ENVIRONMENT
& HEALTH

REVIEW OF ENVIRONMENTAL EFFECTS AND ECONOMIC ANALYSIS OF CORN PRICES: EPA’S PROPOSED RFS STANDARDS FOR 2023-2025

Prepared at the Request:
Growth Energy

Prepared By:
Ramboll and Net Gain Ecological Services

Date:
February 2023

RAMBOLL

Contents

Table of Figures

Table of Tables

Acronyms and Abbreviations

%	percent
CDL	Cropland Data Layer
CRP	Conservation Reserve Program
DDGS	distiller's dried grains with solubles
DRIA	Draft Regulatory Impact Analysis
EPA	Environmental Protection Agency
ERS	Economic Research Service
FAPRI	Food and Agricultural Policy Research Institute with Greenhouse Gases model
FASOM	Forest and Agricultural Sector Optimization international model
HPA	High Plains Aquifer
LUC	land use change
MTBE	methyl tertiary-butyl ether
NASS	National Agricultural Statistics Service
NGES	Net Gain Ecological Services
NWI	National Wetland Inventory
RFS	Renewable Fuel Standard
RIA	Regulatory Impact Analysis
RIN(s)	renewable identification number(s)
SRE(s)	small refinery exemption(s)
US	United States
USDA	United States Department of Agriculture

1. Executive Summary

Ramboll and Net Gain Ecological Services have reviewed the Environmental Protection Agency's (EPA's) Proposed Renewable Fuel Standard 2023-2025 rule (the "Set Proposal" or "Proposed Rule") and the accompanying Draft Regulatory Impact Analysis (DRIA) along with many of the cited articles.[1] After careful review of the Set Proposal and the DRIA, and based on our own literature review and independent analysis, we find that there is no demonstrated causal link between the Renewable Fuel Standard (RFS), and land use change (LUC) or water quality. Furthermore, we conclude that the renewable fuel volumes suggested in the Proposed Rule for 2023-2025 are likely to have minimal or no effects on water quantity, quality or LUC. Our analysis focused on:

- The economic effect of the RFS on corn prices and acres planted in corn.
- The causal linkage between the RFS and LUC.
- Wetlands, ecosystems, habitat, and wildlife.
- Soil and water quality and water quantity.

1.1 Economic Analysis

Based on the economic research and regression analyses developed by Ramboll, we conclude that the RFS implied conventional renewable fuel volume (hereafter "the implied conventional volume")[2] has minimal to no effect on corn prices or acres of corn planted. The economic analysis we conducted for this report used EPA's DRIA as a foundation for evaluating the potential impact of the implied conventional volume on corn prices and acres of corn planted. We utilized 18 years of observational data in our models following fundamental economic theory. This evaluation was conducted and is reported in three main steps:

(1) Review of the Proposed Rule and DRIA.
(2) Review of relevant literature both criticizing and supporting the RFS.
(3) Development of a series of analytical models to determine which literature has the most accurate analysis and to determine whether the RFS is a driving factor influencing corn prices and acres of corn production.

For these purposes, EPA's DRIA reached the following significant economic conclusions:

- The net effect of the implied conventional volume on corn prices from the years 2023 through 2025 is estimated at $0.10/bushel, i.e., it is expected to be minimal. (DRIA, p. 409).
- Distiller's dried grains with solubles (DDGS) is a significant substitute for whole corn in the animal feed market. (DRIA, pp. 406–407).
- Year-ending corn stock-to-usage ratio (amount of corn production stored versus amount used) has a strong inverse correlation with corn futures prices and a dampening effect on prices in years when corn harvest is lean (DRIA, pp. 409–410).

The economic analysis literature review focuses on three primary papers:

---

[1] The recently released Draft Third Triennial Report to Congress External Review that is currently undergoing peer review was not reviewed as part of this analysis.

[2] See Section 2 for further explanation.

- Lark et al. (2022): Environmental outcomes of the US Renewable Fuel Standard.
- Austin et al. (2022): A review of domestic land use change attributable to U.S. biofuel policy.
- Taheripour et al. (2022a): Economic impacts of the U.S. Renewable Fuel Standard: An *ex-post* evaluation.

These three papers provide unique perspectives regarding the RFS program. Lark et al. (2022) takes an overall negative view of environmental and economic impacts of the RFS program. Austin et al. (2022) and Taheripour et al. (2022a) both contain information and analysis that highlight the deficiencies in Lark et al. (2015 and 2022, respectively).

Lark et al.'s (2022) results claim that for the years 2008 through 2016, the RFS program:

- Increased corn prices in the US by 30 percent (%).
- Increased the prices of other crops by 20%.
- Expanded US corn cultivation by 2.8 million hectares (equivalent to 6.9 million acres).

These findings would be reason for concern if valid and reliable; however, we demonstrate herein (Table 3-1 and Figure 3-2) that these results do not correspond with observed data from the referenced years (*e.g.*, corn prices fluctuated and were lower in 2016 than in 2008 and corn acres planted during the time frame of Lark et al.'s [2022] analysis were within historical levels). We conclude that Lark et al.'s (2022) analysis overestimates the impact of the RFS program on corn prices and corn acres planted as result of:

- Using a baseline that is too low (perhaps one third of what it should be).
- Focusing only on the US market and not accounting for the dampening effect of the global market corn prices and acres planted.
- Not accounting for the offsetting impact of DDGS as an animal feed replacement for corn.
- Not accounting for offsetting impact of increasing corn yield on acres planted.

Austin et al. (2022) reviewed and summarized 29 studies published since 2008 that attributed LUC in the United States (US) to the RFS program. In addition, they provided recommendations based on their analysis of the studies. We find that their most important recommendation is that to evaluate the effects of the RFS program, it is necessary to use an integrated model that captures global economy-wide interactions and simulates a detailed representation of the US land sector. Simply stated, a model that evaluates both global and domestic market interactions is needed.

We find that Taheripour et al. (2022a) provides the most credible work regarding the impact of the RFS program. We base this conclusion on the following attributes of their modeling approach:

- Uses an integrated model to account for global market interactions and US land sector.
- Includes an analysis of four different baselines across two different time periods.
- Accounts for increased corn yield, increased ethanol productivity, and the use of DDGS as a whole corn feed replacement.
- Uses observation data for the purpose of model calibration.

Below is a short list of conclusions reached by Taheripour et al. (2022a):

- Real crop prices have increased between 1.1 and 5.5% from 2004 to 2011 with only one-tenth of the price increases attributable to the RFS program.
- For 2011 to 2016, the long-run price impacts of biofuels were less than the period of 2004 to 2011.
- The impact of the RFS program on crop (i.e., corn, soybean, wheat) prices and acres planted is very small.

Regarding the DRIA, we find that the EPA uses an integrated model (DRIA Section 4.2.1.2) that includes international and domestic impacts and a baseline that assumes market production of ethanol without the RFS. The EPA's modeling approach is aligned with that of Taheripour et al. (2022a) and with the approach recommended by Austin et al. (2022). Therefore, EPA's results regarding the corn price impact of the RFS are more consistent with those found by Taheripour et al. (2022a) rather than those provided by Lark et al. (2022).

Ramboll performed its own economics analysis for the purpose of evaluating:

- The effect of the RFS and ethanol production on corn prices and acres of corn planted.
- Which research efforts best represent the potential effect of the RFS on corn prices and corn acreage planted.

Ramboll's analysis involves two primary analytical techniques: linear regression and the analysis of correlation coefficients. Linear regressions are commonly used in economics to establish empirical relationships between variables. Linear regressions can use either a single variable or multiple variables to identify the effect of one variable or a set of variables (i.e., explanatory variables) on the parameters of interest (i.e., dependent variables). Our analysis makes use of 18 years of observational data, i.e., 2005 to 2022. In presenting the result of our analysis we frequently use the term statistical dependency. This term means that a statistical relationship exists such that the independent values (i.e., potential explanatory parameter or X-value) can be used to approximate or explain the dependent value (i.e., value of interest or Y-value). Our analysis uses statistical results from linear regressions in conjunction with correlation to evaluating statistical dependency between the variables of interest and reaching reasonable conclusions regarding the potential degree of statistical dependency. Based on this analysis, we reached the following conclusions.

- The statistical dependency between corn prices and the implied conventional volume is either non-existent or very weak.
- The statistical dependency between corn prices and ethanol plant production is either non-existent or very weak.
- Multi-variate analysis indicates that the implied conventional volume and ethanol production have minimal to no effect on corn prices or corn acres planted.
- Corn futures prices are statically dependent on the corn ending stock-use-ratio and soybean futures prices.
- The number of corn acres planted is statistically dependent on corn futures prices and soybean futures prices; however, neither of these factors are statistically dependent on the RFS volumes.

Overall, our research concludes that the studies conducted by the EPA (2022b), and Taheripour et al. (2022a), are representative of the likely effects of the implied conventional volume and ethanol production on corn prices and corn acres planted whereas Lark (2022) is not.

1.2 Land Use Change

After our review of the EPA's analysis of potential LUC caused by the RFS, we find there is no evidence of a causal link between the RFS and LUC. We further find that the Proposed Rule is likely to result in minimal or no land conversion or significant adverse effects to wetlands, ecosystems, wildlife habitat, or water quality. Our analysis reviews the cited literature in the Proposed Rule and DRIA in addition to other pertinent documents. LUC is referred to in several different sections in Chapter 4 of the DRIA. In these sections, we find that the EPA cites many articles that erroneously purport to establish a causal connection between the RFS and LUC without clearly explaining the shortcomings of the erroneous literature, or consistently citing the literature that finds errors in the methodology. We recommend that in the final Regulatory Impact Analysis (RIA), the EPA clearly document the shortcomings of studies purporting to show a causal link between the RFS and LUC and cite literature critical of those studies. Specifically, we have the following recommendations for how EPA can improve its analysis:

- In the Air Quality section (DRIA section 4.1) and the Conversion of Wetlands, Ecosystems, and Wildlife Habitat Section (DRIA section 4.3), we recommend that the EPA explicitly acknowledge the shortcomings in the use of the Cropland Data Layer (CDL) for analysis of LUC to and from agriculture. The CDL has been documented to poorly differentiate between native grassland, pasture, fallow land, and crops which results in an overestimation of LUC (Copenhaver 2022; Dunn et al. 2017; Pritsolas and Pearson 2019; Shrestha et al. 2019; and Taheripour et al. 2022b). The CDL also has a resolution of 30 to 56 meters, which is too coarse for accurate measurement of LUC (Copenhaver 2022). Unfortunately, several heavily cited papers in the DRIA rely on the CDL to causally link the RFS program to LUC. Papers which depend upon the CDL for their analysis include Lark et al. (2015), Lark et al. (2021), Lark et al. (2022), Wright et al. (2017), and Johnston (2013). When these papers are cited, EPA should acknowledge that they rely on the CDL and refer to an explicit description of the shortcomings of using the CDL to quantify LUC.
- Several cited papers causally attribute LUC to the RFS program without having conducted a quantifiable causal analysis. For example, some authors attributed causality while admitting that other factors were not considered (Wright et al. 2017). We recommend that when the EPA cites these documents, it explicitly acknowledges that a causal analysis was not carried out. The final RIA should include citations for several recent articles that the DRIA does not cite: Copenhaver (2022), Dunn et al. (2017), Shrestha et al. (2019), Pritsolas and Pearson (2019), and Taheripour et al. (2022b). The EPA should acknowledge that these papers analyzed the work of Lark et al. (2015), Lark et al. (2022), and Wright et al. (2017), and clarified the weaknesses in their analyses.
- Finally, some of the cited articles in the DRIA imply, without adequate support or analysis, that a farmer's decision on crop type and where to plant is strongly determined by the RFS (Johnston 2013; Wright et al. 2017). The EPA should clarify that an individual farmer's decision is complex and may take into account many factors including: weather, soil health, market prices, land availability, contracts, prices for other crops, agricultural pests, and other factors.

1.3 Soil and Water Quality

In addition to LUC, the EPA discusses the effects of additional farming pressure on soil and water quality in Section 4.4 of the DRIA. However, because the lack of a *causal* relationship between the RFS and soil and water impacts is not clearly stated in Section 4.4, this this section may wrongly imply that there is such a causal relationship. The soil and water quality section states that "impacts to soil and water quality depend upon the feedstock grown and land use – i.e., the type of land used for growing the biofuel feedstock and the management implemented on that land" (DRIA, p. 254). The section then goes on to detail the negative effects of extensification to soil and water quality. But in the LUC section of the DRIA (DRIA section 4.3) the EPA stated it could not quantify any relationship between the RFS program and LUC[3]. In the beginning of the Soil and Water Quality section (DRIA section 4.4), the EPA explains that additional farming pressure can be caused by either intensification or extensification and can cause further use of pesticides and fertilizers which may lower soil and water quality. The EPA also states that extensification causes more harm than intensification[4], further strengthening the implication that soil and water quality are negatively affected by extensification caused by the RFS. Ramboll and Net Gain Ecological Services (NGES) recommend the following specific changes for the final RIA:

- Clearly state that the EPA has not found a causal link between the RFS program and LUC or extensification in the beginning of the section to alleviate misunderstandings.
- Remove the text calculation (DRIA, p. 255) of a theoretical increase in nitrogen applied to farm fields nationwide due to corn extensification for two reasons: 1) the EPA reported in Section 4.3 of the DRIA that there was has been no quantifiable causal link shown between the RFS and LUC (extensification)[5]; 2) the calculation itself is flawed because the assumption regarding acres of extensification for corn is based on the work of Lark et al. (2015), which is unreliable due to its reliance on CDL data.
- Clearly state that there is no known causal link between the RFS and negative effects to soil health or water quality.
- When mentioning that nutrient loading causes hypoxic zones (DRIA, p. 260), include necessary context such as the US Geological Survey (2021), which shows that nitrogen loading to the Gulf of Mexico remained fairly constant from the early 1990s through about 2008 and then actually began a decreasing trend. Thus, it is unlikely the hypoxic zone is causally tied to the RFS.

1.4 Water Quantity and Availability

We agree that additional farming pressure could lead to more irrigation in water stressed regions without adequate natural rainfall; however, the EPA has not identified any causal connection between the RFS and additional farming pressure. Indeed, we agree with EPA's statement that, "[t]o our knowledge, there have been no comprehensive studies of the changes in irrigated acres, rates of irrigation, or changes in surface and groundwater supplies attributed specifically to the increased production of corn grain-based ethanol and soybean-based biodiesel" (DRIA, p. 273). The EPA finds no quantitative causal link between the RFS and negative environmental effects, which in this case is water quantity. The EPA should therefore make it

---

[3] DRIA Section 4.3, p. 240 – "However, at this time we cannot quantify the amount of land with increased intensity of cultivation nor confidently estimate the portion of crop land expansion that is due to the market for biofuels."

[4] DRIA Section 4.4.2.1, p. 254 – "For a given acre of cropland, planting corn or soybeans onto grasslands (extensification) can be expected to have greater negative effects on soil and water quality relative to the conversion of other existing cropland, such as wheat, to corn or soybeans (intensification)."

clear that section 4.5 of the DRIA is not intended to imply that there is such a causal link. We recommend the following changes for the final RIA:

- Clearly elucidate that there is no published evidence of a causal link between agriculture for biofuel and reductions in surface water or groundwater supplies.
- Remove the citations to Lark et al. (2015) and Wright et al. (2017) in this section as evidence of LUC which could increase irrigation. As explained above, these articles are flawed in their calculation of LUC because of their dependence on the CDL.
- Acknowledge that most of the corn produced for biofuel in Nebraska is grown in regions of the state that primarily use precipitation for crop growth.
- Add information on other factors besides agriculture that affect aquifer levels, such as precipitation patterns and associated recharge, drought years, and technology that improves the efficiency of agricultural and ethanol production.

We encourage the EPA to update its analysis so that the final RIA addresses the above recommendations. Even in its draft form, EPA's analysis firmly supports that the volumes proposed for 2023 through 2025 are unlikely to result in adverse environmental impacts.

2. Introduction

EPA (2022a) proposes volume standards for 2023 through 2025 for cellulosic biofuel, biomass-based diesel advanced biofuel, and total renewable fuel. The focus of Ramboll's analysis is on the economic impact of the conventional renewable fuel volume established by the RFS with respect to potential effects on LUC, habitats, wildlife, and water quality and quantity. Conventional renewable fuel is that portion of the total renewable fuel that meets a 20% greenhouse gas reduction standard and does not qualify as advanced, cellulosic, or biomass-based diesel biofuel. For purposes of this report, conventional renewable fuel, for which there is an implied volume requirement rather than an explicit requirement, refers to ethanol made from corn starch.

Table 2-1 below is an abbreviated version of Table I.A.1-1 from EPA (2022a). The table summarizes the implied conventional renewable fuel volume requirement, which we refer to in this report as the implied conventional volume, for the years 2023 to 2025. All volumes are in billions of gallons per year. Note that the implied conventional volume is obtained by subtracting the advanced biofuel volume from the total renewable fuel volume. The implied conventional volume is 15.00 billion gallons per year for 2023 and 15.25 billion gallons per year for 2024 and 2025. It should be noted that the projected amount of the implied conventional volume to be made up of corn ethanol for the years 2023, 2024 and 2025 are 14.455, 14.505 and 14.534 billion gallons respectively (EPA 2022a Table III.C.3-1). However, for the purpose of this analysis Ramboll made the simplifying and conservative assumption that the implied conventional volumes listed in Table 2-1 would be made up entirely of corn ethanol.

Table 2-1. Implied Conventional Volume in the RFS 2023 - 2025

	2023	2024	2025
Total Renewable Fuel	20.82	21.87	22.68
Advanced Biofuel	5.82	6.62	7.43
Implied Conventional Volume	15.00	15.25	15.25

Source: EPA 2022a

The focus of Ramboll's analysis is on the impact of the implied conventional volume on corn prices, the number of acres of corn planted annually, and other environmental effects. Although the Set Proposal pertains to the years 2023 to 2025, our analysis also considers the impact for the years 2005 through 2022. This is because understanding past impacts is useful for evaluating the quality of forecasted impacts provided by the DRIA. (i.e., EPA 2022b). In addition, understanding past impacts is required to address assertions by some researchers that the RFS program has led to significant increases in corn prices and LUC by the conversion of formerly non-tilled land, or land used for other crops, into land used for corn crops.

In this report, we review and evaluate EPA's Set Proposal and DRIA, including selected literature the agency newly references, and we continue to find that there is no evidence the RFS program causes the above listed adverse environmental impacts. We agree with EPA's finding that there is no evidence the Proposed Rule causally links to land conversion or adverse impacts to wetlands, ecosystems, wildlife habitat, water availability or water quality. We encourage the EPA to update its analysis in the final RIA to address these findings and revise its potentially misleading discussion of environmental impacts of the program where noted.

3. Economic Analysis

This section describes the economic analysis performed by Ramboll to evaluate the impact of the Proposed Rule with respect to corn prices and potential implications for LUC. The DRIA contains a significant amount of information indicating that since the inception of the program, the RFS has had minimal impacts on corn prices and corn acres planted in the past and will likely have minimal impacts in the future. The DRIA contains the following information that Ramboll concludes are reasonable based on our literature review and our own economic analysis, though EPA may overstate the (minimal) impact of the proposed volumes on corn price:

- Trends from 1995 through 2021 indicate that corn production grew steadily at a 25-year average rate of around 2%, or 250 million bushels per year, with no apparent correlation to ethanol production volumes.
- The net effect of the RFS on corn prices throughout the years 2023 through 2025 is 3%, which is equivalent to $0.10/bushel (depicted in Table 3-3). Ramboll's economic analysis did not involve forecasting the impact of the implied conventional volume on corn price. However, our modeling indicates that **the statistical dependency between the implied conventional volume and corn prices is non-existent to very weak**. Therefore, it possible that the impact of the implied conventional volume on corn prices would be much less than $0.10/bushel.

- DDGS, a byproduct of ethanol production, represents a significant factor in the shift of animal feed away from whole corn (i.e., DDGS is a significant substitute for whole corn in the animal feed market).
- Year-ending corn stock-to-usage ratio (amount of corn production stored versus amount used) has a strong inverse correlation with corn futures prices and a dampening effect on prices in years when corn harvest is lean.
- Corn futures prices are a critical factor in farmer's planting decisions.
- The RFS has little to no impact on corn futures prices.

Our economic analysis involved the following four activities:

1. Review of the Set Proposal (EPA 2022a) and the associated DRIA (EPA 2022b).
2. Literature review of research focusing on the economic impacts of the RFS program since inception, particularly in relation to corn prices and annual corn acreage planted.
3. Review of analytical methods used by researchers to evaluate the impact of the RFS program on corn prices and corn acreage planted.
4. Development of our own analytical models for purposes of confirming and/or refuting information in the DRIA and the work performed by other researchers.

Since estimates of the impacts of the RFS (whether developed by the EPA or other researchers) are based on economic modeling, Section 3.1 is included for purposes of describing the complexities associated with modeling the system of interactions that result in corn prices and number of corn acres planted each year. Section 3.2 summarizes our literature review including the assertions of researchers critical and supportive of the RFS program. Section 3.3 presents the results of Ramboll's modeling efforts that evaluate, at a high level, the modeling efforts by EPA and other researchers to estimate the impact of the RFS on corn prices and acres planted. Section 3.4 summarizes the economic analysis results and conclusions.

3.1 Complexities in Modeling the Effect of the RFS on Corn Prices and Acres Planted

As previously stated, the EPA has a statutory obligation to perform an analysis of various environmental and economic impacts of proposed RFS volumes. Economic modeling is useful for such an analysis. The EPA's modeling is forward looking, meaning that it focuses on estimating the impact of the RFS in years 2023, 2024, and 2025. To perform such a forward analysis, the EPA develops two models; the first assumes that the proposed RFS is in place and the second assumes that the RFS is not in place. This second model is a baseline model.

In the future, after the proposed RFS volumes are implemented, it will be possible to collect observational data regarding corn prices and acres planted for the years 2023 through 2025. However, to evaluate the impact of the RFS program, additional modeling efforts will be required. This is because it is not possible to collect observational data for a baseline that assumes no RFS program, when in fact the RFS has been implemented. Therefore, the EPA, or any other research group interested in studying the impact of the RFS program, must develop a baseline model for purposes of comparison. As we demonstrate in Section 3.3, the baseline model and its associated assumptions are crucial to such analysis.

The EPA's modeling efforts go beyond estimating the impacts of the RFS program on corn prices and acres planted in corn. However, many of the other impacts such as the effect on habitat, endangered species, and undeveloped land directly or indirectly relate to changes in the number of acres planted in corn. Therefore, models that can reasonably estimate acres planted in corn, under the assumptions of RFS or no RFS (baseline), are fundamental to evaluating all other impacts.

A fundamental economic principle is that an increase in demand for a particular product will lead to an increase in the price of that product. This is because as demand increases, producers will be able to charge more for the product without experiencing a decrease in the number of products sold (in economic terms, such increased demand is known as an upward shift in the demand curve). Another fundamental principle is that as the price increases, more suppliers will enter the market to take advantage of the higher prices and the opportunity to achieve higher profits. Eventually, as more product is supplied, demand will be met, and producers will have to lower the price to move excess product (the lowering of prices because of increased supply in economic terms is referred to as a downward shift in the supply curve).

A general concern of those critical of the RFS program is that it induces increased demand for ethanol to meet the implied conventional volume. These individuals further assume, based on basic economic principles, that the induced demand for ethanol will increase demand for corn which will in turn increase corn prices. Finally, in this chain of impacts, they assume that farmers will plant more acres of corn to sell at these higher prices. There is concern that available tillable land for corn planting will be exhausted and landowners will begin converting other land previously not used for corn agriculture (e.g., wetlands or grasslands) or they will divert land used for other crops to corn production. The concern regarding the latter choice is that the prices of other crops will go up since their supply in the market would be reduced. Lark et al. (2022) has engaged in significant analysis and modeling which they believe validates this chain of impacts. However, as discussed in the Economic Literature Review section, Ramboll disagrees with Lark et al.’s (2022) results.

Although critics of the RFS program correctly rely on fundamental economic principles, they make errors including assuming a closed system and oversimplifying the planting decision. Assuming a closed system is incorrect because the price of corn within the US is only partially based on economic activities within the US. In reality, there is a great deal of global trade in corn and ethanol. The price of corn within the US is strongly affected by global supply and demand as well as policies in other countries and complex trade agreements. Simplistic concepts of supply and demand do not account for all the complexities associated with global markets. Furthermore, very complex economic modeling is needed to simulate all the interrelated realities of the corn planting decisions made by individual farmers. Figure 3-1 provides a conceptual model of many the factors that farmers may consider when deciding how much of their land to plant in corn and whether to invest in methods to increase corn yield (intensification).

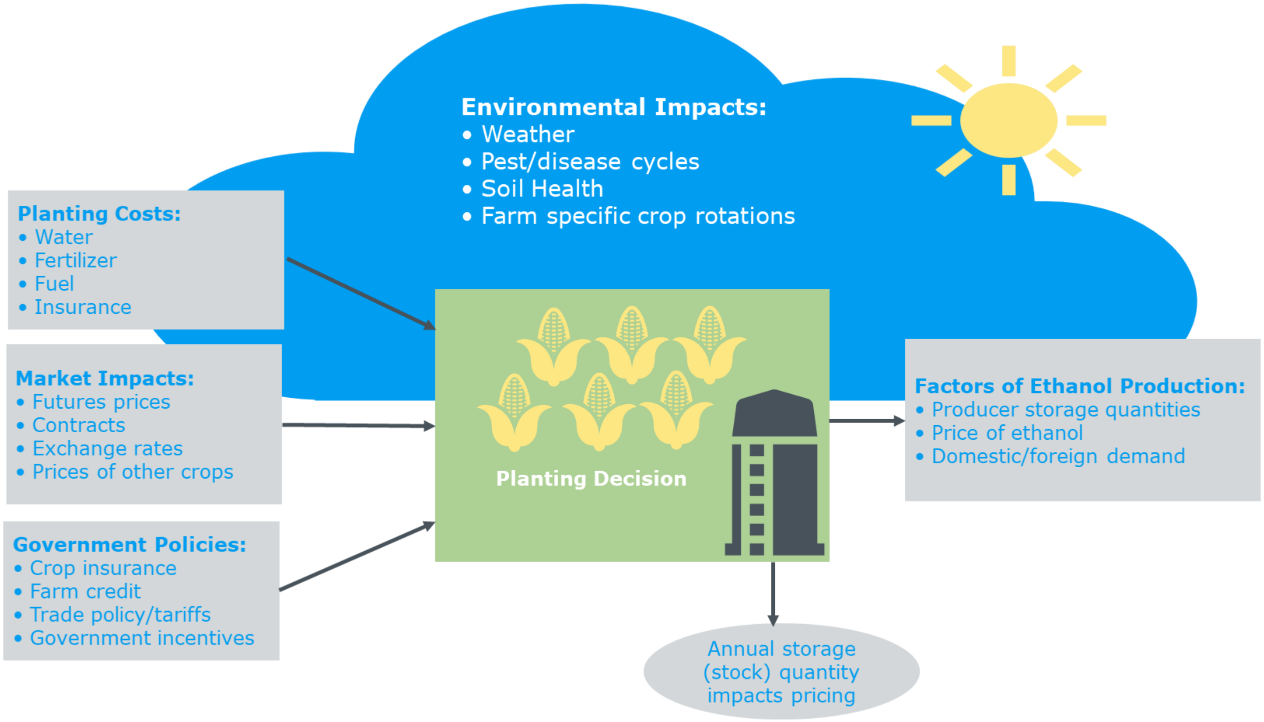

Figure 3-1. Corn Planting Decision Complexity

The various inputs known to play a crucial role in farmer planting decisions include weather, soil health, market prices, land availability, contracts, prices for other crops, and agricultural pests, among others.

It is likely that large corporate farming operations adjust their planting based on all the factors presented in Figure 3-1. However, according to the US Department of Agriculture (USDA), approximately 89% of all US farms are small family farms, having a gross cash farm income of less than $350,000, and these farms make up approximately 53% of corn production (USDA Economic Research Service [ERS] 2022). With small family farms in the US producing most of the corn, farmers may not be able to plant the crop that simply produces the best market prices. Instead, they may need to honor crop rotations, the demands of other aspects of their farm operations (land needed for grazing cattle or sheep), and other factors important to farmers at this scale.

With so many variables entering into the corn planting decision at the local level, isolating and modeling the effects of a single factor such as the renewable fuel volume is extremely difficult. This is especially true when one considers that corn ethanol was being produced prior to the RFS program and that ethanol production would continue without the RFS program. Ethanol production would continue because ethanol is used in many different markets including fuel, pharmaceuticals, cosmetics, and beverages. In addition, ethanol would continue to be added to gasoline as an oxygenate due to the ban on methyl tertiary-butyl ether (MTBE[5]) implemented in 2006. The fact that ethanol production occurs regardless of the RFS program further complicates isolating the effect of a specific policy driven factor.

Ramboll analyzes ethanol production and the implied conventional volume for the years 2005 through 2022. The year 2005 is chosen as the starting point since it represents the year before the RFS program was implemented. In 2005, a total of four billion gallons of ethanol was produced without the incentive of the RFS program. This analysis further indicates that over the 16-year period, actual ethanol production exceeded the implied conventional volume in all but four years, i.e., 2012, 2013, 2014 and 2020 (it should be noted however that 2012 was an extreme drought year and the COVID-19 pandemic was occurring in 2020). In addition, actual ethanol production exceeded the implied conventional volume by an average of 0.73 billion gallons throughout the period of 2006 through 2022. This indicates that the rate of ethanol production is likely determined more by market demand than by the RFS. Furthermore, it demonstrates that it is very difficult to isolate the impact of the RFS from general market demand.

3.2 Economic Literature Review

This section incorporates a review and summary of recent relevant literature regarding the potential impact of the RFS program on the corn industry.

We review the following key papers:

- Lark et al. (2022): Environmental outcomes of the US Renewable Fuel Standard.
- Austin et al. (2022): A review of domestic land use change attributable to U.S. biofuel policy.
- Taheripour et al. (2022a): Economic Impacts of the U.S. Renewable Fuel Standard: An *Ex-Post* Evaluation.
- EPA (2022b): Draft Regulatory Impact Analysis: RFS Standards for 2023-2025 and Other Changes.
- Taheripour et al. (2022b): Comments on "Environmental Outcomes of the U.S. Renewable Fuel Standard."
- Taheripour et al. (2022c): Response to Comments from Lark et al. Regarding Taheripour et al. March 2022 Comments on Lark et al. Original PNAS Paper.
- Carter et al. (2017): Commodity storage and the market effects of biofuel policies.
- Carter et al. (2011): Commodity booms and busts.

Much of the information in this section pertains to the first three papers i.e., Lark et al. (2022), Austin et al. (2022), and Taheripour et al. (2022a), along with the DRIA (EPA 2022b). We use the remaining documents to a lesser degree, primarily to address issues or call attention to data that either confirms or refutes information in the first three papers and the DRIA.

We give special attention to the first three papers in this list because they provide three unique perspectives regarding the RFS program. Lark et al. (2022) took an overall negative view of economic and environmental impacts of the RFS program. Austin et al. (2022) reviewed and summarized 29 studies published since 2008 that attributed US LUC to the RFS program. In addition, Austin et al. (2022)

---

[5] MTBE was used in gasoline starting in the mid-1980s to increase efficiency and reduce pollution. However, MTBE was found in some water sources and in blood in humans and was then banned in several states (Centers for Disease Control and Prevention 2017). Ethanol provides oxygenation of gasoline similar to MTBE and has been used as a replacement (Kanaskie 2000).

provided recommendations based on their analysis of the various studies. Taheripour et al. (2022a) refuted many of the statements contained within Lark et al. (2022).

3.2.1 Lark et al. (2022)

The Lark et al. (2022) paper focused on presumed negative externalities associated with the production of corn-based ethanol in the US, namely, reducing land used for conservation, water quality, and failing to meet the reduced greenhouse gas emissions reduction goals of the program (Lark et al. 2022). From a strictly economic perspective, the findings of concern in the Lark et al. (2022) paper are that for the years 2008 through 2016 the RFS:

- Increased corn prices in the US by 30%.
- Increased the prices of other crops by 20%.
- Expanded US corn cultivation by 2.8 million hectares (equivalent to 6.9 million acres).

These findings would be reason for concern if they were credible; however, they do not correspond with observed data from the referenced years. Table 3-1 below presents the average annual spot price data for corn, soybean and wheat as obtained from the USDA. A review of this data indicates the prices for all three crops varied widely throughout this time frame and the spot price for each crop was lower in 2016 than in 2008.

Table 3-1. Annual Spot Prices for Corn, Soybeans and Wheat

Year	Average Annual Corn Spot Prices	Average Annual Soybean Spot Prices	Average Annual Wheat Spot Prices
2008	$5.30	$12.32	$7.99
2009	$3.75	$10.20	$5.34
2010	$4.31	$10.49	$5.87
2011	$6.80	$13.19	$7.14
2012	$6.92	$14.62	$7.54
2013	$5.69	$13.86	$6.86
2014	$4.16	$12.29	$5.89
2015	$3.78	$9.42	$5.08
2016	$3.60	$9.88	$4.39

Given that the spot price for corn in 2016 was below the price in 2008, one could argue that the lower prices represent the long-term result of increased corn acres planted; perhaps as much as 6.9 million acres as reported Lark et al. (2022). However, USDA data from 1926 to 2022 indicate that there has not been a significant increase in corn production acres, but rather a decrease in total acres of corn planted across the US (see Figure 3-2). The data show peak acreage was planted in 1932 at 113 million acres (USDA National Agricultural Statistics Service [NASS] 2023a).

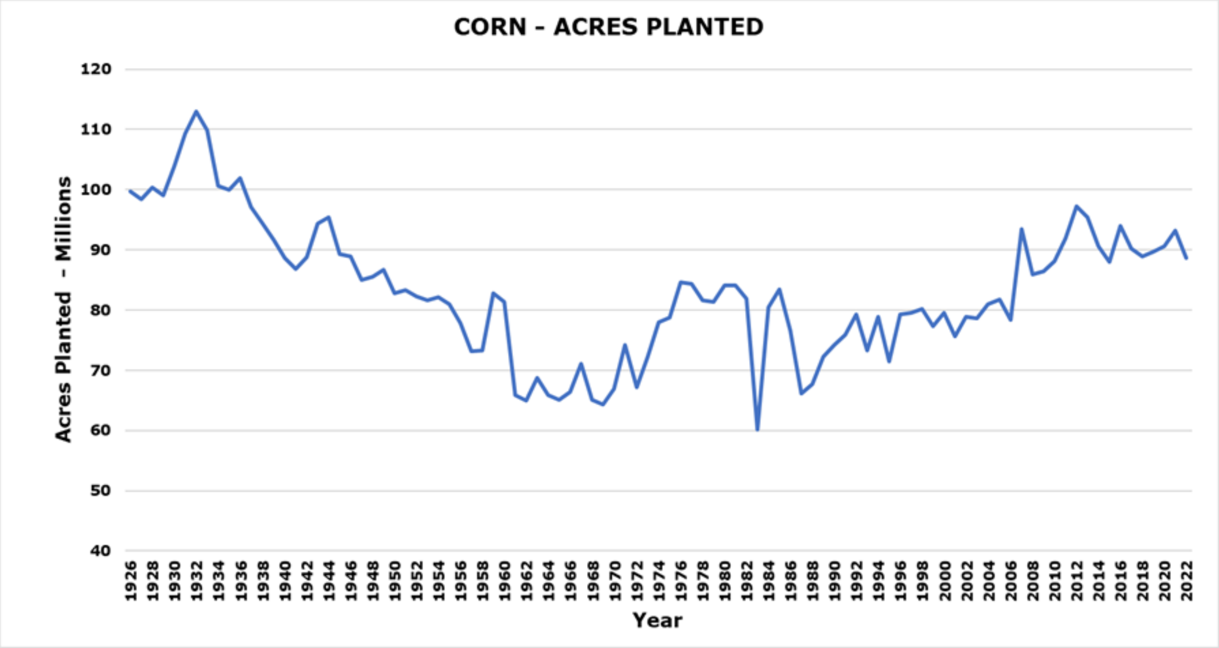

Figure 3-2. Long-Term Acres Corn Planted

Data Source: Corn Acres Planted – USDA NASS 2023a

Given the information in Table 3-1 and Figure 3-2, many would find it difficult to understand how Lark et al. (2022) could make claims that corn prices have increased by 30% and corn acres cultivated have expanded by 6.9 million acres. The answer is likely found in the choice of baseline and modeling methodology in Lark et al. (2022).

Although the baseline chosen by the Lark et al. (2022) paper included only the ethanol needed to meet the requirements under the 1990 Clean Air Act for reformulated gasoline across the period, it is not clear what baseline volume of ethanol production is assumed in their model. Additional online research to assess the volume of ethanol production assumed by the Clean Air Act did not readily produce this information. However, the baseline volume of ethanol production that is assumed in their model appears to be the volume needed to replace MTBE as a fuel additive. According to published transcripts of a 2003 hearing before the US Senate Subcommittee on Clean Air, Climate Change and Nuclear Safety "between 3.5 and 4.5 billion would be needed to replace MTBE." (US Government Printing Office 2004). We believe that Lark et al. (2022) used a volume within this range throughout the time frame of their analysis (2008 to 2016). In addition, it is likely that they used a volume of 4.0 billion gallons, since this was the amount produced in 2005 without the incentive of the RFS program. As previously discussed, the market demand for ethanol on average has been above the implied conventional volume for the period that the program has been in existence (2006 through 2022) by approximately 0.73 billion gallons. The average implied conventional volume for the period analyzed by Lark et al. (2022) is 12.4 billion gallons. Although it is very difficult to determine the annual baseline volume of ethanol production (i.e., the volume of ethanol that would have been produced without the implied conventional volumes) it is likely much higher than the value used by Lark et al. (2022), perhaps as much as three times higher. This is because it appears that Lark et al. (2022) may have used a baseline of 4.0 billion gallons of ethanol and that market demand for ethanol generally has been above the implied convention volume. Therefore, the market demand is likely very close to the average implied conventional volume throughout the period of Lark et al.'s (2022) analysis, i.e., approximately 12 billion gallons.

The methodology in Lark et al. (2022) involved the creation of two distinct models. The first model focused on estimating the effects of the RFS on crop prices. According to Lark et al. (2022), their approach for modeling impacts of the RFS on crop prices closely followed methods used by Carter et al. (2017) but incorporated the RFS program as a persistent shock to the agricultural markets rather than a transitory shock whose price impacts are different (Lark et al. 2022). In addition, Lark et al. (2022) noted that they extended the work of Carter et al. (2017) to include the impact of the RFS program on soybean and wheat prices. Lastly, Lark et al. (2022) explained that their pricing model accounted for the effect of year end storage of crops (i.e., corn, soybeans, wheat), which as they noted, is a staple of literature on the prices of storable commodities.

The second model included in Lark et al. (2022) involved a regression model focused on estimating the probability of crop rotations. Specifically, Lark et al. (2022) assessed the impact of the RFS program on cropland based on the probability of cropland expansion and abandonment at the field level.

Lark et al. (2022) provided additional details regarding their methodology in the supplementary information associated with their report, although working through the various details of this methodology is beyond the scope of this analysis. However, there are two important points regarding this approach that are worth noting. The first is that Lark et al. (2022) was focused, in terms of spatial extent, exclusively on the market within the contiguous US as a closed system. However, the work by Austin et al. (2022) highlighted that studies which only considered domestic impacts reported higher level impacts of the RFS than those that considered global markets, because corn and ethanol are globally traded commodities. The global lens is more appropriate because the global market can dampen the impact of increased demand and/or supply of either commodity.

It is also important to note that the probability model developed by Lark et al. (2022) operated at a field level degree of spatial resolution. Specifically, the identified fields were based on the USDA's common land use boundary. From the standpoint of economic modeling, this is an extremely granular model. In economics, high granularity indicates that the model is attempting to predict the actions of fewer individuals. For example, it is extremely difficult to predict whether one individual will buy a new car in the next year based on population level data, but we can predict how many individuals out of 1,000 will buy a new car in the next year with much more confidence. It is our experience that with any economic modeling effort, increased levels of granularity introduce increased levels of uncertainty due to difficulties obtaining data and structuring simulation models representative of actions at such a high degree of resolution. In essence, the modeling approach of Lark et al. (2022) was aimed at estimating the likely decisions of individual landowners, which can introduce too much variability into the model of a larger market.

Lark et al. (2022) called attention to two peaks in the observed acres planted in corn that were significantly above their assumed baseline, which they attributed to the RFS program. These peaks occurred in 2007 and 2012 and are presented in Figure 3-3.

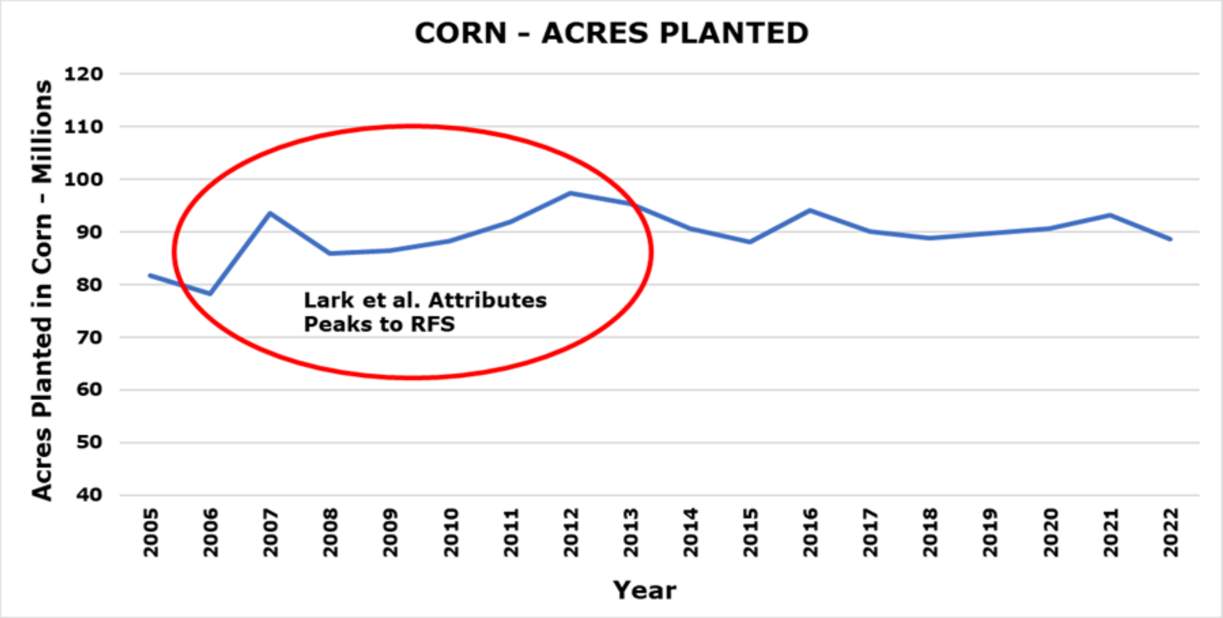

Figure 3-3. Peaks in Corn Acres Planted in 2007 and 2012
Data Source: Corn Acres Planted – USDA NASS 2023a

While Lark et al. (2022) attributed the increases in corn acres planted in 2007 and 2012 solely to the RFS program, other researchers, i.e., Taheripour et al. (2022a), credited the temporary increases to other factors including:

- Ban of use of MTBE in 2006 as a gasoline additive.
- Tax exemption for ethanol of $0.40/gallon through 2011 established by National Energy Conservation Policy Act.
- State incentives for biofuel production.

Carter et al. (2011) offered two additional explanations for the commodity price boom of 2008: rising global demand and weak US federal policy.

In summary, we believe the analysis presented in Lark et al. (2022) overestimates the impact of the RFS program on corn prices and corn acres planted primarily by using a baseline that is too low (perhaps one third of what it should be) by assuming that the implied conventional volume is the only driver for ethanol production. In addition, their approach focused only on the US market which does not account for the dampening effect of the global market on corn prices and acres planted. Furthermore, the model is very granular, from an economics point of view, which in most cases introduces much uncertainty. Lastly, as we shall see in the comments provided by Taheripour et al. (2022a), Lark et al. (2022) did not account for the impact of DDGS as an animal feed replacement for corn. Nor did Lark et al. (2022) account for the effect of increased corn yield.

3.2.2 Austin et al. (2022)

Austin et al. (2022) reviewed a total of 29 studies published since 2008 which attributed domestic LUC to the RFS program. These studies resulted in a wide range of LUC estimates depending on factors such as:

- Type of economic models utilized (simulation based or empirical methods).
- Key attributes or parameters included in the studies.
- Baseline scenario chosen.
- Land use effect (i.e., change in corn crop, change in Conservation Reserve Program [CRP] acreage: changes among cropland, cropland pasture, forested pasture, timberland, developed land, etc.).
- Spatial extent (i.e., global, contiguous US, US region, group of states, particular states).
- Spatial resolution (region of the US, US counties, crop reporting districts, defined grids cells [e.g., 10 by 10 kilometers, 30 by 30 meters, 3.5 by 3.5 miles]).

Austin et. al. (2022) reported that the economic simulation models provided a range of 0.01 to 2.24 million acres of net cropland expansion per billion-gallon increase in biofuels. This is a wide range, spanning two orders of magnitude. Such a wide range demonstrates the difficulties in creating representative models when so many variables are involved.

Furthermore, Austin et al. (2022) noted that in general, international models that capture global responses have a smaller range of variability in corn acres planted. Simply stated, they reasoned that the global market worked to dampen the effect of increased demands in commodities such as corn and ethanol in the US market (i.e., these demands can be met by the global supply).

In addition to differences in geographic scope and resolution, Austin et al. (2022) highlighted that the time periods over which the studies evaluated LUC were highly variable. The time frames ranged from 3 to 30 years. Such a wide range of variability makes it difficult to make substantive claims regarding a general or universal conclusion common among all studies.

Based on a review of the various papers, Austin et al. (2022) made an important point that an ideal simulation modeling study would be global in scope, account for trade dynamics, include international market interactions, and would represent all relevant market interactions together with agricultural, forestry, land transportation, and energy markets (Austin et al. 2022). Moreover, Austin et al. (2022) added that one approach to reconciling these competing goals would be to develop an integrated model that leveraged the benefits of computable general equilibrium modeling to capture global economy-wide interactions and partial equilibrium models that supply a detailed representation of the US land sector.

In addition to creating the combined model as suggested by Austin et al. (2022), based on our analysis of the literature, Ramboll would add that it is important to select a proper time range for the evaluation, establish a proper baseline, account for increased corn yield and increased ethanol productivity, and make use of observed data for model calibration.

3.2.3 Taheripour et al. (2022a)

"Economic Impacts of the U.S. Renewable Fuel Standard: An Ex-Post Evaluation" by Taheripour et al. (2022a) provides the most representative work in our review regarding the impact of the RFS program. We base this conclusion on the following attributes of the work in Taheripour et al. (2022a):

- Use of general equilibrium modeling to account for the global market interactions and partial equilibrium modeling to account for the US land sector.
- Spatial resolution based on US agro-ecological zones (10 in the US).
- Evaluation of a 12-year time frame, 2004 through 2016.
- Inclusion of the analysis of four different baselines across two different time periods, i.e., 2004 to 2011 and 2011 to 2016. The time separation was done because, during the period of 2004 through 2016, crop and food prices followed an upward trend until 2012 and then tracked downward. This trend is seen in the US and globally as well.
- Accounts for increased corn yield, increased ethanol productivity, and the introduction of DDGS as a whole corn feed replacement.
- Use of observed data for the purpose of model calibration.

Below is a short list of conclusions reached by Taheripour et al. (2022a) based on their modeling approach.

1. The bulk of ethanol production prior to 2012 was driven by what was happening in the national and global markets for energy and agricultural commodities.
2. Regardless of the drivers, real crop prices have increased between 1.1 and 5.5% from 2004 to 2011 with only one-tenth of the price increases attributable to the RFS program.
3. For 2011 to 2016, the long-run price impacts of biofuels were less than the period of 2004 to 2011.
4. If there were no RFS program, farmers in the US would produce less corn by 1.2%.
5. When removing the RFS volumes for both ethanol and biodiesel outputs for corn, soybeans, rapeseed, and other oilseeds drop by 1.4, 1.6, 12.4, and 4.3%, respectively.
6. Ignoring the contributions of non-RFS factors, the impact of the RFS on crop prices and acres planted is very small.

The results from Taheripour et al. (2022a) provide considerable evidence that the RFS program has had little impact on both the price of corn and corn acres planted. These results appear to be consistent with observed changes in corn prices shown in Table 3-1 and the long-term acres of corn planted as shown in Figure 3-2; more so than the results produced by Lark et al. (2022).

Taheripour et al. (2022b) produced a second paper for the purpose of providing comments to Lark et al. (2022). One of the comments provided by Taheripour et al. (2022b) was that Lark et al. (2022) reached LUC conclusions without careful consideration of corn yield increases over time and DDGS offsets. As a demonstration of these impacts, Taheripour et al. (2022b) provided an analysis showing an overall net **reduction** of 4.262 million acres of land needed to meet the volume for the RFS in 2008. A summary of their analysis is presented in Table 3-2 below.

Table 3-2. Land Area Savings from DDGS

Base Year	Acres
1. Gross acres needed for increased ethanol volume	10,862,266
2. Land area spared due to DDGS production	-5,539,158
3. Land area spared from corn yield increases on 2008 corn acres (no ethanol production)	-9,585,000
4. Net land area (1+2+3) after considering DDG with ethanol production and corn yield increases	-4,261,892

Source: Taheripour et al. 2022b.

Assuming that this analysis is correct, it is likely that similar, if not larger, net reductions in land needed for corn production would be present throughout the time frame of the RFS program.

3.2.4 EPA DRIA (2022b)

The significant differences regarding the impacts of the RFS program on corn prices and corn production reported by Lark et al. (2022) and Taheripour et al. (2022a; 2022b) demonstrate the need to understand the modeling approach EPA uses before comparisons can be made between the results reported by these researchers and those EPA reports in the DRIA (EPA 2022b).

When the EPA was drafting the 2010 RFS rule, the agency developed an integrated model that utilized both the Forest and Agricultural Sector Optimization Model with Greenhouse Gases model ("FASOM model") and the Food and Agricultural Policy Research Institute international model,("FAPRI model") developed at the Center for Agriculture and Rural Development at Iowa State University, as well as data from many other sources (EPA 2022b). The FASOM model was used to estimate domestic impacts in the agricultural and forestry sectors, and the FAPRI model was utilized to model impacts in the international agricultural sector (EPA 2022b). The EPA's process for developing the modeling framework is discussed in Section 4.2.1.2 of the DRIA.

The DRIA utilizes a baseline scenario that the EPA describes as "No RFS." This baseline assumes that if there were no RFS volumes set by the EPA (2022a), production of ethanol would continue to occur in response to demand. Given that the EPA uses an integrated model that includes international and domestic impacts and a baseline that assumes market production of ethanol without the RFS, their modeling approach is aligned with that of Taheripour et al. (2022a) and the approach recommended by Austin et al. (2022).

Chapter 8 of the DRIA includes a table showing the EPA's corn price increase estimates for 2023, 2024, and 2025. Table 3-3 below is a duplication of Table 8.4-1 found in the DRIA. Note that the corn price increases shown in this table were estimated at $0.10/bushel for 2023 to 2025. This minimal impact in corn prices, although forward looking, is reflective of what Taheripour et al. (2022a) found when looking back at the time frame of 2004 through 2016 using an appropriate baseline. However, Taheripour et al.'s (2022a) results indicate even smaller impacts stating that real crop prices increased between 1.1 and 5.5% from 2004 to 2011 with only one-tenth of the price increases attributable to the RFS program, i.e. 0.11% and 0.55% respectively. Furthermore. Taheripour et al. (2022a), state that for the period 2011 to 2016, price impacts of biofuels were less than the period of 2004 to 2011, i.e., below 0.11% to 0.55% respectively.

Table 3-3. Projected Impact on Corn Prices Relative to the NO RFS Baseline

Parameter	2023	2024	2025
Corn Price Percent Increase per Billion Gallons of Ethanol	3%	3%	3%
Corn Price (RFS Volumes); $/bushel	$4.60	$4.37	$4.13
Corn Price Increase per Billion Gallons of Ethanol; $/bushel	$0.14	$0.13	$0.13
Corn Ethanol Increase; billion gallons	0.706	0.776	0.84
Corn Price Increase; $/bushel	$0.10	$0.10	$0.10
Corn Price (No RFS Baseline); $/bushel	$4.50	$4.27	$4.23

Source: DRIA Section 8.4-1

Consistent with Taheripour et al. (2022a), the DRIA reports that impacts from other market factors could lead to a reduction of acres of corn planted, including a shift away from the usage of whole corn as animal feed with the rise of other substitutes (DRIA, pp. 406-407). According to the USDA, DDGS supply and use rises in concert with ethanol fuel production (Olson and Capehart 2019). As an approximately 1.22 to 1 by weight substitute for corn grain feed rations, DDGS can be a better alternative to corn due to a higher protein content and nutrient density (Wadhwa and Bakshi 2016). The EPA finds that an increase in DDGS is a factor contributing to the longer-term shift of the animal feed industry away from whole corn to increased use of DDGS, thus reducing the amount of corn that needs to be planted (DRIA, p. 407).

The DRIA discusses an important market factor that acts to balance corn prices within the market, that is the corn ending stock-to-usage ratio. Throughout the year, not all corn is used in production. Because corn is only harvested once a year, storage is a large contributor in the supply chain (DRIA, p. 409). What is left over is commonly referred to as corn ending stocks. The DRIA finds that there is a statistically significant negative correlation between the corn ending stock-to-usage ratio and corn futures prices (DRIA, pp. 409-411). This shows that the amount of corn stored at the end of the year has a dampening effect on price (DRIA, p. 409), which further supports that the RFS is not a main driver in corn production. Ramboll’s analysis, which we provide in Section 3.3.3 and present in Figure 3-7, confirms EPA’s findings that there is a statistically significant negative correlation between the corn ending stock-to-usage ratio and corn futures prices. In short, our analysis indicates that corn prices are minimally affected by the implied conventional volume and that corn acreage planted is offset by increased corn yield and DDGS.

3.3 Economic Analysis Methodology

3.3.1 Variables of Ethanol Industry

Based on industry research and interviews with small scale corn farmers and those who work in the ethanol industry, the primary factors that influence farmers’ corn planting decisions by small farmers are futures prices, regular crop rotation, and soil health (EPA 2022c; USDA NASS 2023a)

Due to the interconnectedness of the corn production industry to other industries and dependence on environmental characteristics, attempting to account for each of these unpredictable variables will lead to a model that consists of too many assumptions which will not accurately represent the industry. To prevent introducing too many assumptions and variables into the model, we develop a series of simplified models to better illustrate which variables are or are not explanatory. In addition, the Ramboll models use observed data for evaluating market responses to factors such as the RFS or total ethanol production rather than attempting to simulate (i.e., forecast) market responses to such inputs or developing baseline simulations.

3.3.2 Analysis Objectives

Our analysis focuses on two primary objectives. The first is to evaluate the effect of the RFS and ethanol production on corn prices and acres of corn planted. The second is to evaluate which research efforts best represent the potential effect of the implied conventional volume on corn prices and corn acreage planted. We consider research performed by EPA (2022b) and others that obtained similar results and conclusions, such as those found by Taheripour et al. (2022a; 2022b; 2022c) in addition to results obtained by Lark et al. (2022).

Ramboll's analysis uses two primary analytical techniques: linear regression and the analysis of correlation coefficients. Linear regressions are commonly used in economics to establish empirical relationships between variables. Linear regressions can use either a single variable or multiple variables to identify the effect of one variable or a set of variables (i.e., explanatory variables) on the parameters of interest (i.e., dependent variables). The strength of the relationships between variables are described using regression coefficients. It is important to note that when performing linear regressions, relationships between variables are not necessarily causal. Linear regressions can describe causal relationships; however, these regressions require strong assumptions and a robust understanding of the underlying economic mechanisms (Verbeek 2017).

When interpreting regression coefficients, each slope coefficient measures the expected change in the dependent variable following a one-unit change in the explanatory variable of interest, maintaining all other explanatory variables constant (Verbeek 2017). There are several key statistics that measure whether the regression accurately represents the variables. Below is a list of the statistics we use in our analysis.

- R^2 – Also known as the coefficient of determination, is a statistical measure that indicates how well a regression model fits the data. It is usually interpreted as the percent of variation that is explained by the resulting regression equation. The closer R^2 is to one, the better the explanatory power of the regression.
- F-Statistic – This statistic is used to determine whether the relationship between the Y and X variables occurs by chance (null hypothesis) or is representative of an actual relationship (rejection of null hypothesis).
- T-Statistic – This value is used to determine if a statically significant relationship exists between the explanatory variables (e.g., RFS) and the dependent variable (e.g., corn prices).
- The correlation coefficient is a statistic that is used to determine the degree that one variable is related to another. It is a unitless index that ranges between -1 and +1. The closer this index is to -1 or +1, the greater the relationship.

An often-stated caution regarding the interpretation of correlation is that correlation does not equal causation. There are three reasons that we might observe a correlation between pairs of observed data.

First, a logical relationship does exist between the two variables. Second, there is another external factor that is affecting both variables. Third, the observed correlation has occurred purely by chance and no correlation exists. The second and third explanations of correlation represent the reasons for the often-stated caution regarding the use of this statistic.

Correlation is frequently used along with regression analysis to help evaluate if a dependency relationship exists between the explanatory parameters (the X values or independent values) and the parameter of interest (the Y value). Dependency means that a statistical relationship exists such that the independent values can be used to approximate the dependent value. Therefore, analysis of statistical results from linear regressions in conjunction with correlation is useful in evaluating the potential dependence between the variables of interest and reaching reasonable conclusions regarding this dependency.

3.3.3 Economic Analysis

This section details and depicts the economic models and relationships that were discussed in previous sections of this chapter. To start with the simple relationships, we run a regression of acres of corn planted versus corn futures prices to determine if futures prices have a significant influence on farmers' decisions. January futures were used for this analysis because they would be considered by farmers when making corn planting decision.

Figure 3-4 below presents the analysis between corn acres planted and January corn futures prices.

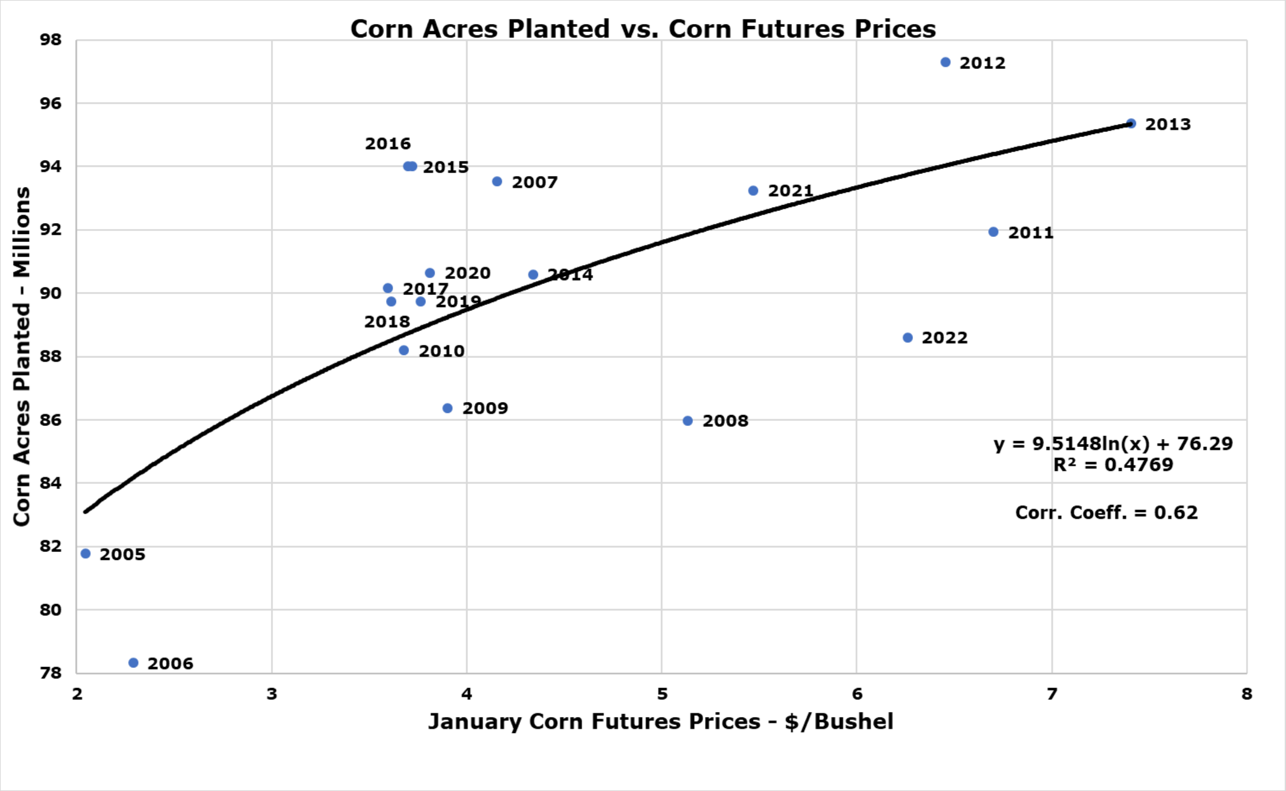

Figure 3-4. Relationship Between Acres Planted and Futures Prices

Data Sources:

Futures Prices – Macrotrends 2022

Corn Acres Planted – USDA NASS 2023a

Interpretation: Based on the outcome of the regression, a moderate statistical dependency exists between corn acres planted and January corn futures prices. However, the January corn futures prices explain less than 50% of the variation in corn acres planted. This shows that futures prices have a significant impact on planting; however, there are other factors not included in this model that may better explain price changes.

An argument made by Lark et al. (2022) was that the RFS program causes an increase in corn prices. Figure 3-5 below shows the lack of a statistical relationship between corn prices and the implied conventional volume[6]. A single variate regression is run to display the possible relationship.

---

[6] Our analysis does not account for small refinery exemptions (SREs). Accounting for the effect of SREs would lower the implied conventional volume although not significantly. Not including the impact of SREs makes our model more conservative in that it assumes a larger number for the implied conventional volume.

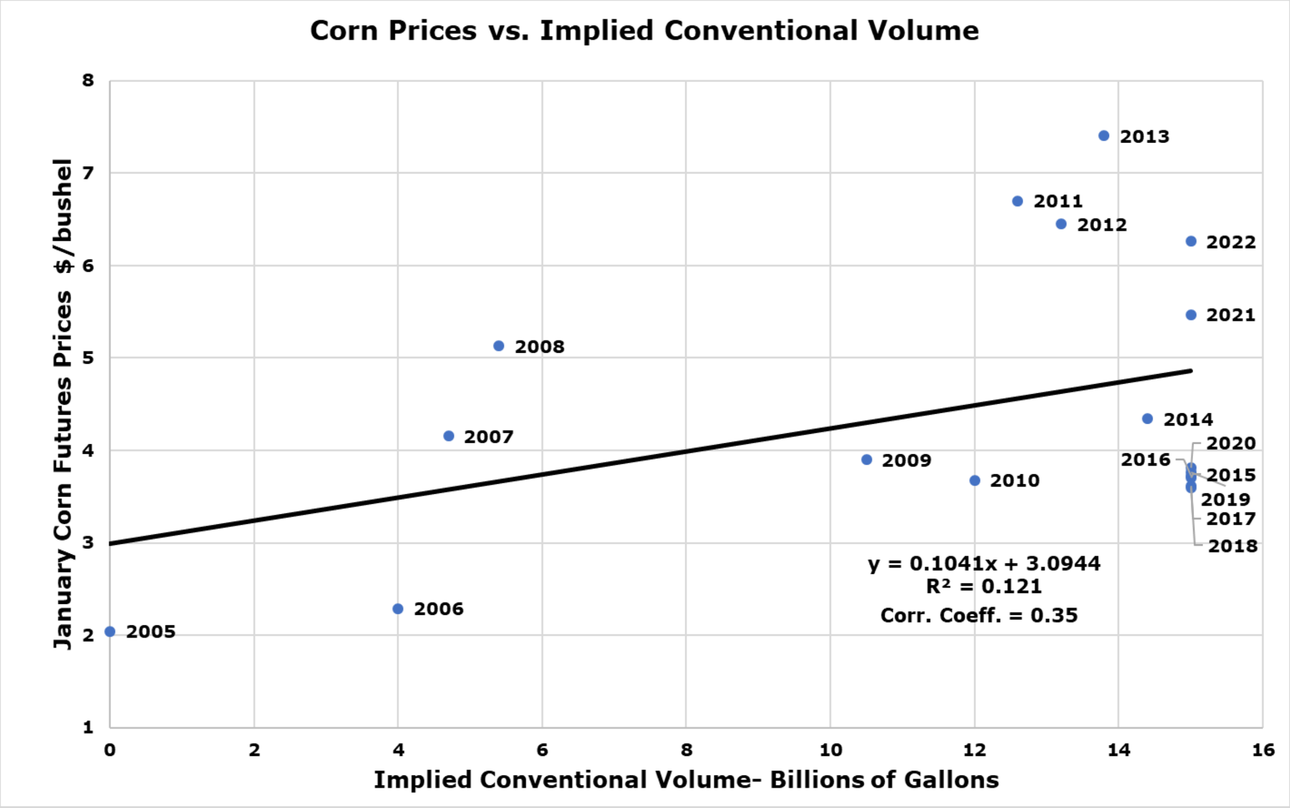

Figure 3-5. Relationship Between Corn Prices and the Implied Conventional Volume

Data sources:

Corn Prices – Macrotrends 2022

Implied Conventional Volume – EPA 2022c

Interpretation: Based on the results of the regression shown in Figure 3-5, the statistical dependency between corn prices and implied conventional volume is either non-existent or very weak, with an R^2 of 12%. As is clear in the figure, corn prices fluctuate widely by year and are not statistically dependent on the RFS. Reasons for price increases since 2005 could be inflation, prices of other commodities, and demand for corn in other industries, which are not displayed in this model.

Next, Ramboll tests the theory that ethanol production causes an increase in corn futures prices by running a single variate regression with ethanol plant production and January corn futures prices. In the following models, we use ethanol plant production values from the previous year's production volumes reported in December of the previous year, which likely have a closer relationship with January corn futures prices for the following year (i.e., the next month), assuming such a relationship exists.

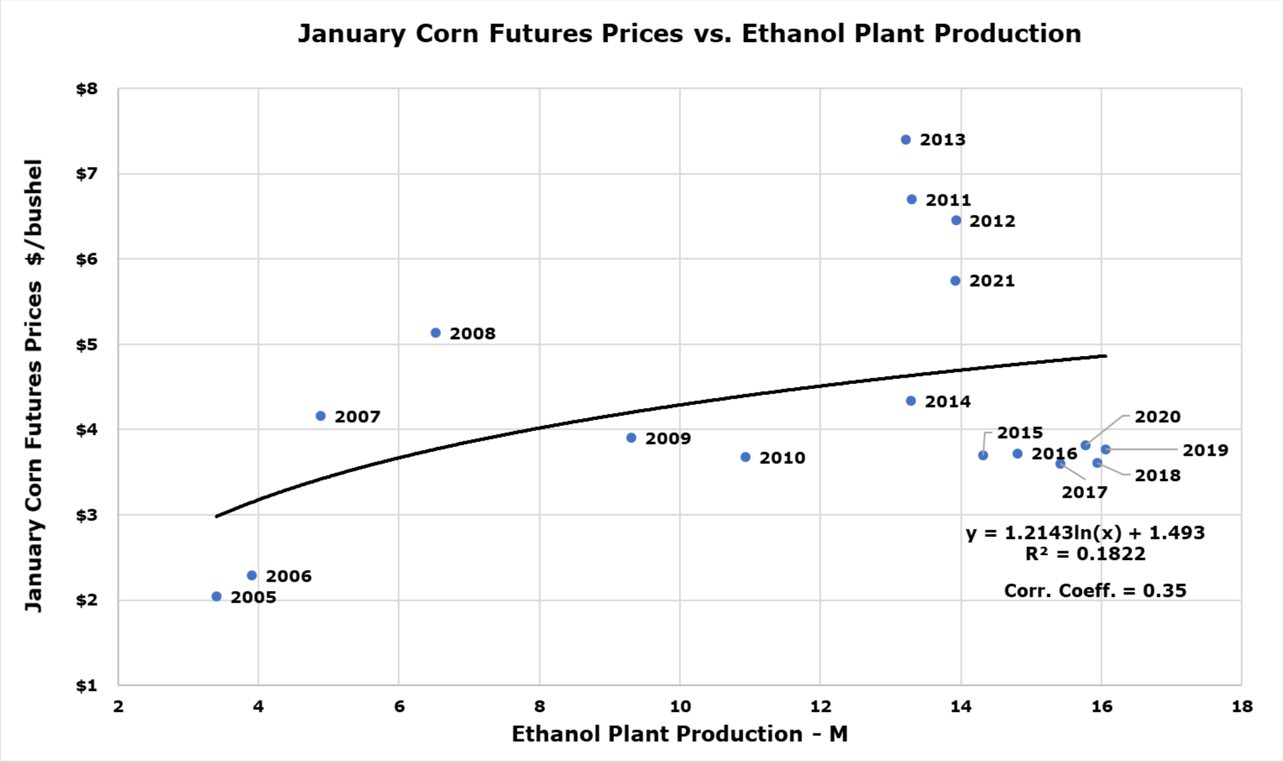

Figure 3-6. Relationship between Corn Futures Prices and Ethanol Production

Source Data:

January Futures Prices - Macrotrends 2022

Ethanol production – Alternative Fuels Data Center 2021

Interpretation: The results show a statistical dependency between corn prices and ethanol plant production is either non-existent or very weak based on the small R^2 value of approximately 18%. This R^2 value and Figure 3-6 indicate that corn prices do not fluctuate in relation to ethanol production. There could be various reasons for this weak relationship including the corn ending stock-to-use ratio (see Figure 3-7).

As stated by the research (DRIA) and supported by industry trends, a statistical dependency exists between corn ending stock-to-usage ratio and corn prices. Therefore, we perform an analysis to test this relationship and present it as Figure 3-7 below.

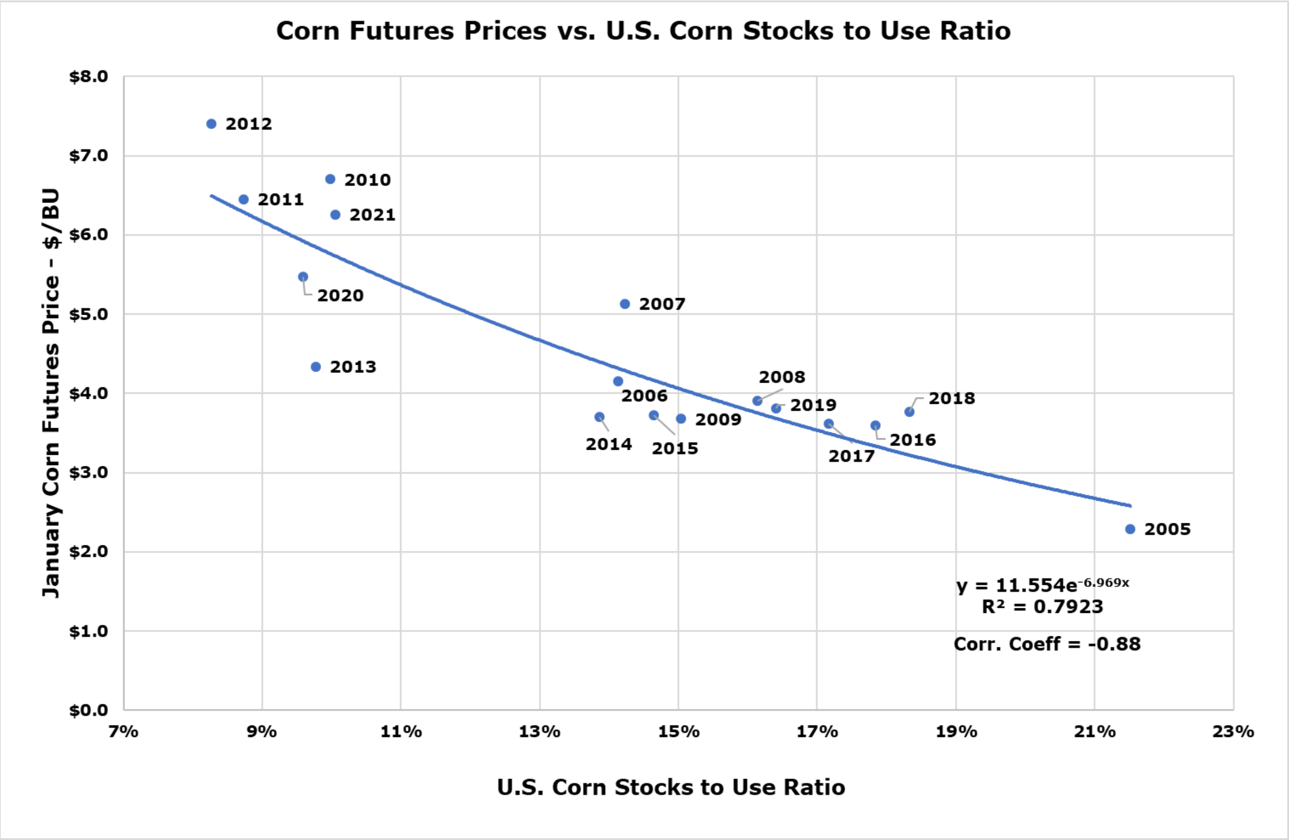

Figure 3-7. Relationship between Corn Futures Prices and Corn Stocks to Use Ratio

Data sources:

Corn Futures Prices – Macrotrends 2022

Con Stocks – Index Mundi 2023

Interpretation: As the results in Figure 3-7 indicate, corn futures prices are statistically dependent on the corn ending stock-to-use ratio, with an R^2 of nearly 80%. The trendline also fits the data relatively well.

We next run a regression including the implied conventional volume and acres of corn planted to test whether the acres of corn planted is statistically dependent on the implied conventional volume.

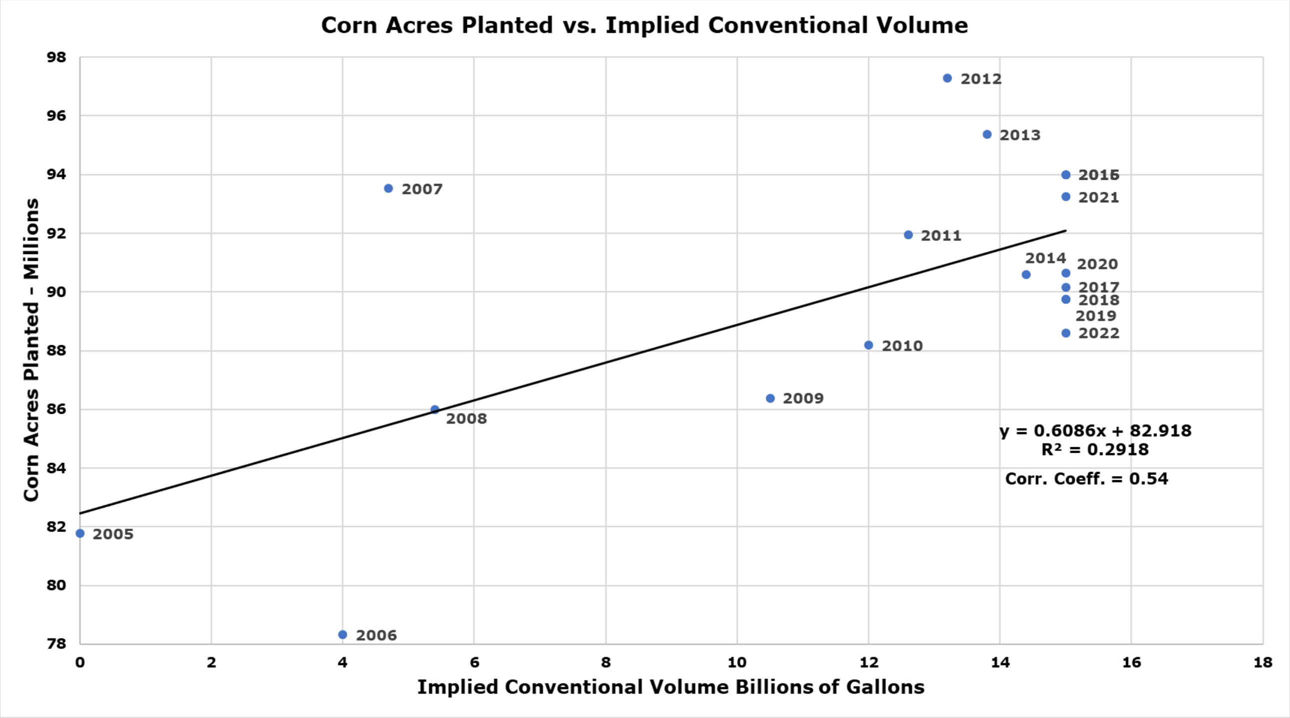

Figure 3-8. Relationship between Corn Acres Planted and the Implied Conventional Volume

Data sources:

Corn Acres Planted – USDA NASS 2023a

Implied Conventional Volume – EPA 2022c

Interpretation: As the figure and the R^2 value of less than 30% show, a weak statistical dependency may exist between the corn acres planted and the implied conventional volume.

Next, we run a single variate regression to determine if there is statistical dependence between the ethanol production quantities and acres planted of corn.

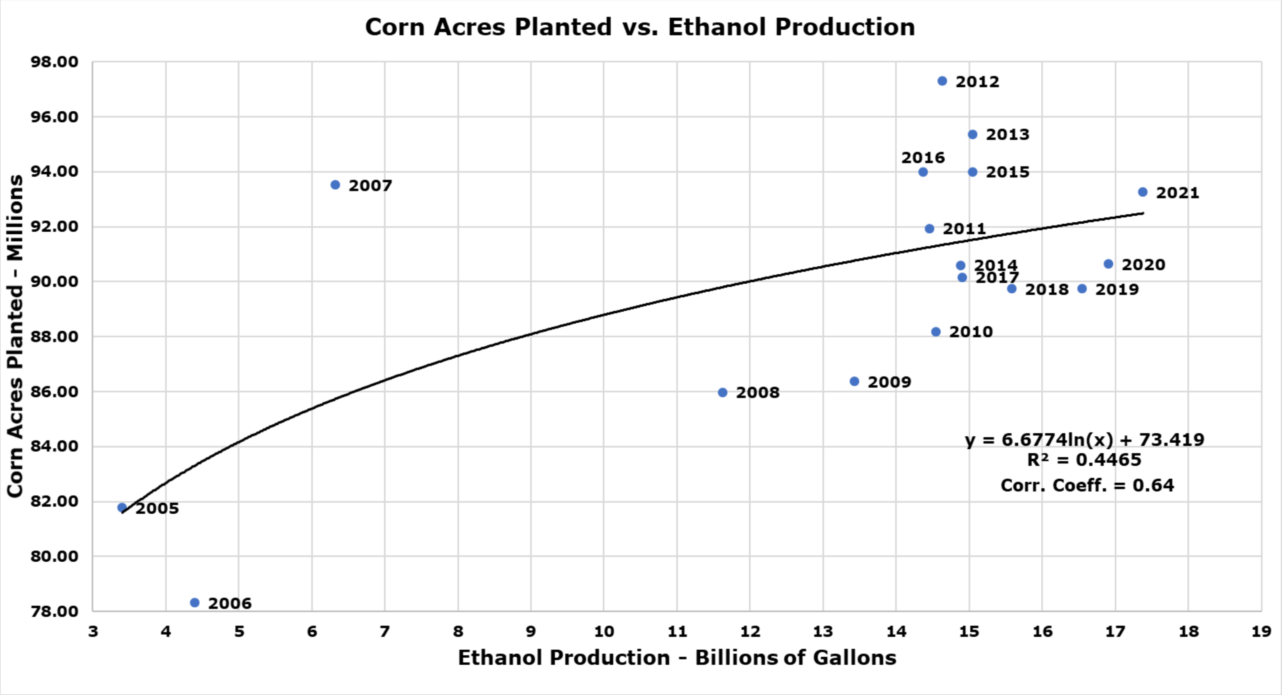

Figure 3-9. Relationship Between Corn Acres Planted and Ethanol Production

Data sources:

Corn Acres Planted – USDA NASS 2023a

Ethanol Production – Alternative Fuels Data Center 2021

Interpretation: Figure 3-9 demonstrates a weak to moderate statistical dependency may exist between the corn acres planted and the ethanol production, with an R^2 value of approximately 45%. However, when we consider the analysis of the multivariate regression performed for corn acres planted, this dependency is found not to be significant when accounting for other explanatory parameters (i.e., wheat prices, soybean prices, and corn ending stock use ratio) as a group. This demonstrates why single variate regressions, although potentially informative, must be considered in conjunction with other potentially explanatory parameters.

Our next regression involves analyzing the relationship between corn prices and crude oil prices. This analysis is performed because crude oil is known to be a supply chain cost for corn cultivation.

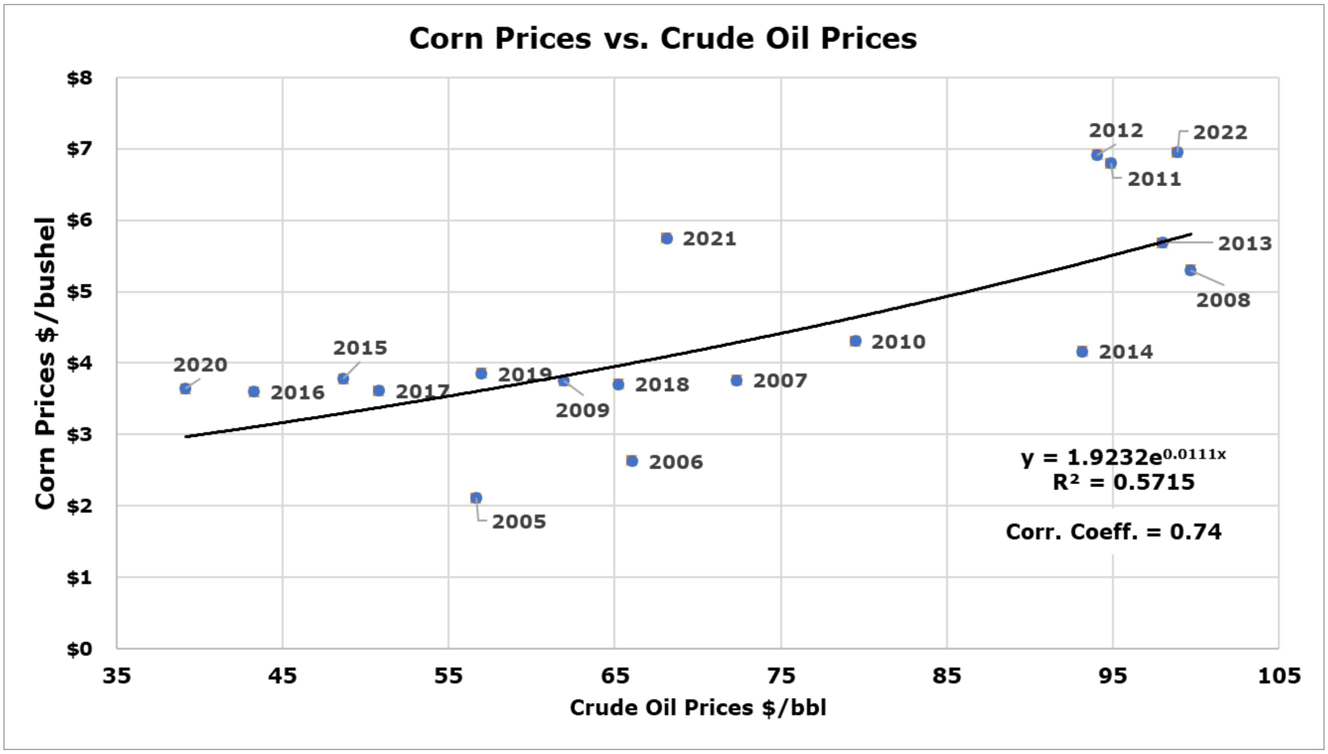

Figure 3-10. Relationship Between Corn Prices and Crude Oil Prices

Data sources:

Corn Spot Prices – Macrotrends 2022

Crude Oil Spot Prices – US Energy Information Administration 2023

Interpretation: Based on Figure 3-10, crude oil spot prices have a moderate statistical significance on corn prices, with an R^2 value of 57%. Due to the moderate level of statistical significance, crude oil prices were included in a multivariate regression; however, it did not present as statistically significant. When included in a multivariate regression, the regression coefficient showed that for every dollar increase in crude oil prices, there is a one cent increase in the price of corn per bushel. Additionally, the inclusion of crude oil removed the statistical significance of other variables, such as soybean prices, which as previously discussed, are known to be an explanatory variable for corn prices. As such, crude oil prices were not included in the final multivariate regression.

Figures 3-4 through 3-10, presented above, present simplistic models to demonstrate that implying one factor is the driving force behind an increase in corn prices and corn planting patterns is simply unrealistic[7]. The two main assumptions made by Lark et al. (2022) were that the volumes established by the RFS program will directly increase the demand for corn, which will increase corn prices and the overall acres of corn planted. To provide a more realistic analysis that considers the effects of groups of

---

[7] An area we did not investigate is the relationship between D4 renewable identification numbers (RINs) and D6 RINs as they are related as part of the overall program. However, our opinion is that the relationship between these potentially explanatory variables, in particular the effect of D4 RINs on corn prices and corn acreage is better addressed by investigating whether soybean prices are statistically dependent on biobased diesel volume requirements, and in turn does any effect on soybean prices impact corn prices and corn acreage. This analysis was performed, and the answer is that corn prices and acreage have a non-existent to weak statistical dependency with biobased diesel standards and production. This analysis is presented on page 31.

potentially explanatory variables, we run two multivariate regressions, one for corn prices and the other for corn acres planted. As presented below, both these multivariate regressions indicate that the implied conventional volume and ethanol production have minimal to no effect on corn prices or corn acres planted.

The explanatory parameters selected for each regression are chosen because they fit one of the following categories:

1. Evaluations of previous single variate regressions and correlation coefficients indicate that corn prices or corn acres planted are statistically dependent on these parameters. For example, corn prices have been shown to be statistically dependent on ending corn stocks-to-usage ratio (Figure 3-7) and corn acres planted have been shown to be statistically dependent on corn futures prices (Figure 3-4).
2. General industry acceptance that certain parameters influence corn prices or corn acres planted (i.e., both soybean prices and wheat prices are generally accepted to influence corn prices and corn acres planted due to natural crop rotations [Camp 2019]).
3. Assertions by Lark et al. (2022) and others that corn prices and acres planted are attributable to certain parameters, i.e., the RFS and ethanol plant production.

We include the following potential explanatory parameters in our multivariate regression for corn futures prices based on the above criteria: implied conventional volume (billions of gallons), ethanol plant production (billions of gallons), January wheat futures price ($/bushel), January soybean futures price ($/bushel), and corn ending stock use ratio (%). Table 3-4 below presents the results of the regression.

Table 3-4. Corn Futures Prices Regression

	Constant, b_0	**Implied Conventional Volume, b_1**	**Ethanol Plant Production (Prev. Yr.), b_2**	**January Wheat Futures Prices, b_3**	**January Soybean Futures Prices, b_4**	**Corn Ending Stock Use Ratio, b_5**
Regression Coefficients	2.03	-0.21	0.19	0.14	0.34	-12.78
T-Statistic	1.68	-1.33	1.21	0.70	2.37	-2.51
T-Critical	2.20	-1.80	2.20	2.20	2.20	-1.80
Significant	No	No	No	No	**Yes**	**Yes**
R-Factor	**0.89**	---	---	---	---	---
F-Statistic	**17.36**	---	---	---	---	---
F-Critical	3.01					

The first row of this table provides the regression coefficients. In the column heading these coefficients have been designated b_1 through b_5. In addition, note that there is a constant term designated b_0. These coefficients represent multipliers used (along with the constant factor) in an equation for estimating corn futures prices (i.e., y value) as follows.

$$y = b_0 + b_1(RFS) + b_2(Eth. Prod.) + b_3(wheat\ fut.) + b_4(soybean\ fut.) + b_5(corn\ stock\ end\ ratio)$$

In terms of the actual coefficients reported in Table 3-4 this equation becomes:

$$y = 2.03 - 0.21(RFS) + 0.19(Eth. Prod.) + 0.14(wheat\ fut.) + 0.34(soybean\ fut.) - 12.78(corn\ stock\ end\ ratio)$$

In other words, we now have the equation of a line that is like the lines presented within Figures 3-4 through 3-10, with the exception that it is multidimensional and therefore impossible to graph. Now that the equation of this line has been determined, the question becomes, does it represent a reasonable or valid model? To answer this question, we return to our previously described R^2, F-Statistic, and T-Statistic to interpret these results.

Interpretation: The R^2 value associated with our model is 0.89, which tells us that nearly 89% of the variability in corn futures prices is explained by the regression model.

The F-Statistic of 17.36 is greater than F-Critical of 3.01, which indicates that we can reject null hypothesis that the relationship between Y's and X's occurs by chance. In other words, based on the comparison of the F-Statistic and F-Critical we can state that the relationship between our explanatory variables and our dependent variable (corn futures prices) does not occur by chance.

Analysis of our T-Statistic versus their associated T-Critical values indicates only two of the explanatory variables are statistically significant, i.e., soybean futures prices and the corn ending stock-use-ratio. These findings are consistent with the nature of the industry and discussions with industry professionals, as Figure 3-11 below further supports. The coefficient for the corn ending stock use ratio tells us that if all other variables were held constant, for every percent increase of the ending stock-use-ratio, the corn price decreases by nearly $0.13 (i.e., 0.01 x -12.78 = -0.1278). For every dollar increase in soybean prices, there is a $0.34 increase in corn prices.

We now turn our attention to the other remaining explanatory parameters that, according to the T-test, were determined not statistically significant. When an explanatory variable is not statistically significant, we cannot reject the null hypothesis associated with this T-test that these regression coefficients are zero. In other words, although we have a valid regression based on the F-Statistic test and the R^2 we cannot be certain that the coefficients for wheat futures, ethanol production, and RFS are not zero. In other words these coefficients may be zero. Therefore, the implied conventional volume and ethanol production are not significant contributors to corn prices. This multivariate analysis provides additional evidence that ethanol production and the implied conventional volume have minimal or no effect on corn prices.

Since the multivariate regression for corn prices indicates soybean prices are significant, we perform further analysis of corn prices versus soybean prices. Figure 3-11 presents the results, which indicate a statistical dependency exists between corn and soybean futures prices.

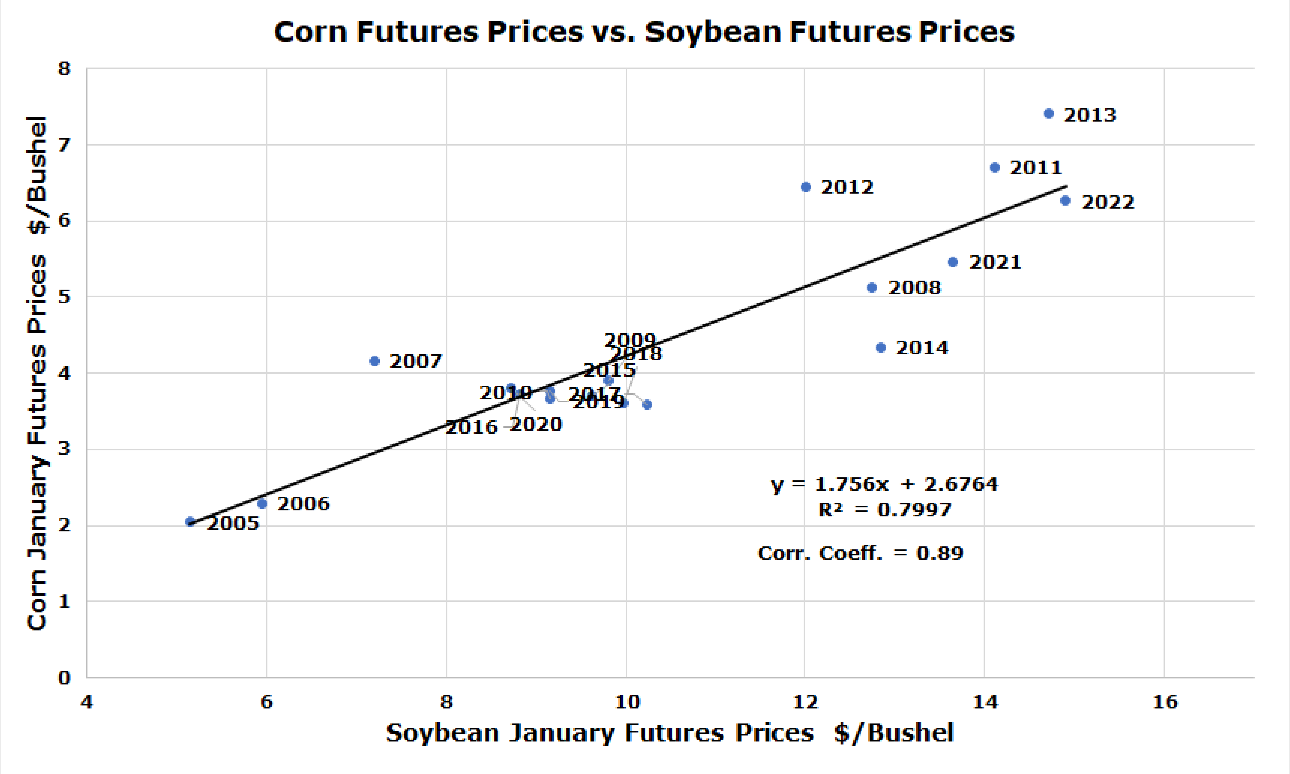

Figure 3-11. Relationship Between Corn Futures Prices and Soybean Futures Prices

Data sources:

Soybean Futures Prices – Macrotrends 2023

Corn Futures Prices – Macrotrends 2022

This provides an additional confirmation that soybean prices should be included as an explanatory variable in the multivariate regression for corn prices.

Having determined that soybean prices are a significant explanatory parameter regarding corn prices, we ran two more single variate regressions. The first to determine if soybean prices are statistically dependent on the biomass-based diesel (biodiesel) volume standard. The second to determine if soybean prices are statistically dependent on biodiesel production. The first regression resulted in an R-Factor of 0.03 and a correlation coefficient of 0.19 thus indicating that soybean prices are not statistically dependent on the biodiesel volume standard. The second regression resulted in an R-Factor of 0.18 and a correlation coefficient of 0.42 thus indicating that there is a weak statistical dependency between soybean prices and biodiesel production. This result led to the decision to perform one more single variate linear regression to determine if corn prices are statistically dependent on biodiesel production. This last single variate regression resulted in an R-Factor of 0.18 and a correlation coefficient of 0.25. These results indicate that there is a very weak to non-existent statistical dependency between biodiesel production and corn prices. Based on the results of this this last single variate regression, Ramboll determined that there is no need to update the multivariate linear regression for corn prices to include biodiesel production.

We run a second multivariate regression to assist with more clearly understanding which variables may be explanatory for corn production. This regression includes implied conventional volume; ethanol production; January corn, wheat, and soybean futures prices; and the corn ending stock-to-usage ratio. We utilize the same thought process and econometric principles to attain the equation of a line for corn plantation in acres.

Table 3-5. Corn Production Regression

	Constant, b_0	**Implied Conventional Volume, b_1**	**Ethanol Plant Production (Prev. Yr), b_2**	**January Corn Futures Prices, b_3**	**January Wheat Futures Prices, b_4**	**January Soybean Futures Prices, b_5**	**Corn Ending Stock-to Usage Ratio, b_6**
Regression Coefficients	72.74	1.20	-0.53	5.12	-0.42	-1.55	41.04
t*	11.87	1.54	-0.68	3.76	-0.44	-1.97	1.42
T-Critical	2.23	2.23	-1.81	2.23	-1.81	-1.81	2.23
Significant	**Yes**	No	No	**Yes**	No	**Yes**	No
R-Factor	**0.81**	---	---	---	---	---	---
F-Statistic	**7.22**	---	---	---	---	**---**	---
F- Critical	3.14	---	---	---	---	**---**	---

Interpretation: The R^2 value in Table 3-5 shows that 81% of the variability in corn production is explained by the model, which ensures this is a strong model.

The F-Statistic of 7.22 is greater than F-Critical of 3.14, which indicates that we can reject null hypothesis that the relationship between Y's and X's occurs by chance. Based on the analysis of our T-Statistic versus their associated T-Critical values, two of the explanatory variables show a statistical significance: corn futures prices and soybean futures prices.

Looking at the regression coefficients, we expect to see a statistically significant relationship between soybean futures prices and corn futures prices based on their use in the industry. Soybean is used to help maintain healthy nitrogen levels in the soil (making it a crop regularly rotated with corn) and is also used in biofuels, so it is often a crop that can also act as a substitute for corn. The statistical significance associated with the corn production acres indicates this model is a good representation of the industry. The regression coefficient for corn prices indicates that for every dollar increase in corn futures prices, corn acreage is expected to increase by 5.22 million acres. The regression coefficient for soybean prices indicates that for every dollar increase in soybean prices, corn acreage is expected to decrease by 1.55 million acres.

Table 3-5 shows that the corn ending stock ratio, wheat futures prices, ethanol production, and the implied conventional volume are all not statistically significant, so although we have a valid regression based on the F-Statistic test and the R^2, we cannot be certain that the regression coefficients of these parameters are not zero. Therefore, this multivariate analysis provides additional evidence that ethanol production and the implied conventional volume have minimal or no effect on corn acres planted.

3.4 Economic Results/Discussion

As we demonstrate by the models and figures in the preceding subsections, the implied conventional volume is not a driving factor of an increase in acreage of corn production and, by proxy, any potential negative environmental effects associated with same. Overall, we conclude that futures prices of soybeans and the year ending stock use ratio are statistically the strongest variables in this analysis for the change in corn futures prices. Based on our regressions, the strongest indicators for corn acreage quantities are soybean and corn futures prices.

A potential gap in these regressions is that seasonality is not included as a potential variable in the analysis and as discussed earlier, seasonality, weather, soil health, and pest control are all crucial factors in planting decisions.

A difficult component to econometrics is the balance between including enough explanatory parameters in a model without over complicating it and clouding the model with variables that hold no statistical significance. Typically, adding parameters can improve an R^2 value even if not all the parameters are found to be significant. This can happen because even though these parameters are not statistically significant, they still have some influence. Lark et al. (2022) may have overcomplicated their model by adding two different time periods and non-representative resolution data, while also making implausible forecasts (as discussed throughout this report) resulting in misleading results that the RFS was directly contributing to LUC and price increases in crops.

Overall, our research concludes that the studies conducted by the EPA (2022b), Taheripour et al. (2022a), and Austin et al. (2022), are more representative of the likely effects of the implied conventional volume and ethanol production on corn prices and corn acres planted than are the results of Lark et al. (2022). The methods used by the EPA (2022b) and Taheripour et al. (2022a) account for effects of the global and domestic economies. The methods we use in this report, although high level, are based on 18 years of observed data. The results of our analysis confirm that the implied conventional volume has minimal to no effect on corn prices and acres of corn planted, consistent with the work by the EPA (2022b) and Taheripour et al. (2022a).

4. Environmental and Ecological Analysis

We support EPA's finding that although some degree of LUC has been "ascribed to biofuel production, and in some cases even to the RFS program itself, in reality, such **a causal connection is difficult to make with confidence**" (DRIA, p. 240) (emphasis added). These findings were originally presented in EPA's Second Triennial Report to Congress (EPA 2018). In fact, recent publications (e.g., Taheripour et al. 2022b), as well as Ramboll's independent analysis described above, demonstrate that any causal relationship between the RFS and LUC is weak at best, and likely results in very small changes in land use as compared to studies previously reviewed by EPA. This newer understanding of the relationship between LUC and the RFS is pivotal to discussions of potential adverse effects to wetlands, other ecosystems, and wildlife and should be acknowledged by EPA throughout the associated section in the final RIA.

4.1 Land Use Change References

This section addresses the references made by EPA to LUC throughout the RFS and DRIA (EPA 2022a; 2022b). This topic merits special review because LUC in the form of agricultural extensification has garnered much attention when it comes to assessing the potential impacts of the RFS on land and water. Agricultural extensification may result in impacts to water quality and water supply, soil quality, and habitat loss and consequent impacts to wildlife (including sensitive and special status species). Some investigators claiming widespread LUC is due to the RFS (e.g., Johnston 2013; Lark et al. 2015; 2022; Wright et al. 2017) are heavily cited in the DRIA even though the EPA found that "in reality, such a causal connection is difficult to make with confidence" (DRIA, p. 240). We support the EPA's assertion that there is no clear causal link given the evidence shown in recent papers that results by Lark et al. (2015; 2022), Wright et al. (2017), and Johnston (2013) appear to have overestimated the magnitude of extensification due to critical methodological flaws (Copenhaver 2022; Dunn et al. 2017; Pritsolas and Pearson 2019; Shrestha et al. 2019; Taheripour et al. 2022b; USDA 2022). None of this recent literature, further discussed below, is cited in the DRIA. We recommend these more recent studies should be added to the final RIA give a more balanced understanding of LUC. Select findings from these recent papers are highlighted below.

1. Taheripour et al. (2022b) "Environmental Outcomes of the U.S. Renewable Fuel Standard" made the following observations regarding Lark et al.'s (2022) estimates of LUC:

    - Increases in corn yield and the offsetting effects of DDGS were inadequately considered.
    - High-end yield increases in 2008 corn acres more than compensate for the increase of 5.5 billion gallons of ethanol assumed by Lark et al. (2022).
    - Ethanol demand may not drive an expansion above the 2008-year corn footprint.
    - Many parcels in the "Cropland Expansion Layer" appeared to be land that is periodically oscillating between agriculture and a fallow state rather than representing long-term extensification.
    - The time period assessed, 2008 to 2016, corresponds to a period of large increases in crop prices which are not attributable solely to biofuels and represents only a short time period as compared to the long-term RFS policy. This temporally biased attribution can result in an overestimate of the magnitude of LUC potentially attributable to the RFS.

2. USDA (2022) found that conclusions by Lark et al. (2022) regarding carbon losses per acre potentially associated with the RFS likely overestimated actual losses by a factor of ten. USDA (2022) identified the following major flaws in the work that are related to estimates of LUC:

    - Failure to account for cropland-to-cropland conversions including land that is moving between corn and other row crops, which may include crop rotations to improve soil health.
    - Misclassification of Conservation Reserve Program (CRP) land as either native lands or longer-term CRP lands.
    - Failure to account for geographic heterogeneity in the demand for corn for ethanol that is driven by the location of ethanol refineries. Instead, Lark et al. (2022) allocated their LUC estimates equally within the study's boundaries.
    - The title of the Lark et al. (2022) paper implies that the findings are causally linked to the impact of the RFS on corn, soybean, and wheat prices. However, the authors modeled the impact on corn prices from corn ethanol demand in general, and this demand was not exclusively influenced by

the RFS. Other major drivers for corn ethanol demand include substitution of corn ethanol for MTBE following the ban of MTBE and increases in oil and gasoline prices.

3. Copenhaver (2022) analyzed many data sources, including aerial imagery, to determine whether the moderate resolution databases used to calculate LUC were accurate. He found that the CDL data layer that Wright et al. (2017) and Lark et al. (2015; 2021) relied upon was unreliable for correctly estimating LUC. Even Lark et al. (2021) report that accuracies for identifying noncropland classes using the CDL data layer can be as low as 50%. Specifically, Copenhaver (2022) had the following findings:

    - "[…]Datasets classified [by CDL] as natural-to-crop land change was idle cropland."
    - Even at a resolution of 30 meters, sufficient granularity to observe change in small plots of land was lacking, and it became increasingly difficult to accurately identify land cover types with larger resolutions.
    - "Moderate resolution satellite imagery is hindered by low accuracies for noncropland classes and limited land cover/use classes."
    - Number of hectares changing to cropland (7,901) was similar to the number of hectares returning to grassland (6,145) after a detailed analysis of counties showing change in hectares farmed.

4. Pritsolas and Pearson (2019) reviewed the research methodologies for the LUC assessments published by Wright and Wimberly (2013), Lark et al. (2015), and Wright et al. (2017). All three of these publications relied on the CDL for their analyses. Some of the main points from their review included:

    - Low accuracy in the CDL for "native prairie, Conservation Reserve Program, grass hay, grass pasture and fallow/idle grasslands."
    - Increased accuracy in the CDL over time due to improving technology which could lead to wrongful findings of LUC. For example, the 2012 CDL was nearly 100% accurate in classification of acres of corn and soybeans, but only 80% accurate in 2008. Therefore, land that was crops in 2008 but was misclassified as natural area would have falsely appeared to have changed to crops in 2012.
    - A net increase of 38,000 acres of cropland, compared to the 263,468 acres found by Lark et al. (2015) or the 295,100 acres reported by Wright et al. (2017) after a close examination of Iowa LUC between 2008 to 2012 using the USDA NASS.

5. Dunn et al. (2017) conducted an analysis of LUC in the Prairie Pothole Region using CDL data, modified CDL data, data from the National Agricultural Imagery Program, and ground-truthing. They found many sources of error when relying only on the CDL. Specifically, they found the following:

    - The CDL and modified CDL analyses vastly overestimated LUC in the Prairie Pothole Region.
    - The CDL and modified CDL analysis did not find land clearing for agriculture when it was less than the 30-meter resolution of the CDL.
    - Areas with more diverse types of land cover and that were less often planted with the same row crops had higher errors in CDL and modified CDL classifications.
    - Topographical features increased the error in CDL and modified CDL classifications.

6. Shrestha et al. (2019) "manually verified" CDL data classification in 664 square kilometers in three areas in the US to determine whether there was a possible link between biofuel production and LUC. They found that automated land classification systems were not effective at accurate estimations of LUC and cited the Lark et al. (2015) paper as one that overestimated LUC because it relied on the CDL. They concluded:

    - LUC to cropland in the areas examined between 2011 to 2015 was 8.53% using CDL data, while manual verification showed only 0.31% change.
    - Land classification systems automated by the CDL and National Land Cover Database were not designed to calculate LUC.
    - Data distributed spatially in the CDL were not official data. Official data was available, but only when aggregated at the county level.

The above listed papers criticized the methods of Lark et al. (2015; 2022), and Wright et al. (2017). However, their criticism is also apt for Johnston (2013). The DRIA refers to Johnston (2013) as potential evidence for wetland loss in the Prairie Pothole Region. Like Lark et al. (2015; 2022) and Wright et al. (2017), Johnston (2013) used the CDL in her LUC analysis by intersecting this layer with the US Fish and Wildlife Service's National Wetland Inventory (NWI) data layer. Not only is the CDL a poor tool for estimating accurate LUC to crops, the NWI layer is also unreliable. As indicated by US Fish and Wildlife Service (2023), the NWI is a planning-level tool that makes "no attempt to define the limits of proprietary jurisdiction," and includes no measure of ground-truthing. Therefore, the NWI is not a robust dataset for estimating wetland loss at a scale as far-reaching as that of the entire Prairie Pothole Region. Furthermore, the analysis of Johnston (2013) did not compare findings from before and after 2008 and provided no acceptable reference or counter-factual scenario for how things may have evolved in the absence of the RFS. Johnston (2013) cited increased demand for corn to produce ethanol as the reason for potential extensification, however her causal analysis lacked rigor. Johnston (2013) did not assess the causal linkage except by association to corn prices. This assumption is erroneous, as we have shown in our economic analysis that there is little direct association between corn prices and demand for ethanol or the RFS volumes.

In summary, to the extent any LUC is driven by US biofuels policy, such change has not been quantified in a predictable and repeatable manner and observed change has not been causally linked to biofuels policy. Nor is there any evidence that LUC will result from the volumes proposed in the current rule. The final RIA should comprehensively address the limitations of the Lark et al. (2015; 2022), Wright et al. (2017), and Johnston (2013) papers or remove citations to them. Additionally, we recommend that the EPA include references to the following articles: Copenhaver 2022; Dunn et al. 2017; Pritsolas and Pearson 2019; Shrestha et al. 2019; Taheripour et al. 2022b; USDA 2022 to clearly explain the shortcomings in the methodologies that have been used to predict LUC, and to acknowledge the studies that conclude that the causal relationship between the RFS and LUC is weak or non-existent.

4.2 Conversion of Wetlands, Ecosystems, and Wildlife Habitats

This section of the report references Section 4.3 in the DRIA: Conversion of Wetlands, Ecosystems, and Wildlife Habitats.

4.2.1 Wetlands

The DRIA states that "[it] does not provide the information needed to determine the portion of wetland acres lost in order to grow feedstocks for biofuels, nor does it attempt to identify the portion of lost wetland acres attributable to the RFS program," (DRIA, p. 242) and further, repeats the acknowledgement in the second Triennial report that EPA cannot quantify the amount of cropland extensification that may have been due to the market for biofuels (and by extension any increased demand for corn for ethanol due to the RFS). These statements require qualification because the literature does not support that there is any wetlands loss attributable to the RFS. In addition, many investigators have suggested that the RFS results in extensive wetland loss, without adequate support. Unfortunately, technical flaws in literature the DRIA cites to show wetland loss due to agricultural extensification (Wright et al. 2017 and Johnston 2013) make the authors' assessments unreliable. These papers use CDL data to create their estimates, which, according to literature we cited in Section 4.1, suggests that they grossly overestimate wetland LUC. They also do not provide a quantitative causal framework for attributing estimated wetland loss to the RFS rule specifically.

Furthermore, Wright et al. (2017) and Johnston (2013) implied that the decision by individual farmers to extend their agricultural land at the expense of wetlands is a simple decision based largely on increased corn prices driven by the RFS. However, our economics section demonstrated that the decision is not simple and that factors apart from corn prices are critical to a farmer's decision. In addition to typical agricultural factors such as soil health and projected profits, there are also many policy provisions in place to reduce the occurrence of wetland conversion due to agricultural extensification. Incentive programs (as outlined by Gleason et al. 2011) included in the Farm Bills such as the Wetland Reserve Program in the 1990 Farm Bill[8] and the Wildlife Habitat Incentives Program and Environmental Quality Incentives Program in the 1996 Farm Bill[9] discourage agricultural extensification by providing financial incentives to a farmer for preserving sensitive ecosystems, such as wetlands. Further, the Swampbuster provisions, included in the Food Security Act of 1985 (Public Law 99-198), deem a farmer ineligible for certain USDA benefits (subsidies, loans, crop insurance, etc.) if agricultural commodities are produced on converted wetlands. Conversion of wetlands is not only decided by the decision of an individual farmer but is also heavily regulated under Section 404 of the Clean Water Act (33 US Code § 1344), which can require extensive permitting, and often compensatory mitigation, for impacts to wetlands greater than 0.1 acres. These mitigating factors and incentive programs are additional factors in a farmer's decision to pursue wetland conversion in favor of agricultural extensification and should be explicitly acknowledged in EPA's final RIA.

4.2.2 Other Ecosystems

The DRIA section on conversion of other ecosystems is largely focused on the conversion of grasslands and the EPA cites Wright et al. (2017) and Lark et al. (2015) as the evidence for grassland conversion. As previously discussed in the current report and in the NGES report (2022), these references have major flaws including the low confidence of the CDL data they used in differentiating between grassland, pasture, and crop-rotation land classifications as described in our report in Section 4.1. For this reason, we urge the EPA to explicitly acknowledge the deficiencies of Wright et al. (2017) and Lark et al. (2015) in the final RIA, specifically as they pertain to reporting grassland conversion, or that the references be excluded entirely.

---

[8] Formally known as the Food, Agriculture, Conservation, and Trade Act of 1990 (Public Law 101-624)

[9] Formally known as the Federal Agriculture Improvement and Reform Act of 1996 (Public Law 104-127)

4.2.3 Wildlife

The DRIA introduces the Wildlife section as a discussion of impacts to wildlife that are linked to changes in wetland and other ecosystems but limits the discussion to birds and pollinators with the reasoning that these groups of organisms are the most studied. The focus on these two receptor groups may result in an unjustified perception that a causal relationship between the RFS and negative effects on wildlife has been established and that these two receptor groups are at particular risk. The discussion of potential impacts to wildlife that the DRIA (and Second Triennial Report) present may give the casual reader a false impression that the impacts it describes are attributable to the RFS. We recommend that EPA consider acknowledging the lack of a quantitative relationship between biofuel feedstock grown specifically to meet the RFS and potential impacts to wildlife from corresponding LUC. Specific comments regarding the discussion of birds and pollinators follow.

4.2.3.1 Birds

The DRIA cites Gleason et al. (2011) in support of the assertion that "Conversion of wetlands to row crops is associated with reduced duck habitat and productivity of duck food sources, including aquatic plants and invertebrates." However, this assertion is not supported by the article cited. Gleason et al. (2011) examined the benefits of programs such as CRP and the Wetland Reserve Program in restoring ecosystem services (including waterfowl habitat services) but did not address habitat loss due to agricultural conversion. Moreover, the paper also did not assess or mention the potential role of the RFS in wetland loss and therefore it has no relevance to the discussion of potential impacts of the RFS. In fact, biofuels are mentioned only in the abstract of the paper and only in the context of the importance of USDA conservation programs in view of increasing demands for agricultural products (food and fiber were also mentioned).

The DRIA cites Fletcher et al. (2011), which conducted a meta-analysis of 15 articles reporting on the difference in vertebrate (mostly bird) biodiversity between agricultural lands devoted to crops that can be used for biofuels and other non-agriculture lands. They noted, however, that only two of the papers that were deemed adequate for their study differentiated between corn and soy. More important, Fletcher et al. (2011) did not attempt to apportion such changes spatially or quantitatively to any direct effects of the RFS. In fact, at an even more fundamental level, the authors acknowledged that "We still know remarkably little about the biodiversity associated with current biofuel crops…." We suggest that EPA acknowledge two things in the final RIA when citing this paper: 1) that the authors made no attempt to quantify any biodiversity impacts to extensification due to the RFS, and 2) the specific weaknesses of the study acknowledged by the authors themselves including the poor state of knowledge regarding biodiversity in fields devoted to growing biofuel feedstock.

Additionally, the DRIA cites a study by Evans and Potts (2015; the DRIA cites Evans et al. 2015) in support of the assertion that grassland bird species are among those species at highest risk from LUC driven by biofuels. Although the DRIA presents a good summary of the study, it does not point out some of the weaknesses of the study that are acknowledged by the authors themselves, for example:

- The counterfactual scenario developed "is simplified in that it does not include a number of other important drivers of agricultural commodity prices and LUC, including growing demand from international markets, commodity market speculation, and exchange rate fluctuations."

- The "results suggest that this approach may overestimate the ecological impact of biofuel expansion due to a relatively inelastic cropland acreage supply response to expected market conditions."
- Use of CDL data which has "very poor" classification accuracy for differentiating between grassland, pasture, and hay management required that the authors merge these land classes into a single category.

We recommend that the EPA explicitly include these weaknesses identified by Evans and Potts (2015) into the final RIA when citing the study.

4.2.3.2 Pollinators

The DRIA discusses the importance of pollinators, mainly focusing on bees, and how populations of bees have declined in recent years. The DRIA acknowledges that pollinator decline is due to many causes such as disease, LUC, and pesticide use[10]. However, the DRIA cites articles which do not directly relate population declines resulting from the production of biofuels or to the enactment of the RFS (Godfray et al. 2014; Goulson et al. 2015; Hellerstein et al. 2017; Koh et al. 2016; Lautenbach et al. 2012; Losey and Vaughan 2006).

The articles the DRIA cites regarding LUC suggest that population declines are due to LUC from many causes, but their estimates of LUC are likely overestimated. Two of the authors discussing the effect of LUC on pollinators used CDL data to calculate LUC (Koh et al. 2016; Hellerstein et al. 2017) which we have shown leads to overestimation of LUC. The analysis in another paper the DRIA cites regarding LUC, Lautenbach et al. (2012), was based on a model using a crop layer with 10 by 10-kilometer resolution. Based on previous critiques of the CDL and the necessary satellite-imagery resolution needed for land cover analyses (Copenhaver 2022), this model from Lautenbach et al. (2012) is not refined enough to differentiate between land use types and their estimates of loss of pollinators due to LUC are likely overestimated.

Understanding the actual harm of pesticide use is complicated for certain types of pesticides. In addition, the mass of pesticide applied to corn crops has decreased since the 1980s (Fernandez-Cornejo et al. 2014; USDA ERS 2018a; USDA NASS 2013). The DRIA cites two articles, Godfray et al. (2014) and Goulson et al. (2015), which discussed the harm to pollinators from neonicotinoid pesticide exposure. These papers reported that neonicotinoid pesticide can impact pollinators but also stated that it is not clear how harmful neonicotinoids truly are. More recent studies have still not clarified the strength of the relationship between neonicotinoid pesticides and pollinator populations. For example, the Singla et al. (2021) paper "Influence of neonicotinoids on pollinators: A review" found that the pesticide negatively impacted various behaviors of pollinators (e.g., foraging, pollination, and reproduction) but did not always lead to pollinator mortality. The authors acknowledged there were many limitations and gaps in this area of research that need to be elucidated in future studies. The final RIA should incorporate discussion of Singla et al. (2021) and clarify that any neonicotinoid harm is not well understood and has not been quantified.

---

[10] DRIA, pp. 250-251 – "A 2016 modeling study suggests that wild bee populations decreased by 23% across the U.S. between 2008 and 2013.437 The causes of these reductions are complex, but include land use change, pesticides, and disease."

Due in part to EPA regulatory efforts, pesticide use has decreased in the US since the 1980s (Fernandez-Cornejo et al. 2014; USDA ERS 2018a). The EPA Office of Pesticide Programs released the "Policy to Mitigate the Acute Risk to Bees from Pesticide Products" (hereafter, the policy) in 2017 and proposed more actions to protect pollinators in 2020 (EPA 2017; 2022d). This 2017 policy was enacted to mitigate acute hazards to bees from pesticide products by regulating application through practical means such as restricting spraying to times when pollinators are least active. The actions to protect pollinators are also known as the "Proposed Interim Decision on Neonicotinoids," which expands on management measures of the policy. The EPA proposes to cancel the spraying of imidacloprid on turf, keep pesticides on the intended target, reduce the amount used on crops associated with potential ecological risks, and restrict when pesticides can be applied to blooming crops to limit exposure to bees (EPA 2017; 2022e). Ramboll and NGES recommend that the EPA review these new policy measures in the final RIA's pollinator discussion to highlight potential future improvements in agricultural practices that may mitigate potential impacts caused by the RFS.

In summary, the DRIA did not cite any specific source which causally tied corn ethanol biofuel production to pollinator population decline, nor are we aware of any. Thus, we recommend that the EPA clarify this section to state that there is no known causal mechanism between the RFS and pollinator declines, that research into this relationship is lacking, and that cited papers about pollinator decline do not relate to the RFS.

5. Soil and Water Quality

The DRIA discusses impacts of biofuels feedstock on soil and water quality together due to their close association. The discussion is mostly general in terms of potential impacts of agriculture, but it does cite several studies that are specific to corn and soy. For example, the DRIA identifies the following potential impacts to soil and water from for agriculture: increased erosion from tilling and other land management practices, fertilizer and pesticide runoff from fields to surface water bodies, depletion of soil organic matter, chemical contamination from releases and spills, and increase loading of nutrients and other agrichemicals resulting in adverse water quality conditions, including potential toxicity to aquatic organisms. The DRIA correctly acknowledges that: 1) The role of the RFS in observed impacts to soil and water quality cannot be estimated (p. 267); 2) future impacts relative to 2022 are likely to be small (p. 267); and 3) there are many effective management practices that can act to counterbalance any negative impacts from corn for ethanol (e.g., p. 257). The final RIA should clarify these positions throughout the discussion of potential water quality impacts.

Over the past few decades, widespread adoption of improved agricultural practices has mitigated many of the impacts described in the DRIA . There is strong evidence that the agricultural community, including biofuel feedstock producers, are adopting modern agricultural practices (Vuran et al. 2018). The EPA (2010 and 2018a) acknowledge and strongly advocate for these modern practices and note that negative impacts to environmental resources will be reduced with the use of modern approaches to tilling, fertilizer use, water use, and precision agriculture. In its discussion of impacts to soil and proximal water quality (DRIA, p. 255), the DRIA presents a calculation of a theoretical increase in nitrogen applied to farm fields nationwide due to corn extensification, but this calculation is flawed because the assumption regarding acres of extensification for corn is based on the work of Lark et al. (2015) which has been shown to be unreliable. We recommend that EPA remove this example calculation from the text of the final RIA because it is erroneous. Similarly, the DRIA cites Garcia et al. (2017) who estimated that corn production between 2002 and 2022 would result in nitrate groundwater contamination of greater than 5 milligrams per liter in areas with sandy or loamy soils. However, this estimate is based on corn production in general and the authors did not attempt to associate the increased nitrates in groundwater to any effect of the RFS. In the absence of evidence of a quantitative causal relationship, the discussion in the DRIA of the relationship between agriculture (and corn growing in particular) and proximal water quality creates the misleading impression of a direct causal relationship.

Similarly, the DRIA presents a discussion of the potential downstream effects of corn and soy cultivation. In terms of aquatic life, the DRIA discusses the biological condition of the nation’s rivers, streams, and lakes and the causative factors contributing to poor conditions. The DRIA cites source documents that mention nutrient enrichment as a leading contributor to degraded water quality conditions nationwide. Throughout these discussions, the DRIA provides no link to biofuels crops or the RFS other than to note that several areas with the worst problems are in areas where biofuels crops are prevalent. Because the DRIA does not acknowledge this lack of nexus to the RFS, it creates the false impression that widespread water quality degradation is due to biofuel crop intensification and extensification that is driven by the RFS. The final RIA should acknowledge that there have been no studies establishing such a quantitative causal link between the RFS and soil and water quality.

As it did in 2021, the DRIA mentions the role of nutrient enrichment in the formation of very large-scale hypoxic events in western Lake Erie or the Gulf of Mexico. However, the DRIA does not discuss what, if any, influence biofuels feedstock production may have in eliciting this phenomenon. Perhaps most important, the DRIA does not mention that regional hypoxic conditions in western Lake Erie and the Gulf of Mexico were increasing in frequency and severity long before ethanol production increased and that nitrogen loading to the Gulf of Mexico remained fairly constant from the early 1990s through about 2008 and then actually began a decreasing trend (Figure 5-1). The DRIA ignores a rich literature describing the complexity of these phenomena and does not explicitly state that the eutrophication studies it cites (e.g., Secchi et al. 2011) did not attempt to estimate increased nutrient input from biofuels crops grown to meet demand from the RFS (this topic is discussed in more detail at Ramboll 2019, pp. 26-27). We recommend that the final RIA include a discussion of the lack of causal evidence linking the RFS to these phenomena.

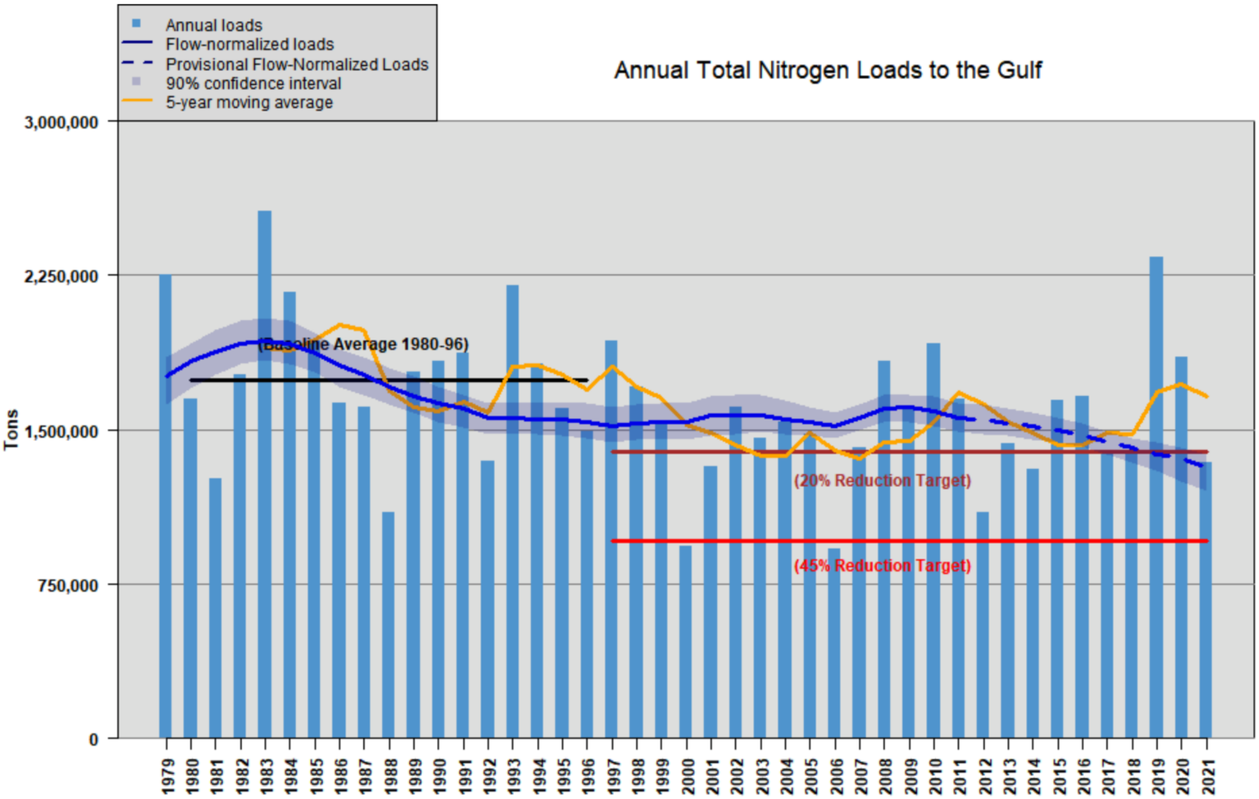

Figure 5-1. Annual Nitrate and Nitrite Loading to the Gulf of Mexico 1980-2021

Data Source: US Geological Survey 2021

The DRIA also discusses the potential for deleterious effects on aquatic life from pesticides applied to corn and soybeans and in support of such statements, cites various toxicological studies. Among the papers EPA cites are studies of glyphosate (the active ingredient in Roundup) on fish including sublethal effects such as DNA damage and altered muscle and brain function. For example, a study by Guilherme et al. (2012) reported on observed genetic damage from acute exposure of a single test species (*Anguilla anguilla*, European eel) to glyphosate in water using the comet assay. The comet assay is a sensitive test that is not specific to chemical stressors in general and certainly not specific to agrochemicals such as glyphosate. In addition, the test is fraught with problems of interpretation as well as laboratory practices that can dramatically affect results. For example, Braafladt et al. (2016) described sources of variability in the comet assay that included variations in the protocol used to process the cells, the microscope imaging system used, and the software used in the computerized analysis of the images. The authors stated that "Manual image analysis revealed measurement variations in percent DNA in tail as high as 40% due to microscope focus, camera exposure time and the software image intensity threshold level." McArt et al. (2009) highlighted limitations in the use of the comet assay, including lack of standardization such as solution molarity, pH, the use of protein digests, wash times, unwinding times, and electrophoresis times which can all contribute to differences in the scoring values obtained. In addition, the authors maintained that certain aspects of the comet protocol are open to selection bias associated with investigator choice on the number and location of comets to analyze. In addition to the poor reliability of comet assays, there is no way to interpret the result in terms of potential effects at the organism or population level.

The DRIA also cites toxicological studies using physiological (biomarker) responses. Like comet assays, such studies cannot be extrapolated to individual or population level effects and are not chemical specific, rather the results simply indicate that an organism, organ, or tissue has been exposed to a substance that is known to elicit the measured response (e.g., Modesto and Martinez 2010). We recommend that EPA delete citations to toxicological studies that rely on biomarkers. For example, both EPA and USDA have issued fact sheets acknowledging that glyphosate is practically nontoxic to fish and aquatic invertebrates (EPA 1993; USDA 1997). More recent review articles of the aquatic toxicity of glyphosate agree with these earlier findings (e.g., Bastos et al. 2018 and Solomon and Thompson 2003). The EPA could cite these studies (EPA 1993; USDA 1997; Bastos et al. 2018 and Solomon and Thompson 2003) in the final RIA in place of the biomarker studies.

In summary, the general discussion of soil and water quality impacts from agriculture is missing an adequate discussion of the lack of a causal relationship between the RFS and the impacts discussed. The DRIA also fails to adequately acknowledge the role of ongoing adoption of modern agricultural practices such as precision agriculture in mitigating such impacts (e.g., see for example Ramboll 2019, pp. 31-33).

6. Water Quantity and Availability

Like other areas of our review (Economic, Environmental & Ecological, Soil & Water Quality), the DRIA provides the foundation for Ramboll's analysis of the effect of the proposed volumes on water quality and water availability. A key statement presented within the DRIA regarding water quantity and water availability is:

> "To our knowledge, there have been no comprehensive studies of the changes in irrigated acres, rates of irrigation, or changes in surface and groundwater supplies attributed specifically to the increased production of corn grain-based ethanol and soybean-based biodiesel." (DRIA, p. 273)

However, current wording in the DRIA suggests that corn, specifically corn for biofuels, is a driver for change in the High Plains Aquifer (HPA) levels. Specifically, the DRIA states "Water intensive corn and soybean production occurs on irrigated acres in states such as Nebraska and Kansas, in particular, the western parts of those states. These states also overlap the High Plains Aquifer (HPA) "where groundwater levels have declined at unsustainable rates. (Smidt et al. 2016)" (DRIA, p. 268) Changing and declining water levels in the HPA are not disputed. However, the EPA cites literature that attempts to connect an alleged increase in corn acreage to changes in HPA water levels such as Smidt et al. (2016), Wu et al. (2014), and Liu et al. (2017).

Ramboll's analysis on water quantity and availability includes reviewing literature the DRIA relies on regarding water quantity impacts and water levels in the HPA (particularly in Nebraska), including the following:

- EPA (2018): Biofuels and the Environment: Second Triennial Report to Congress.
- Wu et al. (2014): Life-cycle water quantity and water quality implications of biofuels.
- Smidt et al. (2016): Complex water management in modern agriculture: Trends in the water-energy-food nexus over the High Plains Aquifer.

- National Academy of Sciences (2011): Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy.
- Dominguez-Faus et al. (2009): The water footprint of biofuels: A drink or drive issue?
- Gerbens-Leenes and Hoekstra (2012): The water footprint of sweeteners and bio-ethanol.
- Liu et al. (2017): Potential water requirements of increased ethanol fuel in the USA.

Ramboll's findings based on a review of this literature are as follows.

- The HPA water levels within the states where most corn is grown, Nebraska and South Dakota, are renewed in a normal precipitation year (McGuire and Strauch 2022).
- HPA levels in Nebraska have remained relatively constant or have increased over time.
- In general, Nebraska corn yields steadily increased in the period from 2005 through 2017 while HPA levels have remained relatively constant. An exception to this general trend is the period from 2011 through 2013 when both corn yields and HPA levels decreased as result of below average annual precipitation.
- Groundwater depletion in the HPA is further south over Oklahoma and Texas where the climate is drier and where only 4% of the ethanol plants in the country exist.
- Technological advances have reduced and are expected continue reducing the amount of water used for corn production.

EPA should address these key points in the final DRIA.

6.1 Impact of Corn Production on the HPA

Although there are eight states that exist within the boundaries of the HPA, corn is the most grown crop in only two of them: Nebraska and South Dakota. In those two states, the HPA water levels are renewed in a normal precipitation year (McGuire and Strauch 2022). Figure 6-1 represents the water level changes in the HPA from pre-development to 2017 over the eight states where the HPA is located along with the location and capacity of ethanol plants in the HPA (McGuire and Strauch 2022; National Renewable Energy Laboratory 2023). This figure indicates that most ethanol plants exist within central and eastern Nebraska where HPA level changes are primarily non-existent or the levels have risen. There are areas of southeast Nebraska where water levels declined within the range of 5 to 25 feet. However, as stated in the introduction, there have been no comprehensive studies that attribute decreasing groundwater supplies to the increased production of corn grain-based ethanol and soybean-based biodiesel.

Figure 6-1 further indicates that the location where significant groundwater depletion is occurring in the HPA is further south over Oklahoma and Texas where the climate is typically drier than the northern HPA. It should be noted that only about 4% of the ethanol plants in the country are in this portion of the HPA.

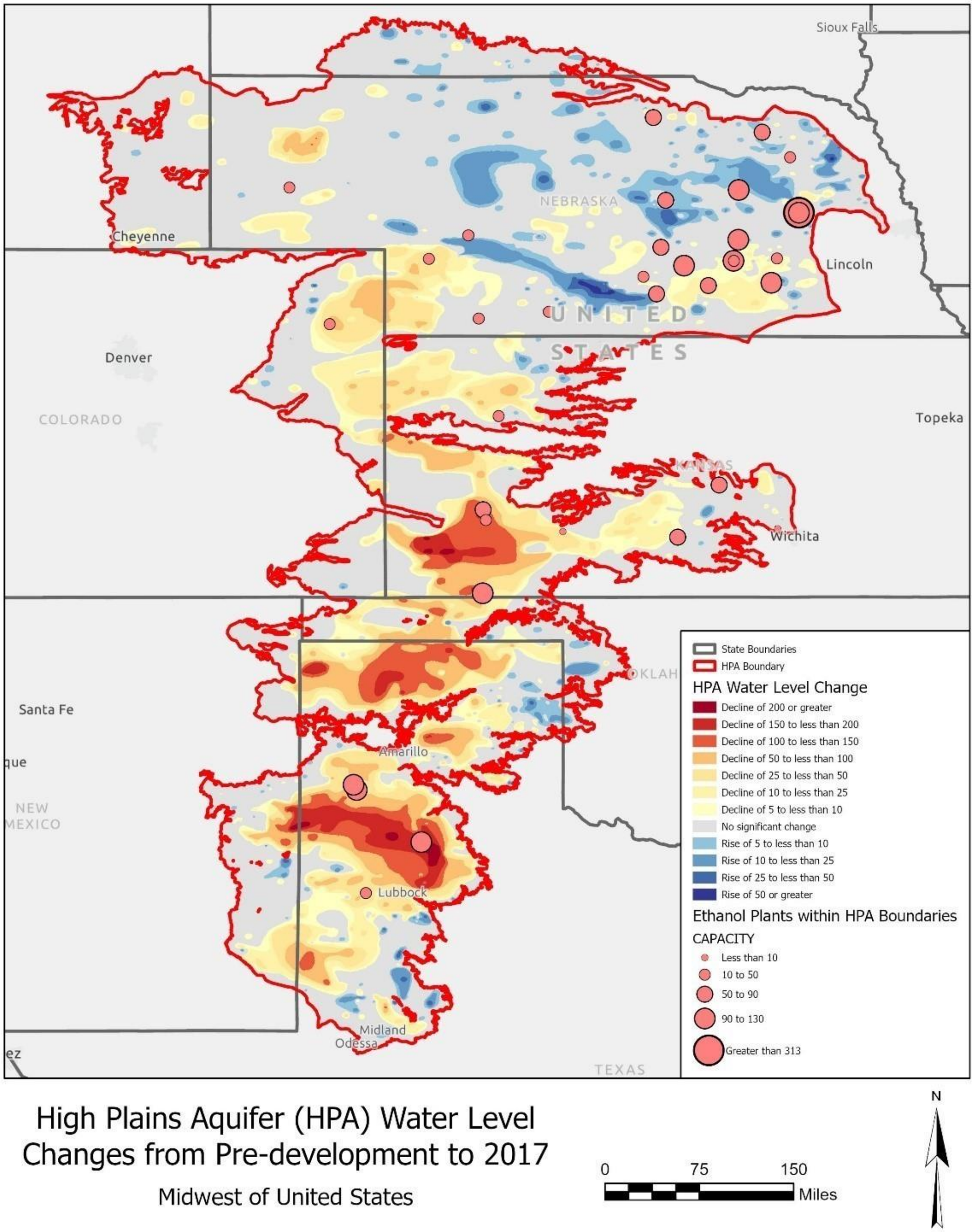

Figure 6-1. High Plains Aquifer (HPA) Water Level Changes from Pre-Development to 2017 in the Midwest of the US and Ethanol Refinery Locations based on their Capacity

Sources: McGuire and Strauch (2022); National Renewable Energy Laboratory (2023)

The fact that the largest amount of groundwater depletion in the HPA occurs in Oklahoma and Texas, where the climate is much drier, points to the fact that when considering changes in HPA levels, one must also consider changes in average annual precipitation. Figure 6-2 shows the relationship between the average annual precipitation and HPA levels in Nebraska overlaid by the bushels of corn produced in the state. Inspection of the figure clearly shows that:

- HPA levels have remained relatively constant or have increased over time, as indicated by the green line representing the HPA level remaining relatively flat over time.
- Years of low average annual precipitation correlate with low HPA levels. This is evidenced by the dips in the blue line, which represents precipitation, being followed by dips in the green line, which represents the HPA level. This is most prominent from 2011 to 2013.
- Corn yields have steadily increased while HPA levels have remained relatively constant. This is evidenced by the orange line representing corn yield increasing over time.
- Corn yield decreases in years of low average annual precipitation as evidenced in the years 2011 to 2013. This decrease also demonstrates that corn production in Nebraska is largely dependent on annual precipitation and not withdrawal from the HPA.

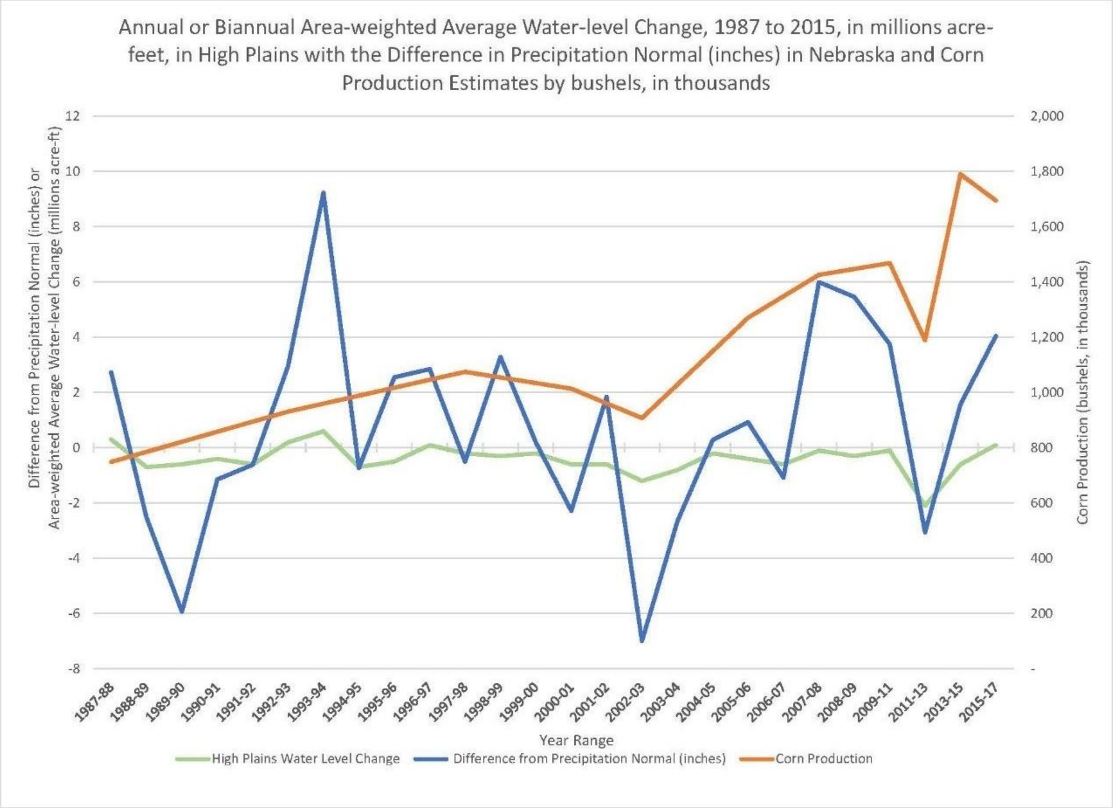

Figure 6-2. Comparison of Average Annual Precipitation to HPA Levels and Corn Production in Nebraska

Sources: Nebraska Corn Board 2023; National Oceanic and Atmospheric Administration 2023; US Geological Survey 2023; USDA NASS 2014

6.2 Other Factors Affecting the HPA

Although our discussions regarding Figures 6-1 and 6-2 focus on the effects of corn production on the HPA, the corn in these figures is not limited to that which is grown for biofuel. Water removed from the HPA is also used to irrigate corn grown for other purposes such as food for livestock. In addition, there are other uses of water that contribute to decreases in the HPA including livestock production, municipal and industrial use, and growth of other crops. The other major crops harvested in the HPA areas of Nebraska are wheat, soybeans, alfalfa, and sorghum. Nebraska commits large areas of production to other crops including approximate 5.5 million acres to soybeans, 5.1 million acres to hay, 1.6 million acres to wheat for a total of approximately 12.2 million acres. The area for these others crops exceed the 9.9 million acres used for corn (Nebraska Corn Board 2022). The state also supplies ~20% of the nation's cattle (USDA NASS 2023b).

6.3 Advanced Agriculture and Reduction in Water Use

The USDA anticipates improvements in corn production practices and techniques to result in a yield increase of 16.1 more bushels per harvested acre by 2028 (USDA NASS 2018); thus, provided that these technological and methodological changes are made, significant reductions in water use will continue to take place for corn production. While the percentage of harvested corn acres has dropped from 80% irrigated in 1979 to 70% irrigated in 2013 (USDA NASS 2013), irrigated corn still disproportionately represents the top source of agriculturally consumed water (USDA-ERS 2022). In 2012, corn production accounted for approximately 25% of total U.S. irrigated acreage harvested (USDA-ERS 2022). With an emphasis on water-related technology and methodological changes in the late 2010s, Table 6-1 provides an overview of a selection of beneficial prevailing opportunities for water savings in irrigated agriculture. A review of literature suggests that upwards of 50% of irrigated water can be eliminated by instituting such pre-established practices (Shangguan et al. 2002).

Table 6-1. Technological and Methodological Improvements to Irrigation of Corn Crops

Technological Advancement	Approximate water savings factor	Baseline scenario	Demonstrated potential yield increase	Notes
Subsurface drip irrigation	**25-35%**	vs. center pivot system	**15-33%**	Costs 40-50% higher than center pivot systems, but returns-on-investment (ROI) can accrue within 2—5 years. In 2007, only 0.1% of irrigated corn farms used this.
Rainwater harvesting and storage	**50+%**	vs. natural soil runoff	**20-52%**	Includes 1) harvesting of surface runoff from roads; 2) field micro-catchment to increase fallow efficiency in rain.

Technological Advancement	Approximate water savings factor	Baseline scenario	Demonstrated potential yield increase	Notes
Precision agriculture	**13%**	vs. without government-run weather network	**8%**	Includes use of GPS, GIS, in situ soil testing, remote sensing crop and soil status, real-time weather info. Adoption rate slightly higher in corn belt.
Conservation structures	**18%**	vs. conventional agriculture	**27%**	Examples include grass vegetation strips. Adoption is higher in areas of highly erodible land.

Because water supply is a concern irrespective of corn and biofuel production, there is also a precedent for subsidized government programs that successfully implement these new technologies for the benefit of the farmers. For example, because of prolonged drought conditions, California installed a network of 145 automated statewide weather stations, so that farmers could manage their water resources more efficiently (California Irrigation Management Information System 2023).

Generally, opportunities for technology improvement are found when considering irrigation system development. For example, in 2018, fewer than 10% of irrigators used soil- or plant- moisture sensing devices or commercial scheduling services, and fewer than 2% used simulation models that are based on corn growth patterns and weather conditions (USDA ERS 2018b). However, adoption of more efficient technologies is growing in the U.S., especially in the western U.S. where the percent of crops irrigated with more efficient pressurized (versus gravity) irrigation systems had increased to 72% by 2018, compared to 37% in 1984 (USDA ERS 2022).

Barriers to implementation of these measures may include such issues as: 1) farmer concerns about the impact of new practices on yields; 2) tenant or lease issues that discourage the installation or use of new equipment; 3) institutional issues related to Federal Crop Insurance Program; 4) irrigation water rights laws like "use it or lose it;" and 5) insufficient self-funding by the farmers. The Great Plains area had traditionally been risk-averse to implementing subsurface drip irrigation techniques because of the upfront costs and uncertain lifespan of the systems, however, there have been improvements in the technology and irrigators are increasingly aware of the additional incentives for water conservation and protecting water quality (Lamm and Trooien 2003).

While controversial, genetic engineering or selection for improved drought tolerant corn cultivars has also contributed to increases in corn crop productivity as part of ethanol production. Genetic breeding has also shown that yields can be maintained with lower water requirements (nearly 25% reduction), in addition to studies that suggest corn crops can forego the initial irrigation without significant adverse effects to the harvest (Xue et al. 2017).

Altogether, there is still significant potential for increases in yield and decreases in irrigation, which ultimately will address water quality concerns caused by leaching or run-off of chemicals to both the subsurface and to surface water.

6.4 Reduction in Water Usage for Ethanol Processing

With the data available, trends suggest an overall decrease in consumptive biofuel production water use over time, due to advances in technology and in the efficiency of existing plants. In 1998, the average dry mill consumed 5.8 gallons of water per gallon of ethanol. However, by 2009, the U.S. Department of Energy estimated this had been reduced to approximately 3 gallons of water per gallon of ethanol. Wu et al. (2018) noted additional trends that suggest decreases in the water demands of existing and new ethanol plants. Freshwater consumption in existing dry mill plants had, in a production-weighted average, dropped 48% in less than 10 years to water use rates that are 17% lower than typical mill values. Water use can be minimized even further, through process optimization, capture of the water vapor from dryers, and boiler condensate recycling to reduce boiler makeup rates.

6.5 Technology Changes and Reduction in Chemical Use

Recent advancement in technology in agriculture practices have increased the crop yield without changes in the water usage. It is not unusual for farmers to adopt such new practices as part of pre-existing agricultural operations. In 2011 and 2012, 78% of total corn acres were planted in rotation with soybean and/or other for-sale crops (Atwell et al. 2016; Azevedo et al. 1999; Barton and Clark 2014; Foodwise 2014). This "conservation tillage" method has been shown to result in an approximately 9.6% increase in yield (Atwell et al. 2016; Azevedo et al. 1999; Barton and Clark 2014; Foodwise 2014).

Based on discussions with Professor M. Ruark of University of Wisconsin, Madison, the application of slow released (or controlled) nitrogen fertilizer during peak uptake is key to improving nutrient efficiency and utilization (Lal and Stewart 2018). Under optimum moisture and temperature conditions, use of slow released nitrogen fertilizer can greatly reduce leaching of nutrients. However, further research is necessary to discern the best slow-release fertilizer for a given crop species (Rose 2002).

A similar method called fertigation (alternate partial root-zone drip irrigation) has been shown to improve the nitrogen uptake in addition to water-use-efficiency (WUE) without greater yield loss. Some additional studies have shown that fertigation can generally improve the WUE while reducing the nitrogen leaching in subsurface (Fu et al. 2017).

Ramboll recognize that genetic engineering can be controversial, but it has enabled these benefits which can be used to address potential challenges such as aquatic dead zones. Combined with advanced chemical technologies, including slow-release nitrogen-based fertilizers and bio-inhibitors, additional reductions in pesticide and fertilizer use are possible in corn production. Use of bioreactors, for instance, which involves redirecting water through tiles to underground woodchips where nitrate is removed by microorganisms, can reduce nitrogen pollution in run-off by 15 to 90% (Christianson 2016; Iowa Corn Growers Association 2023).

6.6 Recommendations Regarding Factors Influencing HPA Levels

From our literature review, we agree with the EPA that the RFS does not have a known causal connection with impacts to water quantity[11], although there is evidence that water quantities could be affected by additional irrigation[12]. However, our research also indicated that there are other factors that influence groundwater withdrawals from the HPA that we recommend be acknowledged and discussed in the final RIA, including precipitation patterns, drought years, other uses of corn production, and improved technology.

7. References

Alternative Fuels Data Center. 2021. U.S. Ethanol Plants, Capacity, and Production. [accessed 2023 Jan 10]. https://afdc.energy.gov/data/10342.

Atwell R, Mirsky S, Moyer J, Poffenbarger H, Reberg-Horton C, Zinati G. 2016. Organic No-Till Corn Production: Cover Crop and Starter Fertilizer Considerations. Rodale Institute. June 2. https://rodaleinstitute.org/science/articles/organic-no-till-corn-production-cover-crop-and-starter-fertilizer-considerations/.

Austin KG, Jones JPH, Clark CM. 2022. A review of domestic land use change attributable to U.S. biofuel policy. Renewable and Sustainable Energy Reviews. 159:Article 112181. doi:10.1016/j.rser.2022.112181.

Azevedo DMP de, Landivar J, Vieira RM, Moseley D. 1999. The effect of cover crop and crop rotation on soil water storage and on sorghum yield. Pesquisa Agropecuária Brasileira. 34:391–398. doi:10.1590/S0100-204X1999000300010.

Barton B, Clark SE. 2014. Water & Climate Risks Facing U.S. Corn Production: How Companies & Investors Can Cultivate Sustainability. Boston, MA: Ceres. June. http://www.ourenergypolicy.org/wp-content/uploads/2014/06/ceres-corn.pdf.

Bastos Gonçalves B, Cardoso Giaquinto P, dos Santos Silva D, Silva Neto CM, Alves de Lima A, Brito Darosci AA, Laço Portinho J, Fernandes Carvalho W, Lopes Rocha T. 2020. Ecotoxicology of glyphosate-based herbicides on aquatic environment. In: Biochemical Toxicology: Heavy Metals and Nanomaterials. IntechOpen. https://doi.org/10.5772/intechopen.85157.

Braafladt S, Reipa V, Atha DH. 2016. The comet assay: Automated imaging methods for improved analysis and reproducibility. Sci Rep. 6(1):32162. doi:10.1038/srep32162.

California Irrigation Management Information System. 2023. CIMIS Overview. [accessed 2023 Feb 1]. https://cimis.water.ca.gov/.

Camp KM. 2019. The relationship between crude oil prices and export prices of major agricultural commodities. Beyond the Numbers US Bureau of Labor Statistics. 8(7). https://stats.bls.gov/opub/btn/volume-8/the-relationship-between-crude-oil-and-export-prices-of-major-agricultural-commodities.htm.

---

[11] DRIA, p. 273 – "To our knowledge, there have been no comprehensive studies of the changes in irrigated acres, rates of irrigation, or changes in surface and groundwater supplies attributed specifically to the increased production of corn grain-based ethanol and soybean-based biodiesel."

[12] DRIA, p. 274 – "While difficult to attribute how much additional water use might be required as a result of the candidate volumes in this rule, there are several lines of evidence that suggest increased production of corn-based ethanol and soybean-based biodiesel will increase water demands and, potentially, affect limited water supplies."

Carter CA, Rausser GC, Smith A. 2011. Commodity booms and busts. Annual Review of Resource Economics. 3(1):87–118. doi:10.1146/annurev.resource.012809.104220.

Carter CA, Rausser GC, Smith A. 2017. Commodity storage and the market effects of biofuel policies. American Journal of Agricultural Economics. 99(4):1027–1055. doi:10.1093/ajae/aaw010.

Centers for Disease Control and Prevention. 2017. Methyl tert-Butyl Ether (MTBE) Factsheet. [accessed 2023 Jan 16]. https://www.cdc.gov/biomonitoring/MTBE_FactSheet.html.

Christianson L. 2016. Reducing Water Pollution with Microbes and Wood Chips. The Conversation. July 5. https://theconversation.com/reducing-water-pollution-with-microbes-and-wood-chips-58852.

Copenhaver KL. 2022. Combining tabular and satellite-based datasets to better understand cropland change. Land. 11(5):714. doi:10.3390/land11050714.

Dominguez-Faus R, Powers SE, Burken JG, Alvarez PJ. 2009. The water footprint of biofuels: A drink or drive issue? Environmental Science & Technology. 43(9):3005–3010. doi:10.1021/es802162x.

Dunn JB, Merz D, Copenhaver KL, Mueller S. 2017. Measured extent of agricultural expansion depends on analysis technique. Biofuels, Bioproducts and Biorefining. 11(2):247–257. doi:10.1002/bbb.1750.

EPA (Environmental Protection Agency. 1993. R.E.D. Facts: Glyphosate. United States Environmental Protection Agency, Prevention, Pesticides and Toxic Substances. Report No.: EPA-738-F-93-011. September.

EPA. 2010. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. United States Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division. Report No.: EPA-420-R-10-006. February.

EPA. 2017. U.S. Environmental Protection Agency's Policy to Mitigate the Acute Risk to Bees from Pesticide Products. U.S. Environmental Protection Agency, Office of Pesticide Programs. January 12. https://www.regulations.gov/document/EPA-HQ-OPP-2014-0818-0477.

EPA. 2018. Biofuels and the Environment: Second Triennial Report to Congress. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development. Report No.: EPA/600/R-18/195F. June. https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=IO&dirEntryId=341491.

EPA. 2022a. Renewable Fuel Standard (RFS) Program: Standards for 2023-2025 and other changes. Proposed rule. Federal Register. 87(250):80582–80756.

EPA. 2022b. Draft Regulatory Impact Analysis: RFS Standards for 2023-2025 and Other Changes. United States Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division. Report No.: EPA-420-D-22-003. November.

EPA. 2022c. Renewable Fuel Standard Program. [accessed 2023 Jan 13]. https://www.epa.gov/renewable-fuel-standard-program.

EPA. 2022d. EPA Actions to Protect Pollinators. United States Environmental Protection Agency. [accessed 2022 Dec 22]. https://www.epa.gov/pollinator-protection/epa-actions-protect-pollinators.

Evans SG, Potts MD. 2015. Effect of agricultural commodity prices on species abundance of US grassland birds. Environmental and Resource Economics. 62(3):549–565. doi:10.1007/s10640-014-9829-1.

Fernandez-Cornejo J, Nehring RF, Osteen C, Wechsler S, Martin A, Vialou A. 2014. Pesticide Use in U.S. Agriculture: 21 Selected Crops, 1960-2008. Economic Information Bulletin No. 124. United States

Department of Agriculture, Economic Research Service. May. https://www.ers.usda.gov/webdocs/publications/43854/46734_eib124.pdf?v=3178.4.

Fletcher RJ, Robertson BA, Evans J, Doran PJ, Alavalapati JR, Schemske DW. 2011. Biodiversity conservation in the era of biofuels: Risks and opportunities. Frontiers in Ecology and the Environment. 9(3):161–168. doi:10.1890/090091.

Foodwise. 2014. 10 Ways Farmers Are Saving Water. August 15. https://foodwise.org/articles/10-ways-farmers-are-saving-water/.

Fu F, Li F, Kang S. 2017. Alternate partial root-zone drip irrigation improves water – and nitrogen – use efficiencies of sweet-waxy maize with nitrogen fertigation. Sci Rep. 7(1):Article 17256. doi:10.1038/s41598-017-17560-2.

Garcia V, Cooter E, Crooks J, Hinckley B, Murphy M, Xing X. 2017. Examining the impacts of increased corn production on groundwater quality using a coupled modeling system. Science of The Total Environment. 586:16–24. doi:10.1016/j.scitotenv.2017.02.009.

Gerbens-Leenes W, Hoekstra AY. 2012. The water footprint of sweeteners and bio-ethanol. Environment International. 40:202–211. doi:10.1016/j.envint.2011.06.006.

Gleason RA, Euliss Jr. NH, Tangen BA, Laubhan MK, Browne BA. 2011. USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. Ecological Applications. 21(Supp 1):S65–S81. doi:10.1890/09-0216.1.

Godfray HCJ, Blacquière T, Field LM, Hails RS, Petrokofsky G, Potts SG, Raine NE, Vanbergen AJ, McLean AR. 2014. A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. Proceedings: Biological Sciences. 281(1786):Article 20140558.

Goulson D, Nicholls E, Botías C, Rotheray EL. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science. 347(6229):Article 1255957. doi:10.1126/science.1255957.

Guilherme S, Gaivão I, Santos MA, Pacheco M. 2012. DNA damage in fish (Anguilla anguilla) exposed to a glyphosate-based herbicide – Elucidation of organ-specificity and the role of oxidative stress. Mutation Research/Genetic Toxicology and Environmental Mutagenesis. 743(1–2):1–9. doi:10.1016/j.mrgentox.2011.10.017.

Hellerstein D, Hitaj C, Smith D, Davis A. 2017. Land Use, Land Cover, and Pollinator Health: A Review and Trend Analysis. Economic Research Report No. 232. United States Department of Agriculture, Economic Research Service. June. https://www.ers.usda.gov/webdocs/publications/84035/err-232.pdf?v=42908.

Index Mundi. 2023. United States Corn Ending Stocks by Year (1000 MT). [accessed 2023 Jan 10]. https://www.indexmundi.com/agriculture/?country=us&commodity=corn&graph=ending-stocks.

Iowa Corn Growers Association. 2023. Conservation Practices. [accessed 2023 Jan 30]. https://www.iowacorn.org/corn-production/environmental/conservation-practices/.

Johnston CA. 2013. Wetland losses due to row crop expansion in the Dakota Prairie Pothole Region. Wetlands. 33(1):175–182. doi:10.1007/s13157-012-0365-x.

Kanaskie LA. 2000. MTBE phaseout: A boon for ethanol producers. Environmental Science and Technology. 34(9):205A-205A. doi:10.1021/es003238w.

Keeney D, Muller M. 2006. Water Use by Ethanol Plants: Potential Challenges. Minneapolis, MN: Institute for Agriculture and Trade Policy.

Koh I, Lonsdorf EV, Williams NM, Brittain C, Isaacs R, Gibbs J, Ricketts TH. 2016. Modeling the status, trends, and impacts of wild bee abundance in the United States. Proceedings of the National Academy of Sciences. 113(1):140–145. doi:10.1073/pnas.1517685113.

Lal R, Stewart BA, editors. 2018. Soil Nitrogen Uses and Environmental Impacts. Boca Raton, FL: CRC Press. https://doi.org/10.1201/b22044.

Lark TJ, Hendricks NP, Smith A, Pates N, Spawn-Lee SA, Bougie M, Booth EG, Kucharik CJ, Gibbs HK. 2022. Environmental outcomes of the US Renewable Fuel Standard. Proceedings of the National Academy of Sciences. 119(9):Article e2101084119. doi:10.1073/pnas.2101084119.

Lark TJ, Salmon JM, Wright CK, Gibbs HK. 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environmental Research Letters. 10(4):Article 44003. doi:10.1088/1748-9326/10/4/044003.

Lark TJ, Schelly IH, Gibbs HK. 2021. Accuracy, bias, and improvements in mapping crops and cropland across the United States using the USDA Cropland Data Layer. Remote Sensing. 13(5):968. doi:10.3390/rs13050968.

Lautenbach S, Seppelt R, Liebscher J, Dormann CF. 2012. Spatial and temporal trends of global pollination benefit. PLoS ONE. 7(4):Article e35954. doi:10.1371/journal.pone.0035954.

Liu X, Hoekman SK, Broch A. 2017. Potential water requirements of increased ethanol fuel in the USA. Energy, Sustainability and Society. 7(1):18. doi:10.1186/s13705-017-0121-4.

Losey JE, Vaughan M. 2006. The economic value of ecological services provided by insects. Bioscience. 56(4):311–323. doi:10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2.

Macrotrends. 2022. Corn Prices - 59 Year Historical Chart. [accessed 2022 Dec 22]. https://www.macrotrends.net/2532/corn-prices-historical-chart-data#:~:text=The%20current%20price%20of%20corn,2022%20is%20%246.5350%20per%20bushel.

McArt DG, McKerr G, Howard CV, Saetzler K, Wasson GR. 2009. Modelling the comet assay. Biochemical Society Transactions. 37(4):914–917. doi:10.1042/BST0370914.

McGuire VL, Strauch KR. 2022. Water-Level and Recoverable Water in Storage Changes, High Plains Aquifer, Predevelopment to 2017 and 2015–17. Scientific Investigations Report 2022-5080. United States Department of the Interior, United States Geological Survey. https://doi.org/10.3133/sir20225080.

Modesto KA, Martinez CBR. 2010. Roundup® causes oxidative stress in liver and inhibits acetylcholinesterase in muscle and brain of the fish *Prochilodus lineatus*. Chemosphere. 78(3):294–299. doi:10.1016/j.chemosphere.2009.10.047.

National Academy of Sciences. 2011. Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy. https://nap.nationalacademies.org/resource/13105/Renewable-Fuel-Standard-Final.pdf.

National Oceanic and Atmospheric Administration. 2023. Statewide Time Series. National Centers for Environmental Information. [accessed 2023 Jan 3]. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series/25/pcp/ann/12/1895-2022?base_prd=true&begbaseyear=1901&endbaseyear=2000.

National Renewable Energy Laboratory. 2023. Biofuels Atlas. Geospatial Data Science Applications and Visualizations. [accessed 2023 Jan 5]. https://maps.nrel.gov/?da=biofuels-atlas.

Nebraska Corn Board. 2022. Using Corn for Food and Fuel - Where Nebraska Corn Goes. [accessed 2023 Jan 5]. https://nebraskacorn.gov/corn-101/corn-uses/.

Nebraska Corn Board. 2023. Growing Nebraska Corn - Past and Present. [accessed 2023 Jan 3]. https://nebraskacorn.gov/corn-101/growing-corn/.

NGES. 2022. Analysis of EPA's Proposed Rulemaking for 2020, 2021, and 2022 RVOs Regarding Land Use Change, Wetlands, Ecosystems, Wildlife Habitat, Water Resource Availability, and Water Quality. Shelton, WA: Net Gain Ecological Services. February 3.

Olson DW, Capehart T. 2019. Dried Distillers Grains (DDGs) Have Emerged as a Key Ethanol Coproduct. Amber Waves. https://www.ers.usda.gov/amber-waves/2019/october/dried-distillers-grains-ddgs-have-emerged-as-a-key-ethanol-coproduct/.

Pritsolas J, Pearson R. 2019. Critical Review of Supporting Literature on Land Use Change in the EPA's Second Triennial Report to Congress. Prepared for Renewable Fuels Association.

Ramboll. 2019. The RFS and Ethanol Production: Lack of Proven Impacts to Land and Water. Prepared for Growth Energy by Ramboll. August 18.

Rose R. 2002. Slow release fertilizers 101. In: National Proceedings: Forest and Conservation Nursery Associations - 1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: United States Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 304–308. https://www.fs.usda.gov/rm/pubs/rmrs_p024.pdf.

Secchi S, Gassman PW, Jha M, Kurkalova L, Kling CL. 2011. Potential water quality changes due to corn expansion in the Upper Mississippi River Basin. Ecological Applications. 21(4):1068–1084. doi:10.1890/09-0619.1.

Sexton AN, Emery SM. 2020. Grassland restorations improve pollinator communities: A meta-analysis. Journal of Insect Conservation. 24(4):719–726. doi:10.1007/s10841-020-00247-x.

Shangguan ZP, Shao MA, Lei TW, Fan TL. 2002. Runoff water management technologies for dryland agriculture on the Loess. International Journal of Sustainable Development & World Ecology. 9(4):341–350. doi:10.1080/13504500209470129.

Shrestha DS, Staab BD, Duffield JA. 2019. Biofuel impact on food prices index and land use change. Biomass and Bioenergy. 124:43–53. doi:10.1016/j.biombioe.2019.03.003.

Singla A, Barmota H, Kumar Sahoo S, Kaur Kang B. 2021. Influence of neonicotinoids on pollinators: A review. Journal of Apicultural Research. 60(1):19–32. doi:10.1080/00218839.2020.1825044.

Smidt SJ, Haacker EMK, Kendall AD, Deines JM, Pei L, Cotterman KA, Li H, Liu X, Basso B, Hyndman DW. 2016. Complex water management in modern agriculture: Trends in the water-energy-food nexus over the High Plains Aquifer. Science of The Total Environment. 566–567:988–1001. doi:10.1016/j.scitotenv.2016.05.127.

Taheripour F, Baumes H, Tyner WE. 2022a. Economic impacts of the U.S. Renewable Fuel Standard: An ex-post evaluation. Frontiers in Energy Research. 10:Article 749738. doi:10.3389/fenrg.2022.749738.

Taheripour F, Mueller S, Kwon H, Khanna M, Emery I, Copenhaver K, Wang M. 2022b. Comments on “Environmental Outcomes of the U.S. Renewable Fuel Standard.” March. https://erc.uic.edu/wp-content/uploads/sites/633/2022/03/Comments-on-Paper-on-Environmental-Outcomes-of-the-U.S.-Renewable-Fuel-Standard-final.pdf.

Taheripour F, Mueller S, Kwon H, Khanna M, Emery I, Copenhaver K, Wang M. 2022c. Response to Comments from Lark et al. Regarding Taheripour et al. March 2022 Comments on Lark et al. Original PNAS Paper. May. https://growthenergy.org/wp-content/uploads/2022/05/Response-to-Lark-et-al_b-May-2022.pdf.

US Energy Information Administration. 2017. Nebraska: State Profile and Energy Estimates. February 16. [accessed 2023 Jan 13]. https://www.eia.gov/state/analysis.php?sid=NE.

US Energy Information Administration. 2023. Petroleum and Other Liquids: Spot Prices. [accessed 2023 Jan 31]. https://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm.

US Fish and Wildlife Service. 2023. National Wetlands Inventory: Frequently Asked Questions. United States Fish and Wildlife Service. [accessed 2023 Jan 12]. https://www.fws.gov/page/national-wetlands-inventory-frequently-asked-questions.

US Geological Survey. 2021. Trends in Annual Water-Quality Loads to the Gulf of Mexico. [accessed 2023 Jan 12]. https://nrtwq.usgs.gov/nwqn/#/GULF.

US Geological Survey. 2023. High Plains Water-Level Monitoring Study. Summary Statistics from Past USGS Reports 1987 to 2015. [accessed 2023 Jan 3]. https://ne.water.usgs.gov/projects/HPA/wlc3.html.

US Government Printing Office. 2004. Hearing before the Subcommittee on Clean Air, Climate Change, and Nuclear Safety of the Committee on Environment and Public Works, United States Senate, One Hundred Eighth Congress, First Session on Provisions of the Clean Air Act to Support Clean-Burning Fuel Alternatives, March 20, 2003. Senate Hearing 108-300.

USDA (United States Department of Agriculture). 1997. Glyphosate: Herbicide Information Profile. United States Department of Agriculture, Forest Service, Pacific Northwest Region. February. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_025810.pdf.

USDA. 2022. Technical Memorandum: Review of Recent PNAS Publication on GHG Impacts of Corn Ethanol. United States Department of Agriculture, Office of the Chief Economist, Office of Energy and Environmental Policy. December 14. https://www.usda.gov/sites/default/files/documents/USDA-OCE-Review-of-Lark-2022-For-Submission.pdf.

USDA ERS (Economic Research Service). 2018a. Fertilizer Use and Price. United States Department of Agriculture, Economic Research Service.

USDA ERS. 2018b. Irrigation & Water Use. United States Department of Agriculture, Economic Research Service. [accessed 2018 Feb 1]. https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/#crops.

USDA ERS. 2022. Farming and Farm Income. United States Department of Agriculture, Economic Research Service. [accessed 2022 Dec 22]. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/farming-and-farm-income/.

USDA NASS (National Agricultural Statistics Service). 2013. Farm and Ranch Irrigation Survey. United States Department of Agriculture, National Agricultural Statistics Service.

https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

USDA NASS. 2014. 2012 Census of Agriculture. Nebraska State and County Data. Volume 1, Geographic Area Series, Part 27. AC-12-A-27. May. https://agcensus.library.cornell.edu/wp-content/uploads/2012-Nebraska-nev1-1.pdf.

USDA NASS. 2018. QuickStats [Search Query]. United States Department of Agriculture, National Agricultural Statistics Service. [accessed 2018 Feb 1]. https://quickstats.nass.usda.gov/#09FECD51-EE42-3385-B86A-0CD59F0841A0.

USDA NASS. 2023a. Statistics by subject. United States Department of Agriculture, National Agricultural Statistics Service. [accessed 2023 Jan 5]. https://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS.

USDA NASS. 2023b. 2021 State Agriculture Overview: Nebraska. United States Department of Agriculture, National Agricultural Statistics Service. [accessed 2023 Jan 5]. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=NEBRASKA.

Verbeek M. 2017. Using linear regression to establish empirical relationships. IZA World of Labor, Article 336. doi:10.15185/izawol.336.

Vuran MC, Salam A, Wong R, Irmak S. 2018. Internet of underground things: Sensing and communications on the field for precision agriculture. In: 2018 IEEE 4th World Forum on Internet of Things (WF-IoT). p. 586–591. https://doi.org/10.1109/WF-IoT.2018.8355096.

Wadhwa M, Bakshi MPS. 2016. Application of waste-derived proteins in the animal feed industry (Chapter 10). In: Dhillon GS, editor. Protein Byproducts: Transformation from Environmental Burden into Value-Added Products. Elsevier. p. 161–192. https://doi.org/10.1016/B978-0-12-802391-4.00010-0.

Wright CK, Larson B, Lark TJ, Salmon JM, Gibbs HK. 2017. Recent grassland losses are concentrated around U.S. ethanol refineries. Environmental Research Letters. 12:Article 044001.

Wright CK, Wimberly MC. 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proceedings of the National Academy of Sciences. 110(10):4134–4139. doi:10.1073/pnas.1215404110.

Wu M, Mintz M, Wang M, Arora S, Chiu Y-W, Xu H. 2018. Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline—2018 Update. Lemont, IL: Argonne National Laboratory. Report No.: ANL/ESD-09/01 Rev. 2. https://publications.anl.gov/anlpubs/2019/01/148043.pdf.

Wu M, Zhang Z, Chiu Y. 2014. Life-cycle water quantity and water quality implications of biofuels. Current Sustainable/Renewable Energy Reports. 1(1):3–10. doi:10.1007/s40518-013-0001-2.

Xue Q, Marek TH, Xu W, Bell J. 2017. Irrigated corn production and management in the Texas High Plains. Journal of Contemporary Water Research & Education. 162(1):31–41. doi:10.1111/j.1936-704X.2017.03258.x.