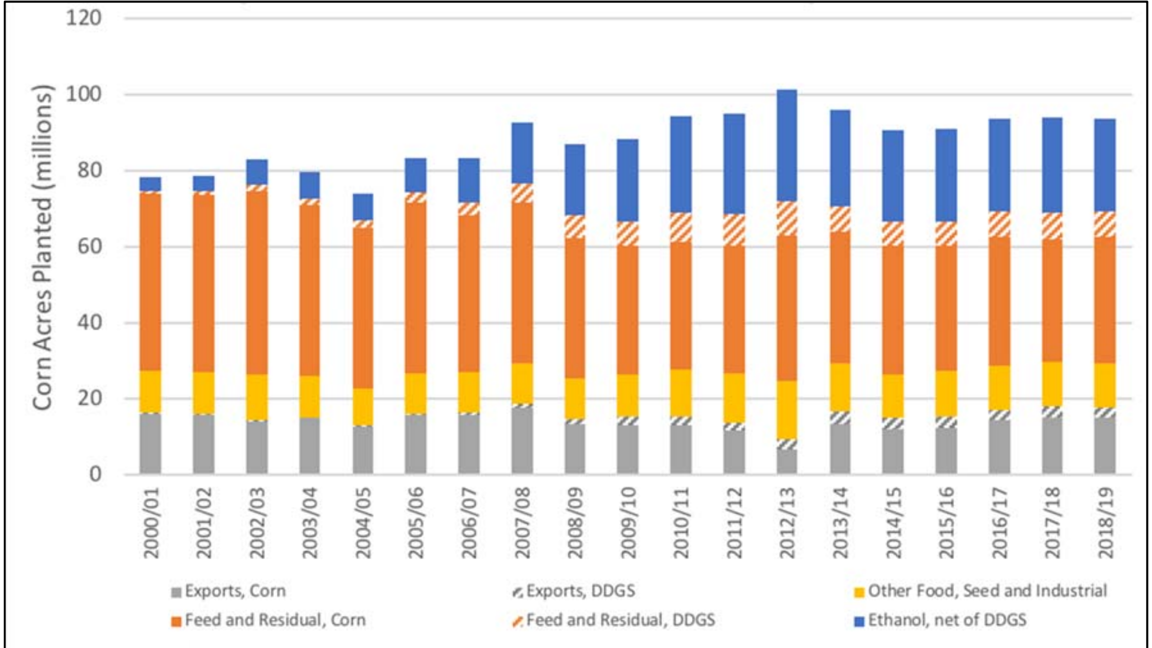
[18] Accordingly, allocated acres in this analysis need to be increased in years when there is an inventory draw and decreased in years when there is an inventory build. The size of the increase or decrease in allocated acres is the inventory change divided by that year's average yield.

[19] Data on DDGS production and use are taken from Table 08 of U.S. Bioenergy Statistics published monthly by USDA's Economic Research Service (ERS) and available at https://www.ers.usda.gov/data-products/us-bioenergy-statistics/. For comparison to corn production in bushels, DDGS production is converted to bushels at 56 pounds per bushel.

the U.S. market has increased from 7.5 million metric tons (294 million bushels) per year pre-RFS to 26.2 million metric tons (1,029 million bushels) per year since 2008.

Figure 2 illustrates the annual allocation of corn acres to these different uses by year. It illustrates that while U.S. corn acreage (adjusted for inventory changes and DDGS) has increased with the advent of the RFS, this effect maximized in the 2012/2013 market year and has since decreased and leveled off even as corn ethanol production continues to grow.

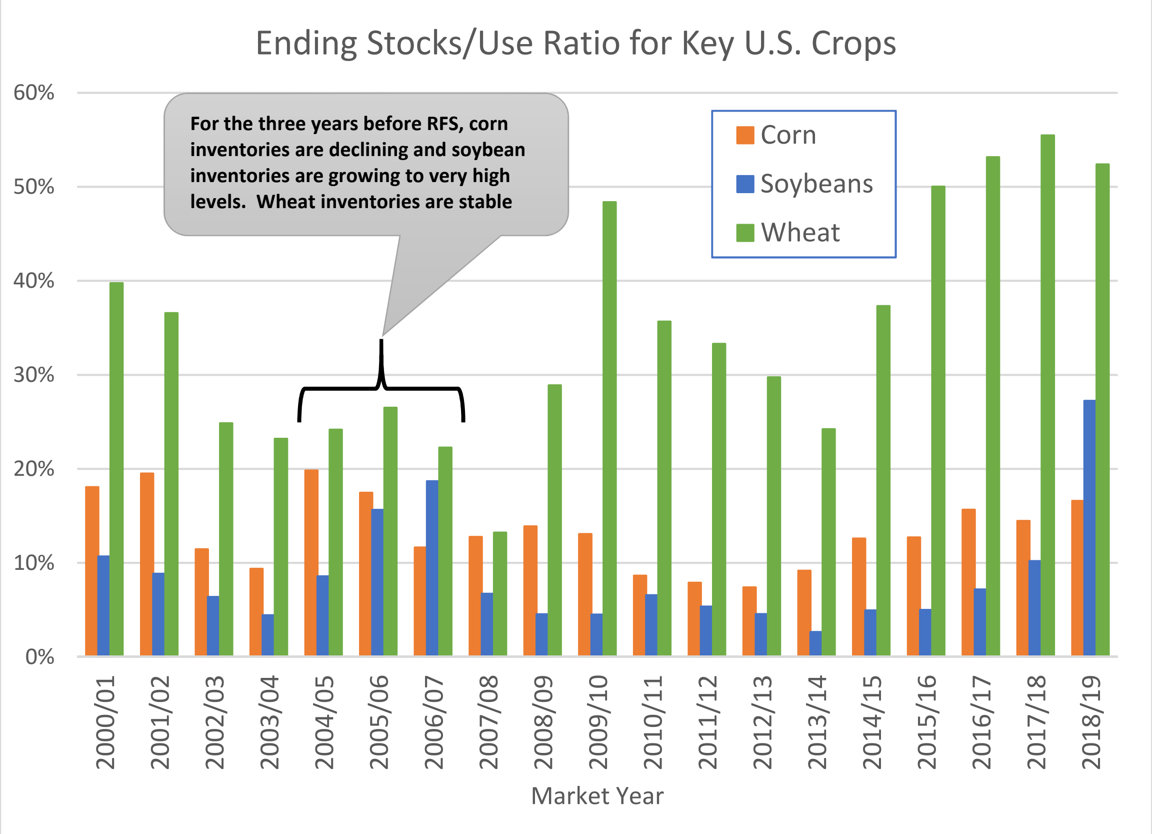
Figure 2. Adjusted Corn Acres Planted Allocated by End Use



***source**: USDA, Stillwater Analysis*

The increase in corn acres for 2007/2008 shown in Figure 2 is often attributed to increased corn demand due to the RFS. Corn acres planted were 15 million acres higher than the prior year and came largely from an 11-million-acre reduction in soybean acres (wheat acres increased by three million acres, total acres increased by 4.4 million). However, it is not possible to conclusively assign a single reason to this change, the collective result of individual planting decisions made by tens of thousands of farmers across all of the states where these crops are grown. A different explanation, based on market supply and demand factors independent of RFS can be seen in Figure 3, displaying the annual ending stocks-to-use ratio (the ending stock level for the market year divided by total use for the same market year). This chart shows that the ending stocks-to-use ratio for corn had declined from a relatively high 20 percent to a relatively low 12 percent in the three years prior to the RFS; since then, the ratio has oscillated between about 8 and 15 percent. The three years prior to the RFS also saw the corresponding ending stocks-to-use ratio for soybeans increased from a historically low nine percent to a historically high 19 percent during the same time period; since then the ratio has generally remained below 10 percent (2019 saw a record soy crop and the stocks-to-use ratio climed to 27%). In the U.S. Midwest, it is common practice for corn and soybeans to be grown in rotation – soybean crops replenish soil nitrogen levels, reducing the need for nitrogen fertilizer for corn crops grown the following year on the same acres. Accordingly, the large number of farmers who grow both crops can readily shift acres between the two in response to market conditions. (Wheat ending stocks-to-use ratios were relatively constant during this period, but have since risen markedly. Farmers have responded by steadily reducing wheat acres while increasing acres dedicated to corn and soybeans). Given those market trends, it was very logical for the many farmers who grow both corn and soybeans to shift their plantings to favor corn, enabling inventories for both commodities to move back towards their long-term averages.

Figure 3. Ending Stocks-to-Use Ratio for Key U.S. Crops



In summary, the U.S. crop acreage required to supply all demands for U.S. corn, including a steady level of exports, has been broadly constant since the 2007/2008 market year (prior to enactment of the RFS). This was achieved while U.S. ethanol production increased from 6.5 billion gallons in 2007 to 15.9 billion gallons in 2017.

1.4 The Evolution of Soybean Supply and Demand

Comparing the pre-RFS period (2000-2007) to the RFS years (2008-2018), soybean planted acres have increased from 72.9 million to 80.7 million. Soybean yields also increased from an average of 39.5 bushels per acre harvested pre-RFS to 45.7 bushels per acre harvested since 2008. Combined, this has resulted in an increase in the U.S. soybean crop from 2.83 billion to 3.66 billion bushels per year. Of this 830 million-bushel-per-year increase, about 440 million bushels can be attributed to increased yield while 390 million bushels are attributable to the increased acreage[20].

The two key uses for soybeans as tracked by USDA are crushing (to produce soybean meal and soybean oil) and exports of whole beans. Comparing the pre-RFS period to the years starting with 2008, soybean crushing increased from 1.68 billion bushels to 1.82 billion bushels. The primary change in soybean demand, however, has been in exports, with average annual exports increasing from 1.03 billion bushels per year to 1.67 billion bushels per year. Increased exports actually account for 80 percent of the increase in U.S. soybean production. As U.S. exports of soybeans have increased substantially since the start of the RFS, soybean acres planted in the rest of the world have not needed to increase due to the RFS.

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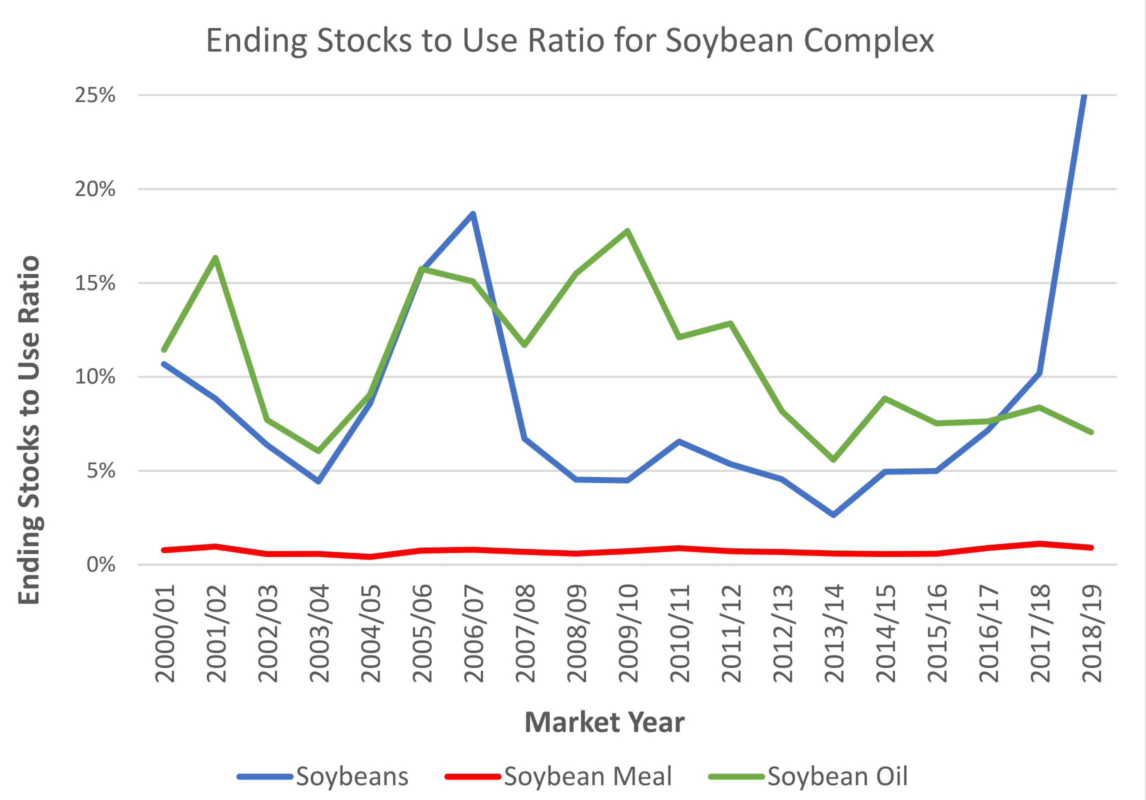
[20] The 2.83 billion bushel average for 2000-2007 comes from an average of 71.7 million acres harvested at an average yield of 39.5 bushels per acre. Increasing the yield to the 2008-2018 average of 45.6 bushels per acre, while holding harvested acres constant, would yield 3.27 billion bushels per year (71.7*45.6/1000), an increase of 440 million bushels. Increasing the harvested acres to the 2008-2018 average of 79.9 million, gives the post-RFS average of 3.66 billion bushels, a further increase of 390 million bushels per year.

The crushing process separates the protein-rich solids, which comprise about 80 percent of the whole soybean, from the soybean oil, which comprises about 20 percent of the whole soybean. The solids (soybean meal) are utilized primarily as a high-protein animal feed with most of the production consumed within the U.S. Exports of soybean meal have, however, also grown substantially from an average of 7.5 million short tons per year pre-RFS (2000-2007) to 11.4 million short tons per year on average since 2008. Corresponding domestic demand has declined slightly from an average 32.9 million short tons per year pre-RFS to an average of 32.0 million short tons per years since 2008. Some of this decline can be attributed to increasing competition from DDGS. Crushing plants produce soybean meal to meet market demand and the soybean oil produced in the process is then priced to sell in competition with other vegetable oils in the market. This management of soybean crushing rates can be seen in Figure 4 which compares ending stocks-to-use ratios for whole soybeans, soybean meal and soybean oil – while the ending stocks-to-use ratios for both soybean and soybean oil vary considerably from year to year, the ending stocks-to-use ratio for soybean meal is considerably lower with minimal year to year variability. While biodiesel is an important and growing use for soybean oil, soybeans are not grown to produce oil; the biodiesel market provides a valuable outlet for an otherwise surplus product.

Figure 4. Ending Stocks-to-Use Ratio for Soybean Complex



Source: *USDA WASDE, Stillwater analysis*

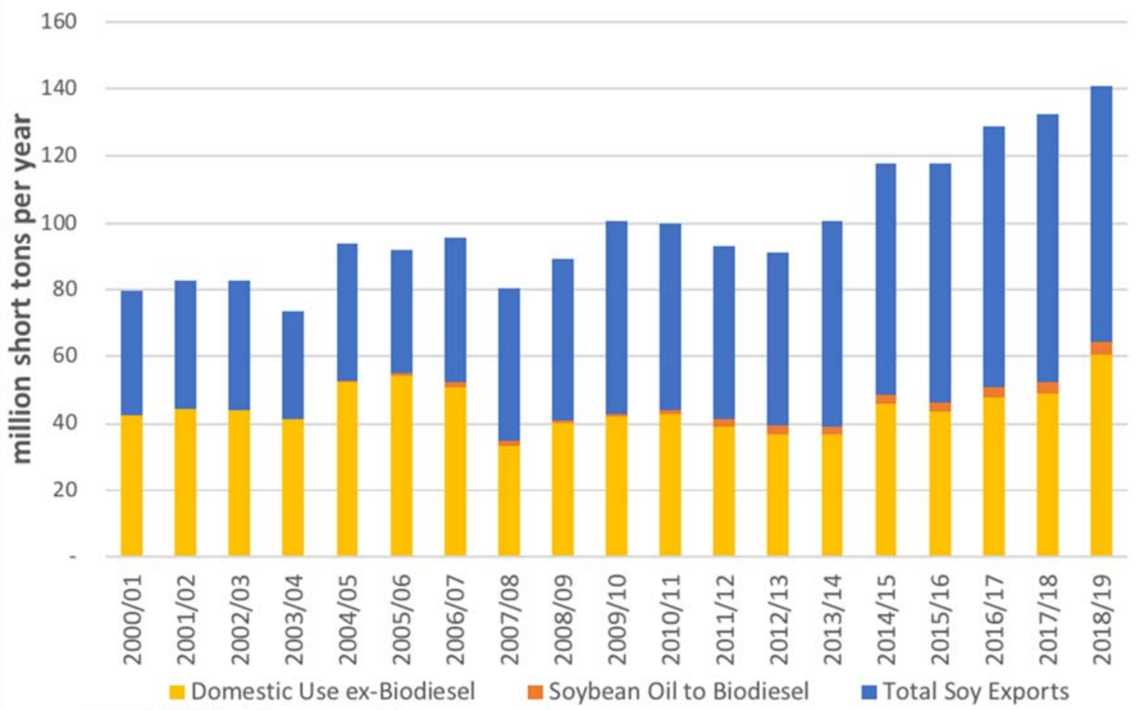
The primary market for soybean oil is food, feed, and industrial where it competes with a number of other vegetable oils (primarily corn oil, canola oil and sunflower oil). Use as a biodiesel feedstock has grown steadily under the RFS where it also competes with other vegetable oils (primarily non-food-grade corn oil co-produced with ethanol) as well as animal fats and greases. Exports of soybean oil have also grown steadily. A summary of average annual production and demand for soybean oil, as reported by USDA WASDE is provided in Table 2.

Table 2. Average Annual Production and Demand for Soybean Oil

	Pre-RFS (2000-2007)		RFS (2008 to Date)	
Billion pounds per year	Average	Standard Deviation	Average	Standard Deviation
Production	19.1	1.3	20.9	1.8
Food, Feed and Industrial	16.3	0.6	14.1	0.3
Biodiesel	1.0	1.3	4.8	2.0
Exports	1.7	0.7	2.3	0.6

Figure 5 summarizes the annual uses for the U.S. soybean complex (whole soybeans, soybean meal and soybean oil combined) since 2000 as reported by USDA in the WASDE. For all domestic uses, including biodiesel feedstock, 2018 is the first year when the projected demand for soybeans exceeds pre-RFS levels. As illustrated in Figure 5, growth in demand for the U.S. soybean complex since the 2008/2009 market year is primarily driven by growing demand in export markets, not the RFS. The projected 2018/2019 growth in U.S. domestic demand is attributable to a projected record crop in 2018 and an anticipation of weak demand for U.S. exports due to current trade disputes. Reduced domestic use of soybeans is attributable to growing competition with DDGS in animal feed markets.

Figure 5. Summary of U.S. Soybean Disposition



***source**: USDA WASDE, Stillwater analysis*

1.5 Review of U.S. Crop Acreage and Disposition Analysis in EPA's Second Triennial Biofuels Report

EPA's Second Triennial Report to Congress is intended to be the definitive look at RFS landuse impacts. However, we have found several shortcomings in this report. Many of these are acknowledged by EPA in the report but are not highlighted in a manner that would attract the attention of the average reader. In the following section we offer a critique of EPA's Second Triennial Report informed by the preceding analysis of annual USDA data.

EPA's key land-use finding in their Second Triennial Report[21] relevant to land-use change is primarily that biofuel feedstock production is responsible for some of the observed and reported changes in agricultural land use, but EPA is unable to quantify this land-use increase with any degree of precision. USDA, as described above, publishes annual data on U.S. agricultural land use with detailed review of the precision. EPA states that since the passage of the Energy Independence and Security Act of 2007 (EISA or RFS), actively managed cropland has increased by 4-7.8 million acres. This is contrary to what can be clearly observed in USDA's acreage reports. EPA also states that cropland expansion and natural habitat loss (including forests) have been observed internationally during the implementation of the RFS program. The fact that exports of the three major U.S. export crops have held stable (corn and wheat) or substantially increased (soybeans and derivatives) since the start of RFS strongly counters any causal linkage between international cropland expansion and the RFS.

In its Second Triennial Report, EPA makes bold statements about the RFS's responsibility for land-use increases but also admits there are significant uncertainties making it impossible to precisely quantify the amount of land with increased intensity of cultivation or to confidently estimate the portion of crop land expansion that is due to the market for biofuels. EPA also points out the need for more research and improvement in the models used for this research. Our preceding analysis of USDA's annual data on corn and soybean useage shows that (1) corn acreage has been relatively constant (after adjusting for annual inventory changes) since 2007 despite conventional ethanol production increasing from 6.5 billion gallons in 2007 to 15.9 billion gallons in 2017; and (3) total domestic demand for soybeans, soy meal and soybean oil remained below pre-RFS levels from 2008 through 2017, with all of the increase in soybean planting to support exports of soybeans, soy meal and soybean oil.

Table 4 of the Second Triennial Report summarizes the land-use studies EPA drew upon to reach its conclusion that the RFS has driven agricultural land-use changes. These studies (all of which ended in 2012) found land-use changes of 5-7.8 million acres amounting to changes of 1.5, 2.4, 1.4, 1.2 and 1.0 percent. The implied accuracy of 1.0 to 2.4 percent in crop acreage measurement is very difficult to achieve in a database that is created by surveys in which there is not 100% participation. USDA estimates the 95 percent confidence limits of their annual estimates of corn and soybean acreage as the equivalent of ±2 million acres for each crop. The year-to-year variability in planted acres for these crops (see Table 1) is considerably larger. Accordingly, the utility of comparing acreage between two individual years is severely limited; analysis of multiple years of annual data, such as that published by USDA, is needed to demonstrate the presence or absence of a trend. Given the many factors impacting planting decisions of individual farmers, attributing any such trend data to the RFS requires further analysis on the actual use of the corn and soybean crops.

These studies all looked at total land use and total corn and soy bean production.[22] They had no ability to look at corn acres used for the RFS but assumed that all of the land use increases were due to RFS biofuels. In fact, only about 30 to 35 percent[23] of corn has been used for ethanol production, and ethanol production was already at nearly five billion gallons per year (bgy) in 2006 before the the RFS was in effect. As such, EPA should have only looked at corn planted for incremental ethanol produced in 2007 and later. Further, analysis of USDA WASDE data shows that demand for all uses of corn and DDGS have increased since the implementation of the RFS and that land required to supply all of these demands (domestic and export) has been essentially flat since 2007.

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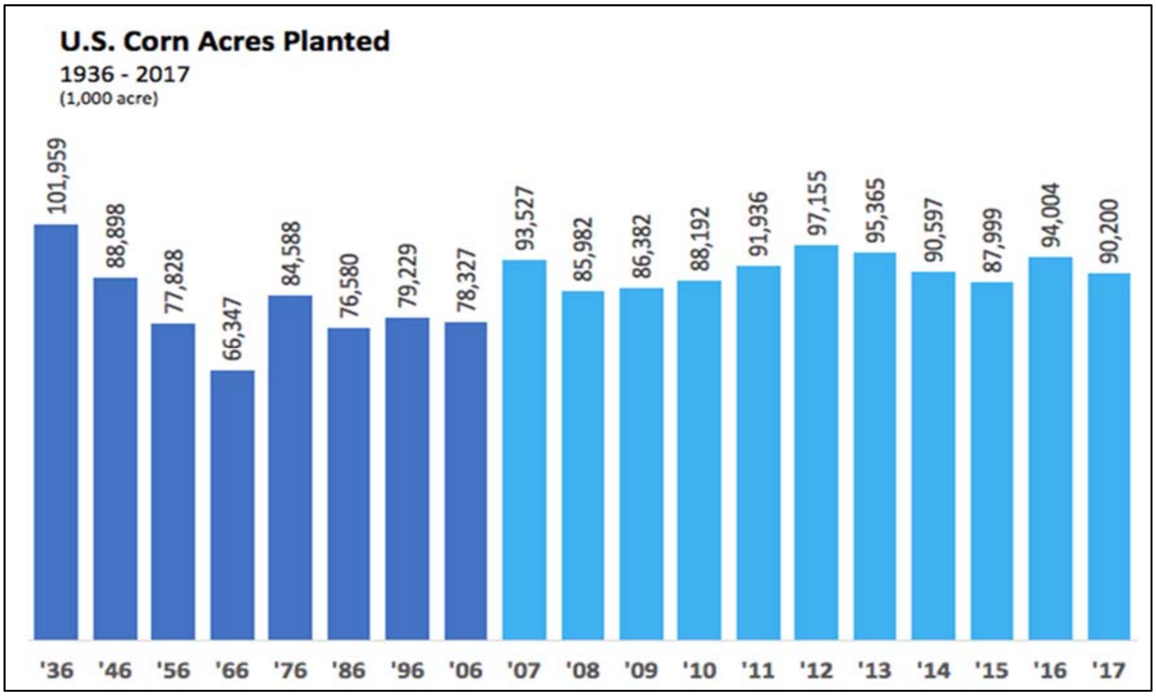
[21] U.S. Environmental Protection Agency. Biofuels and the Environment: The Second Triennial Report to Congress. June 29, 2018. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=IO&dirEntryId=341491

[22] Note that in Figure 1 of the Second Triennial Report, EPA uses data from USDA and other public sources to build up to its 16.6 bg of biofuels in 2016. The ethanol portion of this is 15.33 bg. Figures 10-13 in this report use data from the National Corn Growers Association. Use of this data in Tables 2, 4, and 5 results in a calculated ethanol volume of 15.4 bg in 2016. There are only very small differences between the two data sets.

[23] According to DOE's Alternative Fuels Data Center, in 2008 30.8 % of US corn produced was used to manufacture ethanol.

On the surface, EPA's approach to comparing the ten years before the RFS to the first ten years of the RFS might seem reasonable. However, data variability makes it possible to demonstrate land use increases or land use decreases simply by changing the beginning and ending years of the analysis. Looking at Figure 6 below reveals that 2012 and 2013 had the highest acreage planted in corn in recent years, and 2012 was the last year examined by most of the studies EPA referenced. This means that any examination of land use with 2012 as its endpoint would portray the appearance of land-use increases. However, if any of the years 2014 or later are used as the endpoint of the analysis, any previously perceived land-use increases disappear—even though the relevant RFS volume requirements continued to increase in those later years. EPA does not acknowledge this in their analysis.

Figure 6. U.S. Corn Acres Planted 1936-2017[24]



EPA has a similar problem with using 2007 as the beginning year in their analysis. While the EISA legislation is dated 2007, it was not signed by president Bush until December of 2007. As such, it had very little impact on 2007 corn production. Looking at Figure 7 below, it can be seen that the corn acres planted in 2007 are an anomaly and are higher than the years before and after. This increase in acres planted occurred before the RFS drivers were in place and were the result of the overall corn market drivers (non-RFS drivers), such as increased corn exports, unusually low corn inventories, and unusually high soy bean inventories. Rather than using the year 2007 as the beginning of the RFS-driven land use analysis, EPA should have viewed 2007 as the last year before EISA and the RFS impacted corn-planting decisions.

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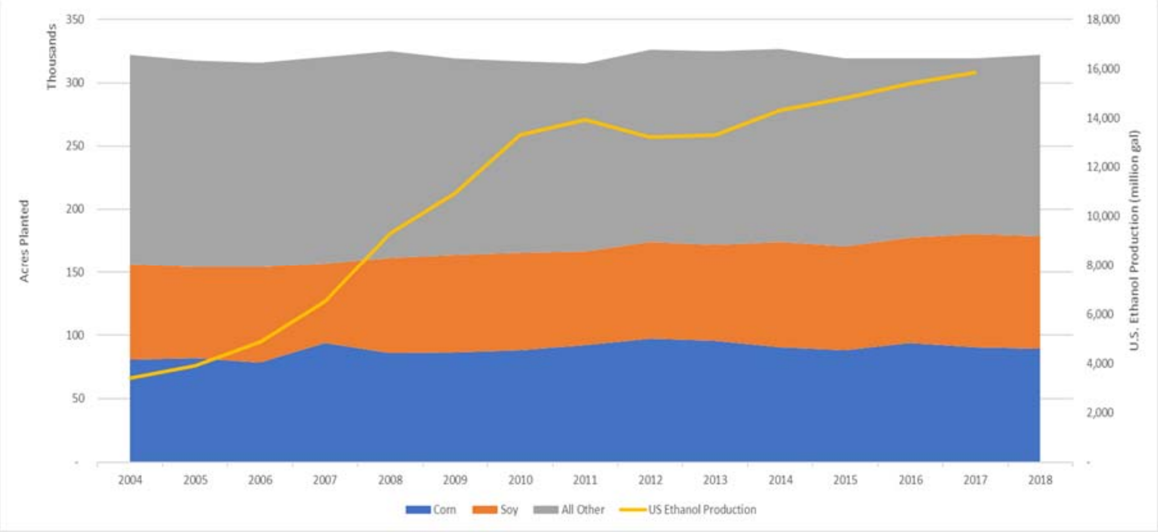
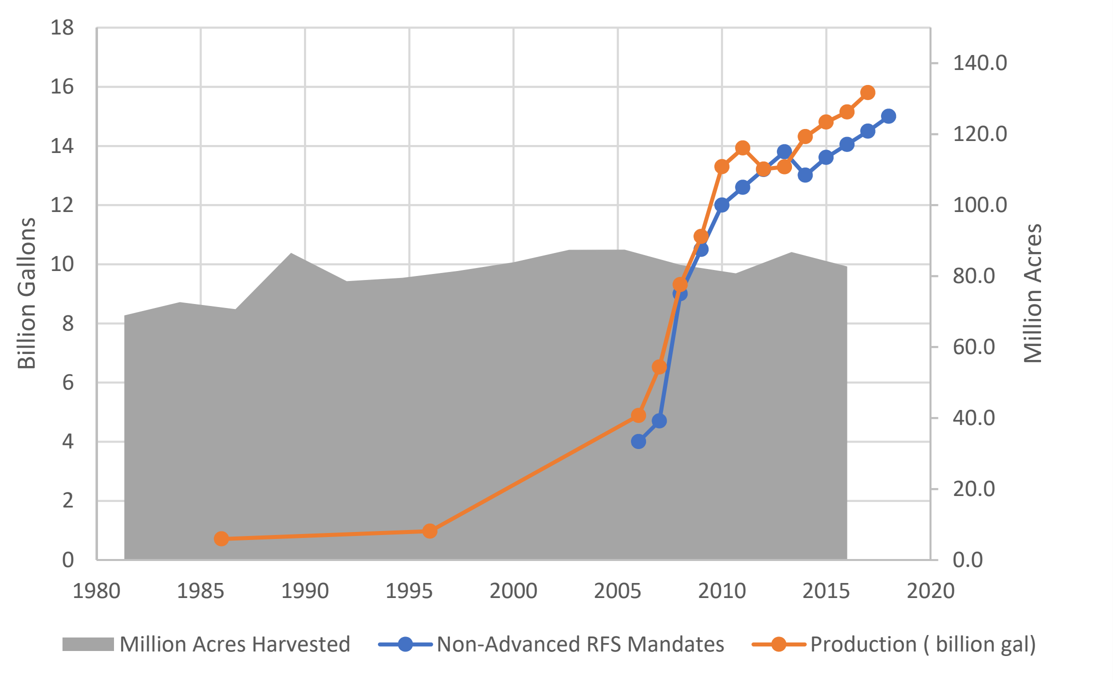
[24] National Corn Growers Association. U.S. Corn Acres Planted 1937-2017. January 12, 2018. http://www.worldofcorn.com/#us-corn-acres-planted

Figure 7. U.S. Crop Acreage 2004-2018



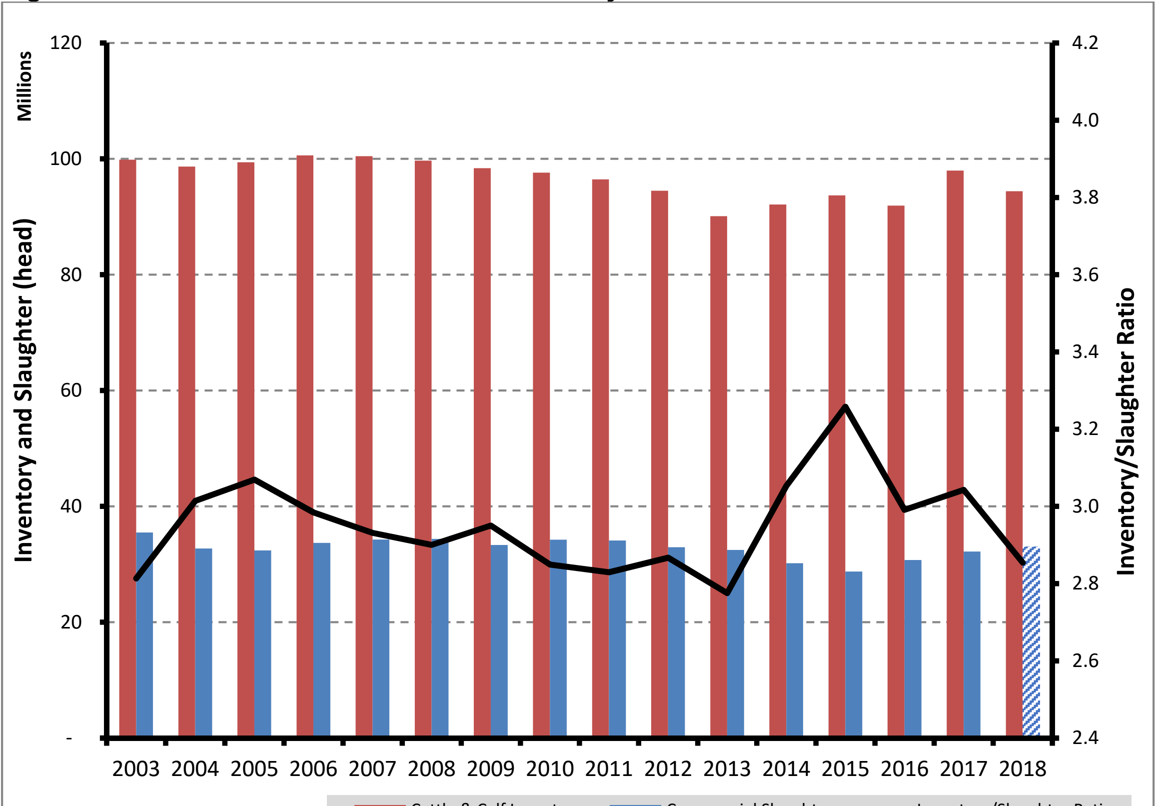
As shown in Figure 8 below, ethanol production has grown since long before the RFS and domestic ethanol production has exceeded the RFS non-advanced requirements every year except 2013 (in recent years, the U.S. has been a net exporter of ethanol). As reviewed in Section 1.3, the corn acreage utilized for this ethanol production has been relatively unchanged since the beginning of the RFS, so any land use concerns relative to conventional ethanol preceded, and were not caused by, the RFS.

Figure 8. Conventional Ethanol Production vs. RFS Non-Advanced Requirements



Yet another factor to consider when looking at land use in the U.S. is the cattle herd as feed is a major source of demand for corn, DDGS and soy meal. U.S. cattle herd size has varied significantly since 2003. Herd size fell significantly from 2006 though 2013 due to the U.S. outbreak of Bovine Spongiform Encephalopathy (BSE, commonly “mad cow disease”) first detected in mid-2005 and the consequent loss of export markets. U.S. herd size has expanded since the 2013 low as the impacts of the 2005 BSE outbreak ended and U.S. beef exports began to recover. Each of these up years corresponds to an increase in demand for cattle feed in the form of corn or DDGS and of course the down years represent a reduction in demand for cattle feed. Significantly, from 2013 to 2017 the cattle and calf inventory increased from 90 million to almost 100 million, causing a corresponding ten-percent increase in cattle-feed demand. Some of this increasing feed demand has been met by increased DDGS production which was available due to the increase in corn ethanol production. USDA WASDE data reviewed in Sections 1.3 and 1.4 above estimate the quantities of corn, DDGS, and soy meal utilized in domestic and export markets. In summary, increasing production of DDGS, coupled with growing yields for corn and soybeans, have enabled U.S. feed demands to be met with fewer acres. The topic of changing land use is complex, and EPA should take into account all of these factors when evaluating the U.S. cropland used for biofuel production.

Figure 9. Trends in U.S. Cattle and Calf Inventory



***source**: USDA, Stillwater Analysis*

In summary, individual farmers make their annual decisions on how much acreage to devote to each crop based on their expectations of how the future corn and soy markets will value those products, their expected yields and input costs, and alternative uses for their land. While EPA's annual RFS standard-setting can have some influence in the future market valuation of corn and soy, it is only a small piece of the valuation puzzle. EPA acknowledges this complexity in its Second Triennial Report:

> *Farmers' decisions regarding land use and management are influenced in part by market prices (e.g., future price of corn), which are in turn affected by myriad antecedent factors, such as weather and policies (Roberts et al. 2013; Hellwinckel et al. (2016); Carter et al. 2017). The dominant biofuel feedstocks in the U.S. currently are corn and soybeans (see Section 2.2); thus, the environmental effects of biofuels at this time are due to some portion of the land use and management of growing corn and soybeans. However, these feedstocks are also produced for*

> *other purposes, such as animal feed, many food and industrial products, and export. Soy, for example, is primarily grown for the meal (about 80% of the bean). The oil (20%), which gets used for food as well as biodiesel, is a by-product whose supply depends on soy meal demand.*
>
> *Therefore, only a percentage of the environmental consequences of growing corn and soybeans can be attributed to biofuel feedstock production. The question is what percentage of the environmental effects of producing corn and soybeans are attributable to corn-grain ethanol and soy biodiesel, respectively? And, from this follows – what percentage of these environmental effects are attributable to the Renewable Fuel Standard Program specifically?*[25]

Stillwater believes that crop acreage and supply/demand reports produced by USDA provide considerable insight into how the RFS has affected U.S. agricultural land use and the variety of markets which U.S. farmers supply.

1.6 **Indirect Land Use Concerns**

The indirect land use discussions have raised concerns about the need for countries other than the U.S. to contribute crops to aid in meeting the U.S. RFS mandates. The premise is that the use of U.S. farmland to produce biofuels feedstocks (such as corn and soybeans) will reduce the supply of those crops for other demands and, therefore, result in new land being converted to agriculture to make up for the presumed shortfall. EPA implies there are indirect land use issues due to the RFS in its Second Triennial report. However, analysis of U.S. agricultural land use and trends in U.S. agricultural exports contradict that assertion. As reviewed in Section 1.2 above, U.S. agricultural land use has not increased since implementation of the RFS and, as displayed in figure 10 below, USDA data[26] on U.S. exports for the three large commodity crops – wheat, corn and soy – show that, since the start of the RFS, U.S. exports for corn and wheat have stayed largely flat while soy exports have markedly increased. (Not shown in this figure is the increase in U.S. DDGS exports during this timeframe.) Decreases in U.S. crop exports in the 2018/19 market year can best be attributed to current trade disputes that are not related to the RFS. These data suggest that the RFS is not responsible for any increase in agricultural land use either inside the U.S or outside of the U.S. (i.e., no need for other countries to grow more to offset U.S. production sent to biofuels).[27]

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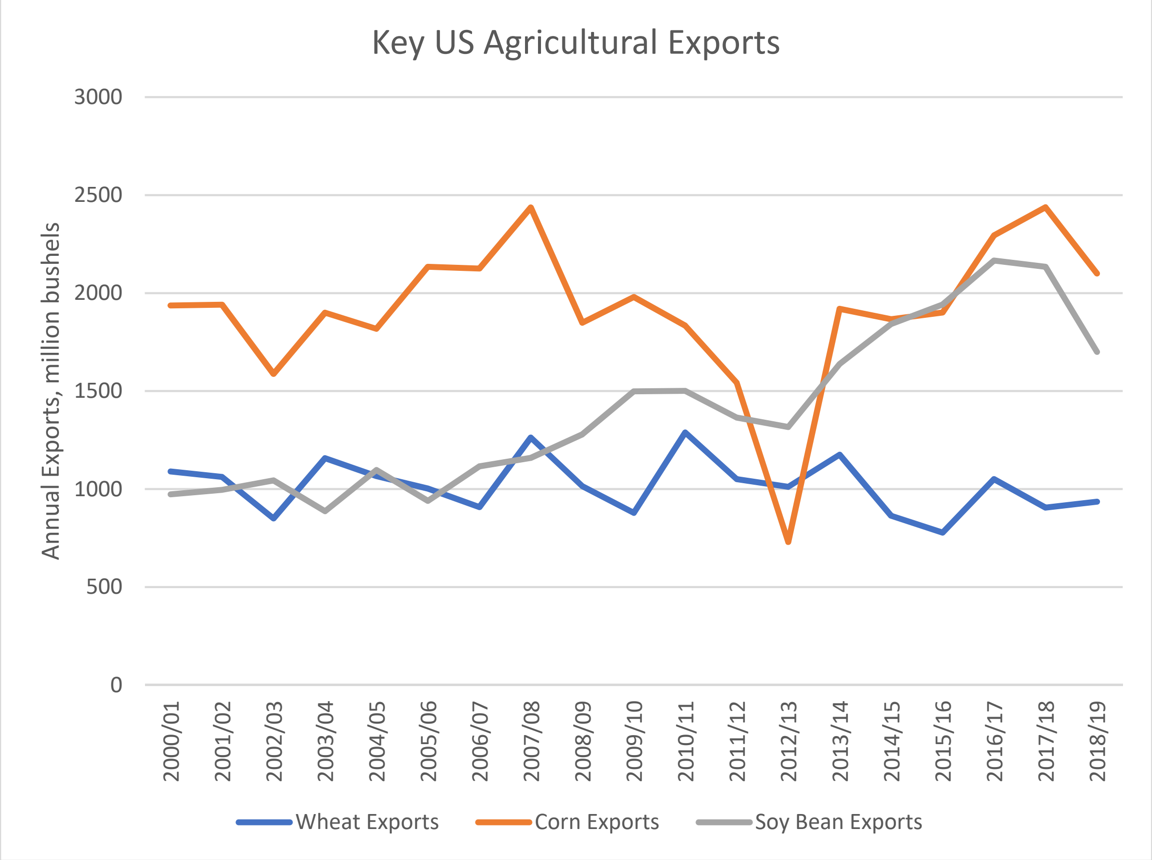
[25] U.S. Environmental Protection Agency. Biofuels and the Environment: The Second Triennial Report to Congress. June 29, 2018. pg. 54. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=IO&dirEntryId=341491

[26] Data drawn from USDA World Agricultural Supply Demand Estimate (WASDE) published monthly. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1194.

[27] Note: 2011 and 2012 for corn diverge from the corn trend due to back-to-back low-yield years due to floods and then drought.

Figure 10. Key U.S. Agricultural Exports



Source: USDA WASDE

1.7 Summary on Land Use Concerns

While the RFS volume requirements mandates increased ethanol production by 12.4 bgy from 2004 to 2017 (from 3.4 bg to 15.8 bg), corn acreage in the U.S. only increased by nine million acres. Furthermore, while BBD mandates increased from 0.5 to 2.0 bg under EISA, U.S. soy acreage increased by about 20 million acres. Both of these mandated increases had a small impact on the total amount of corn and soy beans grown during the RFS years. Since corn used for ethanol is about 30 percent of total corn, the prorated acreage for ethanol-directed corn was just three million acres (30 percent of nine million acres) and since only 12 percent of soy is directed to RFS requirements, only about 2.4 million acres of soy production can be attributed to this use. Also, corn used for ethanol above 15 bgy is not driven by RFS; it is driven by ethanol demand in export markets.

Combined, these acreage increases for corn and soy represent only 5.4 million acres compared to the 4.0-7.8 million acres of general agricultural land use which EPA discusses in its latest Triennial Report. This acreage increase represents one-to-two percent of total U.S. crop land and thus is roughly the same size as the variability within the data.

Since the U.S. is exporting corn and soy beans plus ethanol and DDGS at amounts at or above pre-RFS levels, imports of ethanol and BBD are currently minimal, and U.S. agricultural land use is decreasing, there are no indirect land use impacts for corn ethanol or BBD either within the U.S. or the rest of the world resulting from the RFS.

2 The Ethanol Industry's Production Capabilities

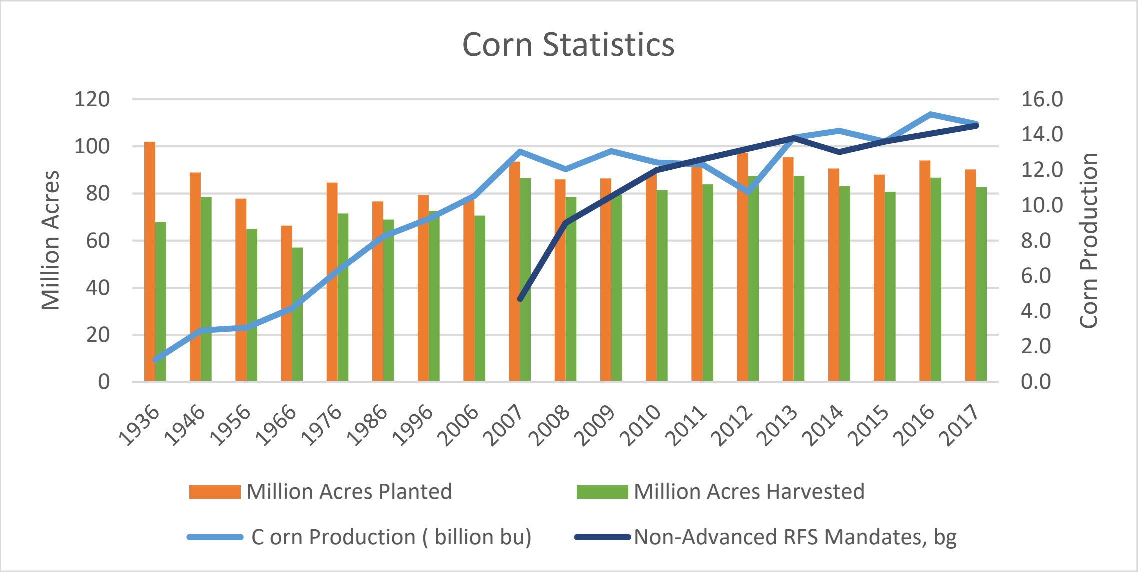
Having examined corn land use and EPA's Triennial report in the above sections, this report now examines whether the ethanol industry could take advantage of continued improvements in corn production and ethanol manufacturing to produce additional volumes of conventional ethanol without the need for increased acreage for growing corn.

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. Using a 92% ratio factor for the ratio of acres planted in corn to acres harvested, 86.5 million acres harvested would required 94 million acres of planted corn. For the purposes of this analysis, non-ethanol corn usage has been allowed to increase each year by 1%, the same rate as the world population is projected to grow. These two steps should minimize environmental and food concerns.

2.1 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 11 shows 80 years of corn production, ending with 14.6 billion bushels of corn in 2017. It also shows 80 years of the farm acres planted in corn and the actual acres of corn harvested in the same time period.

Figure 11. U.S. Corn Statistics 1936-2017[28]



The increased corn production shown in Figure 11 has come from roughly the same number of harvested acres. 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. The ratio of acres harvested to acres planted has been steady for many decades. The USDA data used in Figure 11 indicates that in 1936, only roughly 2/3 of the planted acres were harvested, but within ten years it had reached about 90 percent, and since 1996 it has been nearly constant at 92%.

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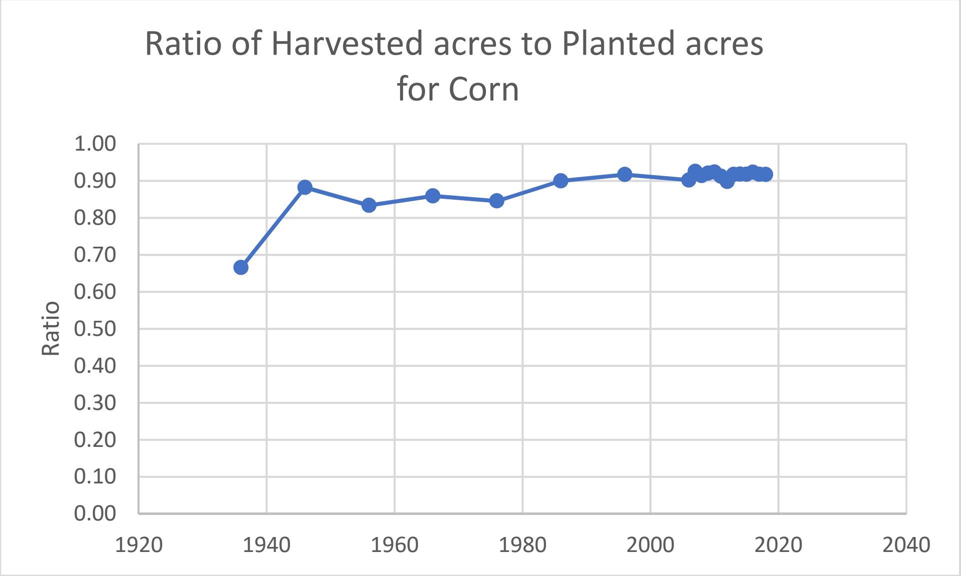
[28] National Corn Growers Association. U.S. Corn Production 1936-2017. January 12, 2018. http://www.worldofcorn.com/#us-corn-production

Figure 12. Ratio of Harvested Acres to Planted Acres for U.S. Corn[29]



In looking at Figure 11, from 2007 forward (the year before the RFS effects started) 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 red and blue bars as representing an increasing or decreasing farm land use for corn over this period. Yet EPA, in their Second Triennial Report, found that: “It is likely that the … impacts associated with land use change are, at least in part, due to increased biofuel production and use associated with the RFS.” Our analysis in section 1 found that while corn production and yields have increased, as shown in Figures 11 and 13, land use for corn has remained relatively stable from 2007 to 2017.

One of the largest keys to increased corn production is the increase in corn yield per acre, which is shown in Figure 13. 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 represented an all-time high for the U.S.

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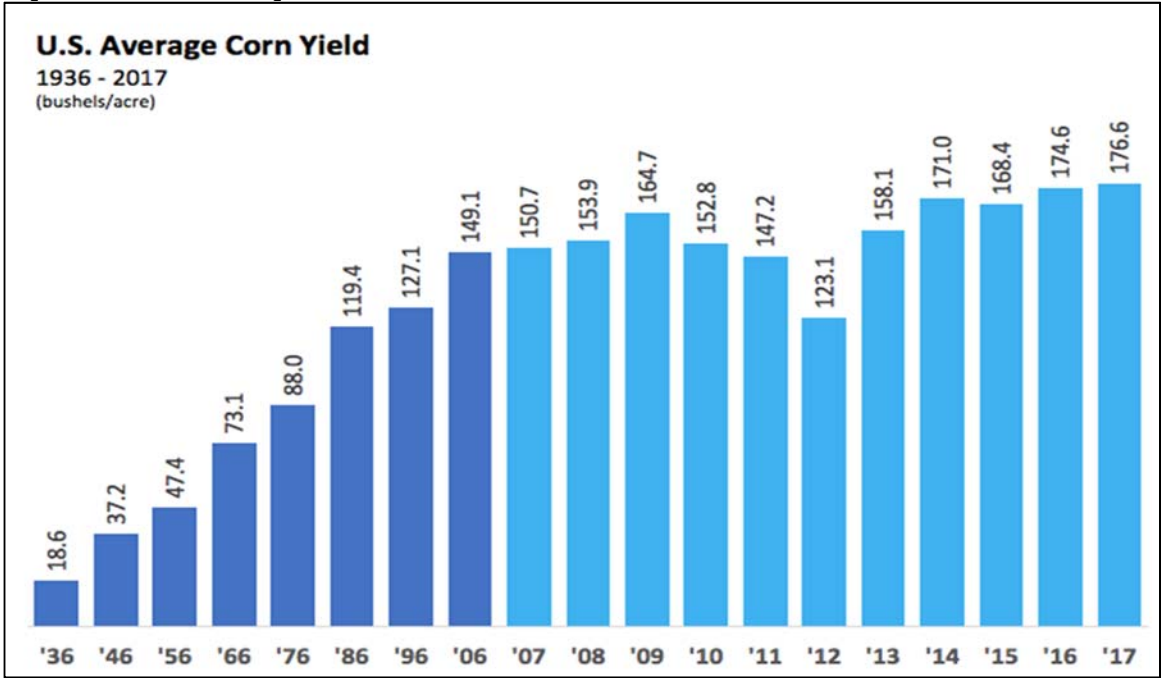
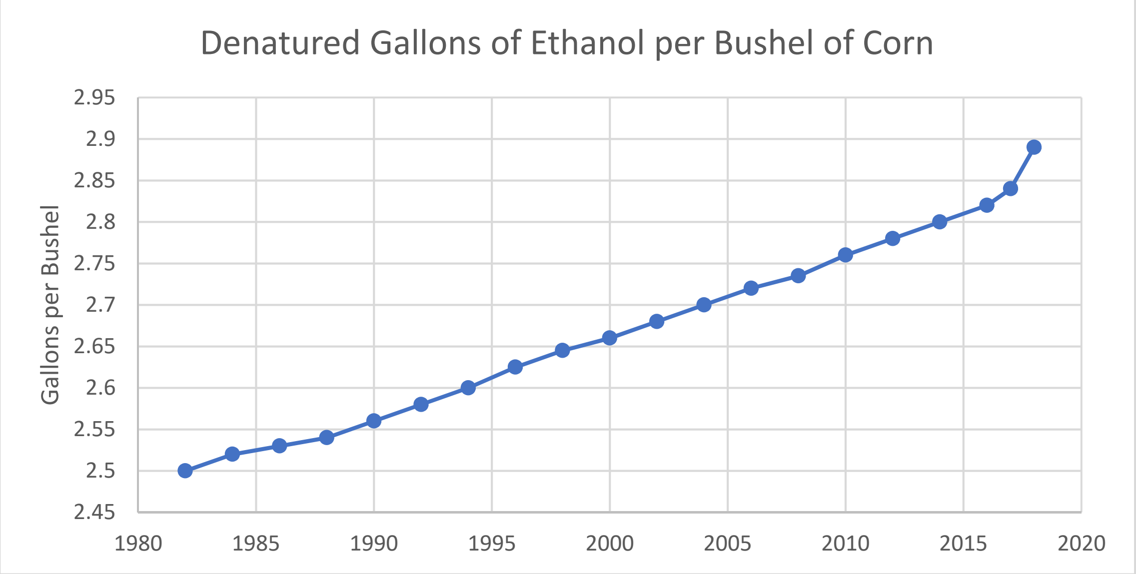
[29] https://quickstats.nass.usda.gov/

Figure 13. U.S. Average Corn Yield 1936-2017[30]



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 into 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 14.

Figure 14. Conventional Ethanol Refinery Conversion Efficency[31]



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[30] USDA Quick Statistics, https://quickstats.nass.usda.gov/

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

2.2 Modeling Future Conventional 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.

2.2.1 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.

2.2.2 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 3 below 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. Although there is no guarantee that this rate of increase will continue through 2022, there is no particular basis to believe that the rate will decline over the next few years. On the contrary, there are solid reasons to believe the rate will hold, or even rise further: About 33% of the total corn production in 2017 came from Illinois[32] and Iowa[33], where statewide yields were above 200 bushels per acre. New developments, such as precision agriculture,[34] GPS planting[35], improved seeds, and planting narrower rows[36] should enable these rates of increase in corn yields to continue. Iowa and Illinois have the advantage of larger farms. These larger farms have the ability to implement these new farming developments earlier and some of the yield increase to above 200 bushels per acre is due to this early adoption. Once a new development is recognized as beneficial, it can quickly be adopted on smaller farms elsewhere in the country. New developments are implemented over time and over different farms, bringing about the increase of 2.3 bushels per acre per year that has been seen over the past 12 years. Future improvements at this rate are already "locked in" by practices being tried by the early-adopter farmers.

Table 3. **Corn Yield Increases**

For the past:	**Average Increases per Year (bushels per year per acre)**
10 years	2.3
22 years	2.2
42 years	2.1
82 years	1.9

2.2.3 Increased Conventional Ethanol Refinery Productivity

Figure 14 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. The 2018 ethanol plant efficiency of 2.89 represents a significant increase from the straight line trend from 1982 to 2017. The 1982 to 2017 data 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.

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[32] https://www.nass.usda.gov/Statistics_by_State/Illinois/Publications/County_Estimates/2017/IL-Corn-Production-by-County.pdf

[33] https://www.nass.usda.gov/Statistics_by_State/Iowa/Publications/County_Estimates/2018/IA-CtyEst-Corn-16-17.pdf

[34] 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.

[35] https://boucherfarms.wordpress.com/2014/04/10/how-farmers-use-gps-and-vrt-technology-to-plant-efficiently/

[36] www.agriculture.com/crops/corn/production/narrow-advtage-f-narrow-rows_137-ar21003

There are many reasons to believe that these increases in ethanol refinery productivity can continue into the future. Future increases based on the implementation of technology improvements in ethanol plants – corn kernel fiber to ethanol[37], fiber separation to ethanol, improved selective milling processes[38] – will contribute to improve productivity. There are already many refineries achieving higher than 2.84-gallons-per-bushel productivity and the 2018 rate of 2.89 gallons per bushel maybe indicative of a faster adaptation of new technology. Most ethanol refineries should be able to achieve similar future gains. Some new refinery designs are projecting 3.1 gallons per bushel.[39]

2.2.4 Conventional 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, our model allows non-ethanol corn production to grow by one percent per year, matching the growth rate of the world's population projected by the U.S. Department of Agriculture for the same period.[40] 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 demand in these areas. Given these assumptions, new ethanol production above the 2018 levels is projected to increase by 3.9 bg – from 16.1 to 20.0 bgy – in 2022. This analysis also shows ethanol production could increase by almost 0.5 bgy or about 4.0 bg every 4years *without* increasing the number of corn acres planted and harvested. But even if the gain in plant efficiency experienced in 2018 is an anomaly, a return to longstanding historical trends would still mean that ethanol production would increase by about 0.3-0.4 bgy annually through 2022.

Table 4. Projected Conventional Ethanol Production 2016-2022 Base Case*

	2016	2017	2018	2019	2020	2021	2022
Corn Acres Planted, million acres	94.2	89.9	89.1	94.0	94.0	94.0	94.0
Planted to Harvested Ratio	92%	92%	92%	92%	92%	92%	92%
Corn Acres Harvested, million acres	86.7	82.7	81.7	86.5	86.5	86.5	86.5
Corn Yield, bushels per acre	174.6	176.6	176.4	178.7	181.0	183.3	185.6
Corn harvested, billion bushels	15.1	14.6	14.4	15.5	15.7	15.9	16.1
Corn used for non-Ethanol Purposes	9.7	9.0	8.9	9.0	9.0	9.1	9.2
Corn Used for Ethanol Production, Billion Bushels	5.5	5.6	5.6	6.5	6.6	6.7	6.8
Ethanol Plant Efficiency, gallons per bushel	2.82	2.84	2.89	2.90	2.91	2.92	2.93
Ethanol Production, billion gallons	15.4	15.8	16.1	18.8	19.2	19.6	20.0
Ethanol Production above 2018, billion gallons				2.8	3.2	3.6	4.0

** 2016, 2017 and 2018 are actual values while 2019-2022 are projections.*

2.2.5 Modeling Sensitivity

Because the model presented here projects volumes in the face of uncertainty, its robustness can be examined by looking at its sensitivity to the impact of changes in its input variables. The key variables used in this ethanol production model are Acres Harvested, Corn Yield per Acre, and Ethanol Plant Conversion Efficiency. Acres Harvested is assumed to remain constant.

Tables 5, 6, and 7 show the values used for these two variables in the base case shown in Table 4 plus values ten percent lower and ten percent higher than the base case to demonstrate the sensitivity of the model to changes in these variables.

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[37] https://www.energy.gov/sites/prod/files/2017/10/f38/cagle_bioeconomy_2017.pdf

[38] https://grains.org/wp-content/uploads/2018/07/Chapter-5.pdf

[39] 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

[40] 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

Table 5. Comparison of Variables Used in Sensitivity Cases

	10% Low Case	Base Case	10% High Case
Corn Yield per Acre Increase	2.07	2.3	2.53
Ethanol Plant Efficiency Increase	0.009	0.01	0.011

Table 6. 10% Lower Case

	2016	2017	2018	2019	2020	2021	2022
Corn Acres Planted, million acres	94.2	89.9	89.1	94.0	94.0	94.0	94.0
Planted to Harvested Ratio	92%	92%	92%	92%	92%	92%	92%
Corn Acres Harvested, million acres	86.7	82.7	81.7	86.5	86.5	86.5	86.5
Corn Yield, bushels per acre	174.6	176.6	176.4	178.5	180.5	182.6	184.7
Corn harvested, billion bushels	15.1	14.6	14.4	15.4	15.6	15.8	16.0
Corn used for non-Ethanol Purposes	9.7	9.0	8.9	9.0	9.0	9.1	9.2
Corn Used for Ethanol Production, Billion Bushels	5.5	5.6	5.6	6.5	6.6	6.7	6.7
Ethanol Plant Efficiency, gallons per bushel	2.82	2.84	2.89	2.90	2.91	2.92	2.93
Ethanol Production, billion gallons	15.4	15.8	16.0	18.8	19.1	19.4	19.7
Ethanol Production above 2018, billion gallons				2.7	3.1	3.4	3.7

Table 7. 10% Higher Case

	2016	2017	2018	2019	2020	2021	2022
Corn Acres Planted, million acres	94.2	89.9	89.1	94.0	94.0	94.0	94.0
Planted to Harvested Ratio	92%	92%	92%	92%	92%	92%	92%
Corn Acres Harvested, million acres	86.7	82.7	81.7	86.5	86.5	86.5	86.5
Corn Yield, bushels per acre	174.6	176.6	176.4	178.9	181.5	184.0	186.5
Corn harvested, billion bushels	15.1	14.6	14.4	15.5	15.7	15.9	16.1
Corn used for non-Ethanol Purposes	9.7	9.0	8.9	9.0	9.0	9.1	9.2
Corn Used for Ethanol Production, Billion Bushels	5.5	5.6	5.6	6.5	6.6	6.8	6.9
Ethanol Plant Efficiency, gallons per bushel	2.82	2.84	2.89	2.90	2.91	2.92	2.93
Ethanol Production, billion gallons	15.4	15.8	16.0	18.9	19.4	19.8	20.3
Ethanol Production above 2018, billion gallons				2.9	3.3	3.8	4.2

The sensitivity cases show that if the estimated corn yield per acre increase and the ethanol plant efficiency are ten percent higher or lower than those estimated for the base case, the amount of calculated ethanol produced above 2018 volumes can range from 3.7 to 4.2 bg in 2022. This is compared to the base case increase of 4.0 bg. Further, these results imply that, without increasing corn acres harvested, the industry could produce an additional 0.3 to 0.4 bg of ethanol in one year (2022 compared to 2021) and 1.0 to 1.3 bg can be produced in the three years between 2019 and 2022. As we explain in an accompanying report,[41] that incremental volume of ethanol could easily be distributed and consumed in 2022.

2.2.6 Comparison of Corn Yield Improvements to Ethanol Plant Improvements

Figure 15 shows a comparison of the gallons of increased ethanol production due to increased corn yields per acre and the gallons of increase ethanol production due ethanol plant improvements. While the improvements in ethanol plant efficiencies has steadily increased since 2007, the largest contribution to the increased ethanol production has been made by the increases in corn yields per acre. Going forward the relative sizes of increased ethanol production are expected to continue to follow this trend.

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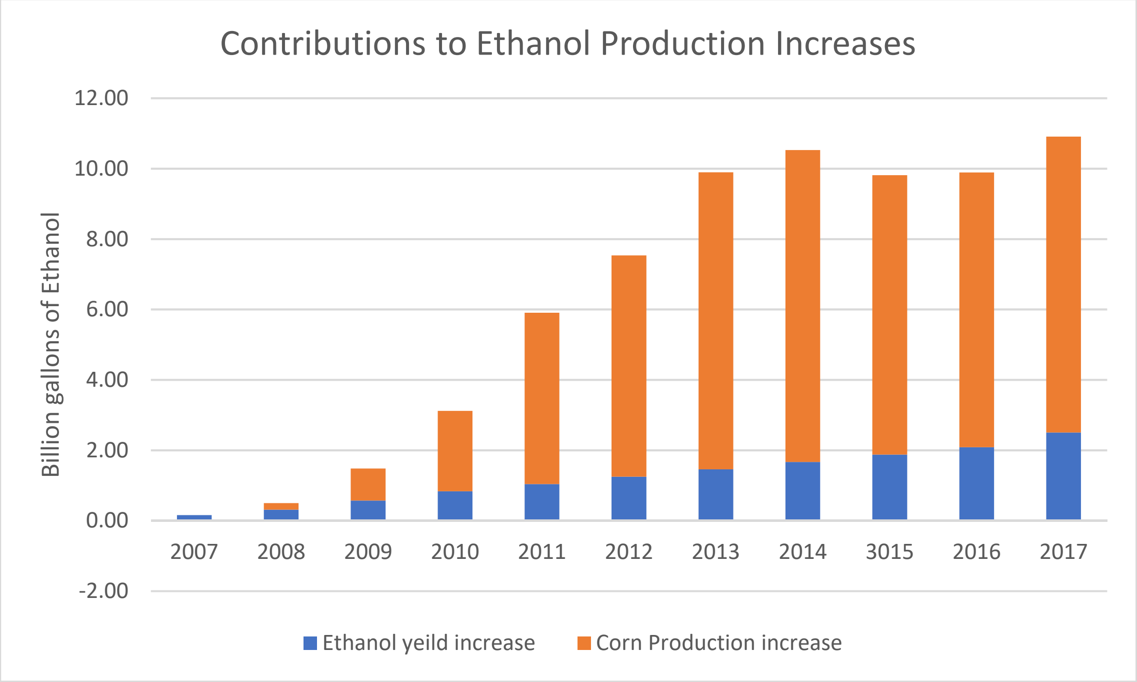
[41] *See* Stillwater Associates LLC, *The RFS Reset and Potential Increased Ethanol Sales Through E85 and E15* (DATE, 2019).

Figure 15. Contributions to Ethanol Production Increases



3 Environmental Impacts

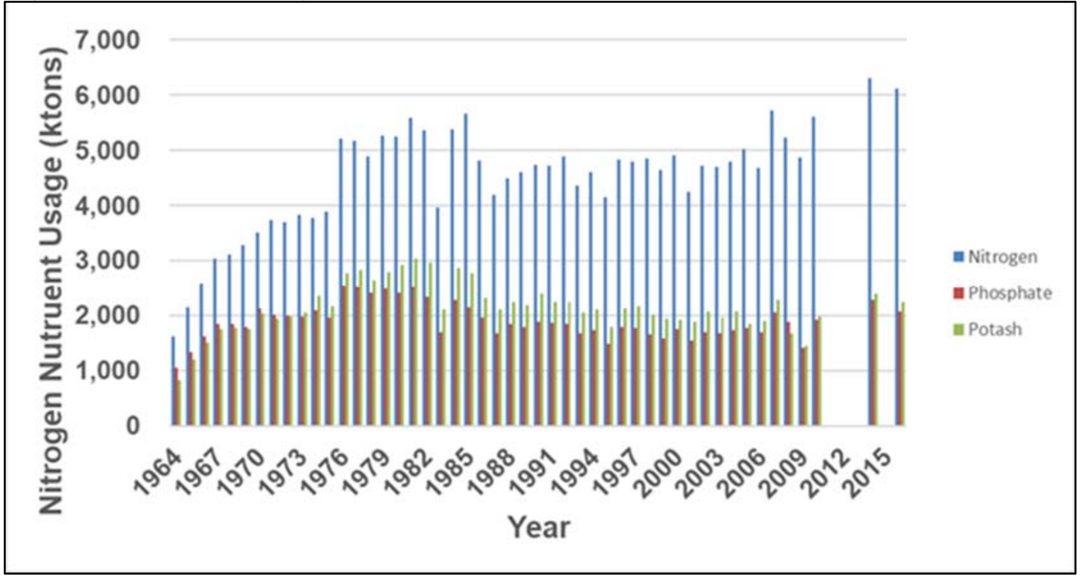
There are several environmental concerns involved with the continued increasing growth of corn and production of conventional ethanol. These concerns principally include greenhouse gas (GHG) lifecycle emissions, water usage, over-usage of agricultural land, runoff and drainage issues, and increased nitrogen 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 20.0 bgy in 2022 is about a 23 percent increase in ethanol production, while total corn production increases from 15.1 billion to 16.1 billion bushels – or almost a seven percent increase – in a six-year period with no additional acres of farmland being used for corn. 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 seven percent improvement in the GHG reduction benefits per acre of corn grown. The growth of seven percent more corn per acre enables the production of 4.0 bgy of ethanol over the four years from 2019 through 2022 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 most of these are based on the use of new acreage, which would not occur in this scenario. In addition to the removal of 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 percent through the application of NOx inhibitors.[42,43] Fertilizer use can be reduced through the use of precision agriculture, variable-rate application, and GPS- and sensor-based mapping which restrict the addition of fertilizer to the area immediately around the plant.[44] Seed improvements have produced plants with improved 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 such concerns from becoming any worse and may help minimize such concerns 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 16 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 17, however, it can be seen that nutrient requirements are trending down on a per-bushel basis.[45] This means that even though the model shows increased production of corn, this does not result in the increased usage of nutrients and in fact has resulted in a reduction in nutrients on a per gallon basis.This improvement comes from better placing the correct amount of nutrients, which reduces the amount of excess nutrients applied.

Figure 16. Nutrient Usage in U.S. Corn Production



Source: USDA

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[42] 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.

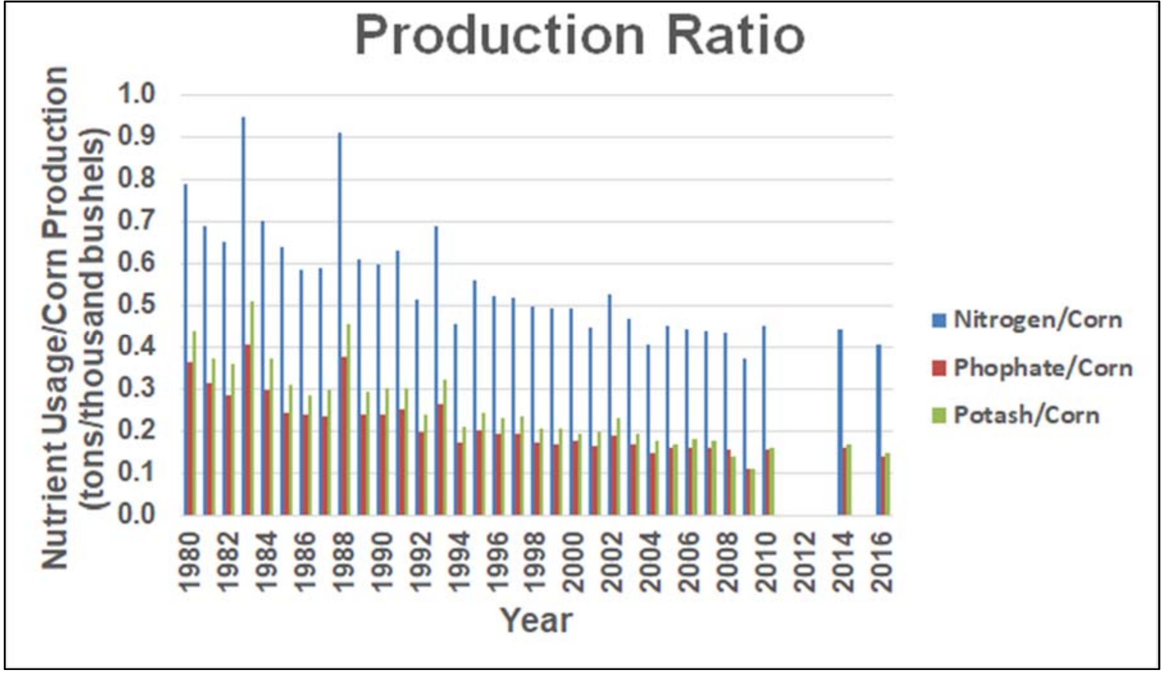
[43] Thapa et al., 2015. Stabilized Nitrogen Fertilizers and Application Rate Influence Nitrogen Losses under Rainfed Spring Wheat. Agronomy Journal, 107(5): 1885-1894.

[44] The Fertilizer Institute. Fertilizer Use. 2016. https://www.tfi.org/statistics/fertilizer-use

[45] Stillwater and EPA are using the same data. EPA looks at Nitrogen (N), Phosphate (P), Potash (K) and Sulphur (S) fertilizers in total (stacking the bars) while Stillwater looks just at N, P, and K and does not stack the bars. EPA's then looks at total application rate per acre and sees it leveling off. They further comment that as application rates per acre have leveled and per-acre yields improve, application rates per bushel have declined. Stillwater does not comment on application rates per acre but goes directly to rates per bushel and shows a decline. Stillwater then moves its focus to future trends which are expected to further decrease per-bushel application rates while EPA's Second Triennial Report looks only at trends up to the present.

Projecting out through 2022, 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[46] 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. This will result in even lower nutrient usage per gallon of ethanol. 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 have taken place for the past 50-80 years in the production of corn and ethanol.

Figure 17. Nutrient Usage in Corn Production on a Per-Bushel Basis



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[46] 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.

4 Conclusions on the Growth of Conventional Ethanol Production

The farmland acreage devoted to corn production for the past ten years since the beginning of the RFS (2008-2017) has been fairly constant while corn yields have increased 12 percent from 13.0 billion 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. 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. Our analysis anticipates that these trends will continue through 2022.

This analysis has examined the continuation of these trends and found that from 2018 to 2022 an additional 1.7 billion bushels of corn can be produced on the same number of acres that was used in 2007. Assuming that non-ethanol demands for corn grow at the same rate as population, 0.3 billion additional bushels would be required annually to supply feed, seed, and non-ethanol industrial uses of ethanol (such as high fructose corn syrup, cationic starch and renewable chemicals feedstock). This would leave 1.4 billion bushels of new corn available for ethanol production, enough to achieve a production rate of 4.0 bgy of new ethanol in 2022.

Since this 4.0 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.