OCTOBER 14, 2015

10-YEAR REVIEW OF THE RENEWABLE FUELS STANDARD:

IMPACTS TO THE ENVIRONMENT, THE ECONOMY, AND ADVANCED BIOFUELS DEVELOPMENT

AGRICULTURAL & RESOURCE ECONOMICS

UTIA INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

University of Tennessee Knoxville

DISCLAIMER

This report was commissioned by the American Council for Capital Formation (ACCF), a member of the Smarter Fuel Future coalition. The findings and views expressed in this study are those of the authors and may not represent those of ACCF, or the University of Tennessee's Department of Agricultural and Resource Economics or the Institute of Agriculture.

Principal Authors:

Dr. Daniel De La Torre Ugarte
Dr. Burton English

Additional copies of this report may be obtained from:

Department of Agricultural and Resource Economics
The University of Tennessee
2621 Morgan Circle
Knoxville, TN 37996-4518
(865)-974-3716

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Today's U.S. ethanol industry was born in the 1970s as a result of two major oil embargoes and the environmental impacts of lead in the environment.[1] Federal and state subsidies were initiated to support the ethanol industry as an answer to these concerns. In the 1980s, the ethanol industry struggled to materialize, however, as gasoline prices decreased substantially and MTBE emerged as the preferred replacement to lead as an oxygenate.[2] In the 1990s, MTBE was placed on the drinking water Contaminant List[3] and was later banned by 25 states from 2001 to 2009.

By the mid-2000s, ethanol became the dominant oxygenate to replace MTBE given profitable price spreads between gasoline and corn along with government-funded support. In 2001, slightly more than 2 billion gallons of ethanol were produced. By 2005, annual ethanol production increased to almost 4 billion gallons.

To further accelerate corn ethanol's market penetration, the first version of the Renewable Fuels Standard ("RFS"), or RFS1, was enacted a decade ago in 2005. RFS1 and its successor, RFS2, enacted in 2007 under the Energy Independence and Security Act, were designed to achieve four main policy objectives:

1) improve air quality by introducing additional oxygenates to the country's fuel supply,

2) lower greenhouse gas ("GHG") emissions,

3) increase rural economic viability, and

4) reduce U.S. dependence on foreign oil.

In the 2005 legislative signing ceremony, President George W. Bush summed up these objectives:

> *"Using ethanol and biodiesel will leave our air cleaner. And every time we use a home-grown fuel, particularly these, we're going to be helping our farmers, and at the same time, be less dependent on foreign sources of energy."*

The most obvious and measurable impact of the implementation of RFS1 and RFS2 has been the rise in corn ethanol production from 3.9 billion gallons in 2005 to 14.3 billion gallons in 2014 (Figure 1), which represents an increase of 267 percent. In 2014, fuel ethanol accounted for 87 percent of the nation's total biofuel production and composed 10 percent of the gasoline market sales by volume.

Corn ethanol's role in the transportation fuels market has created a national debate. The RFS establishes GHG standards that a biofuel conversion technology must meet. As such, much of the discourse has

[1] Tetraethyl lead was used to reduce engine knocking and boost octane ratings. Oxygenates, such as ethanol, provide similar benefits but without the environmental impacts that are caused by lead.

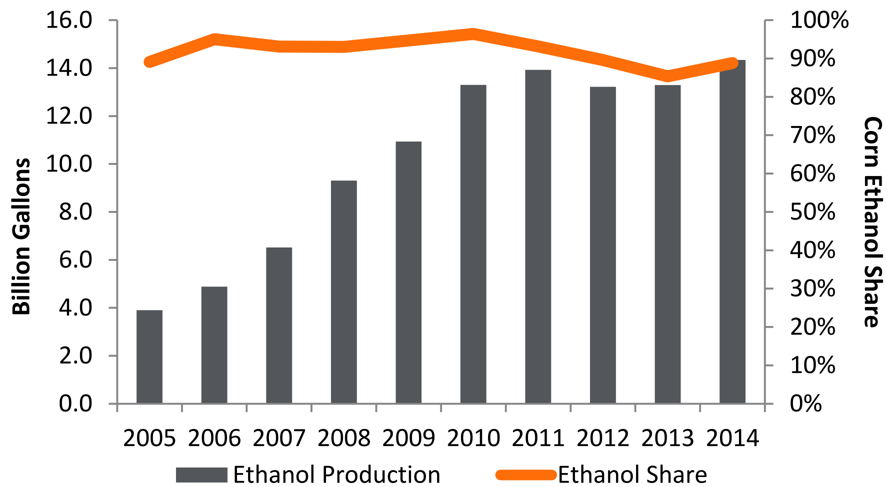
[2] Gustafson 2015.

[3] EPA 2015.

been on corn ethanol's environmental merits. Additionally, the economic merits of corn grain conversion into a transportation fuel source are in question.

This study applies a data-driven perspective to that discussion using economic analysis, agricultural modeling, and literature review. While many academic researchers have focused on either the environmental or economic aspects of the RFS and biofuel subsidies, we have presented them together, not only at the refinery level but also at the macroeconomic level. We believe this wider review is necessary given the biofuels industry has had 10 years to show progress under the RFS.

Figure 1: Corn Ethanol Production and Share of Total Biofuels Produced



Sources: Environmental Protection Agency; Energy Information Administration

Looking forward, we devote the last two sections of this study to a review of the state of the advanced biofuels industry and the near-term prospects for its emergence, especially in light of the congressionally-mandated RFS targets. The results from our findings have the potential to inform proposed policy changes that would accelerate advanced biofuels development.

Corn Ethanol's Environmental Record

Looking back over the last 10 years, the RFS and its resulting promotion of corn ethanol as a leading oxygenate supplement to conventional transportation fuels did not meet intended environmental goals. Corn ethanol's environmental record has failed to meet expectations across a number of metrics that include air pollutants, water contamination, and soil erosion.

Corn ethanol has resulted in a number of less favorable environmental outcomes when compared to a scenario in which the traditional transportation fuel market had been left unchanged.

From a GHG perspective, corn ethanol's emission reduction potential for *future* facilities is a highly debated topic. Studies that evaluate lifecycle GHG emissions range from corn ethanol decreasing GHG emissions relative to gasoline, to others showing that corn ethanol increases GHG emissions relative to gasoline, especially when considering direct and indirect land-use change ("LUC").[4] Figure 2, while not

[4] Direct Land Use Change is the conversion of land, which previously was not used for crop production, into land used for producing biofuel feedstocks; Indirect Land Use Change is a market effect that occurs when biofuel feedstocks are planted on areas already used for agricultural products, inducing formerly unused areas to be converted to food production.

all-encompassing of the many studies on corn ethanol GHG emissions that have been produced over the past decade, provides additional context to this range.

Figure 2: Corn Ethanol GHG Lifecycle Emission Increase for New Facilities Relative to Gasoline

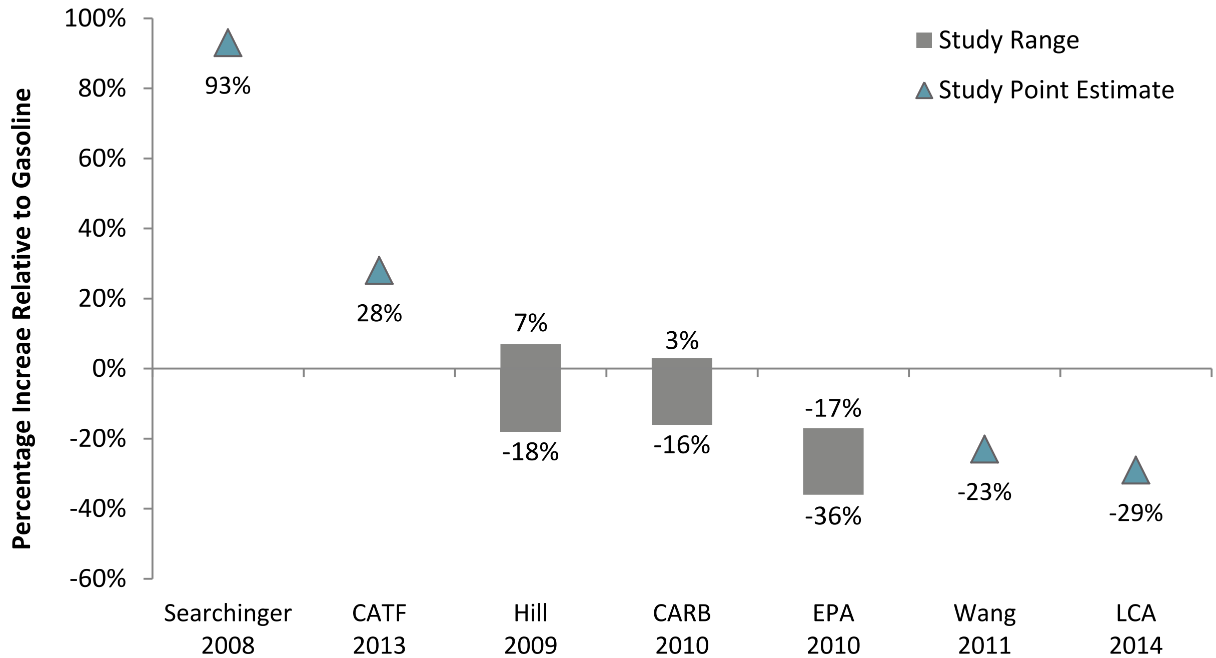


Figure 2 reflects the range of GHG lifecycle outcomes for future ethanol refineries, which is where most of the debate heretofore has been focused.

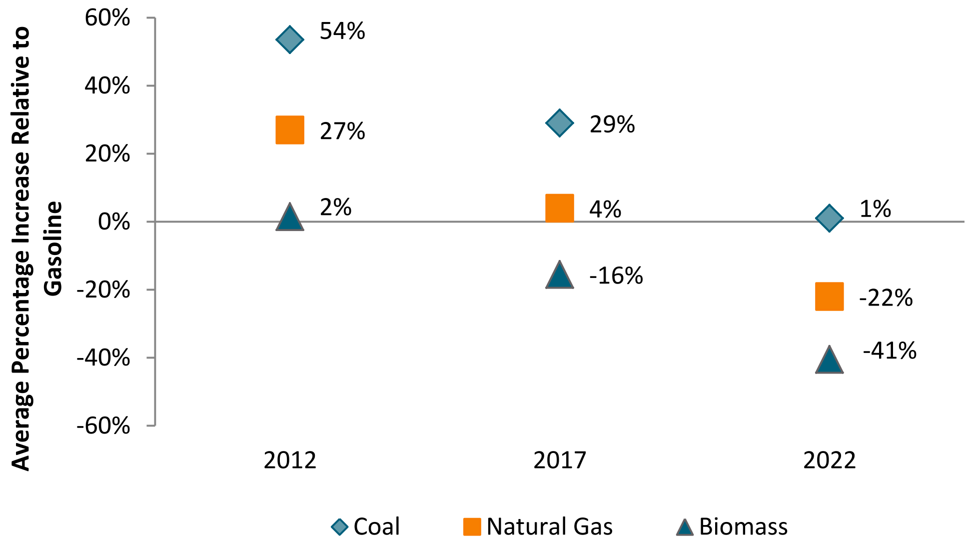
Relatively little attention, however, has been given to lifecycle emissions of corn ethanol from existing refineries. A 2011 National Academies of Sciences ("NAS") report provides some clue to what these emissions might be relative to a gasoline baseline as it examines near-term (2012 and 2017) corn ethanol refinery technologies. Figure 3, reproduced from a NAS report table, shows that current generation technology generally has lifecycle emissions that exceed gasoline as most ethanol refineries use natural gas as process heat.[5]

Given the trend from 2017 back to 2012 shows that earlier technologies produce higher GHG emissions relative to gasoline, one would expect that ethanol refining technologies prior to 2012 would have even worse GHG emissions profiles. This is a major concern given the RFS's objective of reducing GHG emissions, especially as 85 percent of current U.S. ethanol refineries commenced operation by 2012.[6]

[5] EPA 2010, Table 1.5-4.

[6] Based on authors' review of ethanol refineries' commercial on-line dates.

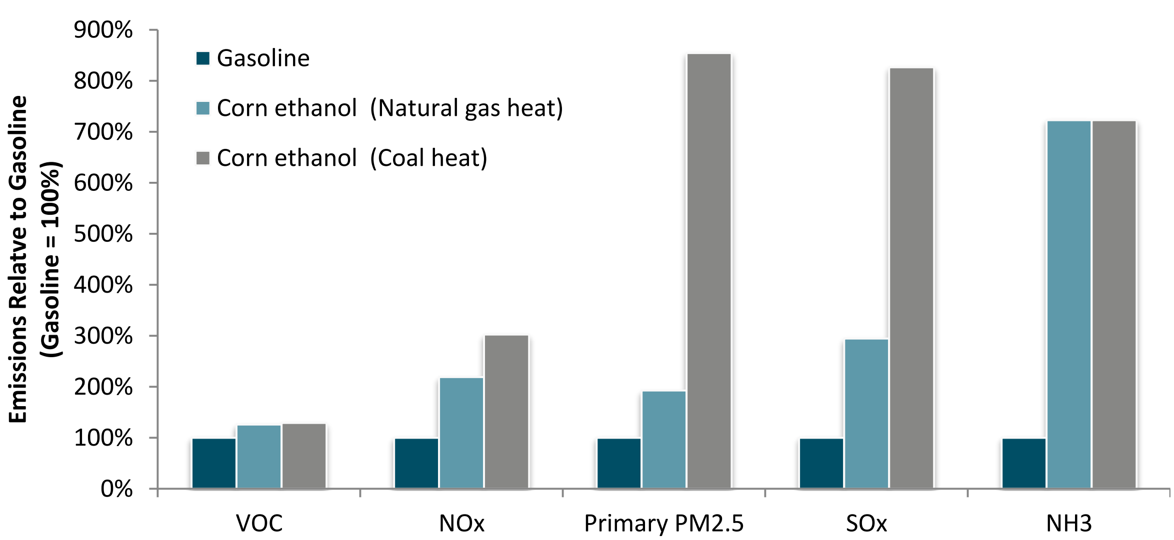
Figure 3: Corn Ethanol GHG Lifecycle Emission Increase Relative to Gasoline by Refinery Vintage Year as Determined by EPA in the Final Rule for RFS2[7]



Besides GHGs, other major pollutants associated with corn ethanol production and use include volatile organic compounds (VOCs), nitrogen oxides (NOx), particulate matter (PM), sulfur dioxide (SOx), and ammonia (NH_3).

Dr. Jason Hill of the University of Minnesota, for example, has extensively studied the lifecycle emissions of these pollutants from corn ethanol. His results show that corn ethanol increases emissions of these pollutants relative to gasoline (Figure 4).

Figure 4: Corn Ethanol Lifecycle Emissions of other Air Pollutants Relative to Gasoline[8]



[7] National Academy of Sciences (NAS) 2011; EPA 2010.

[8] Hill 2009.

From the inception of the original RFS mandate, ethanol has been lauded as an environmentally-friendly oxygenate. Oxygenates are added to gasoline mainly to reduce carbon monoxide (CO). While ethanol has been shown to reduce CO[9], Figure 4 shows that other major pollutants actually increase over the ethanol lifecycle.

Corn Ethanol's Financial and Economic Impact Record

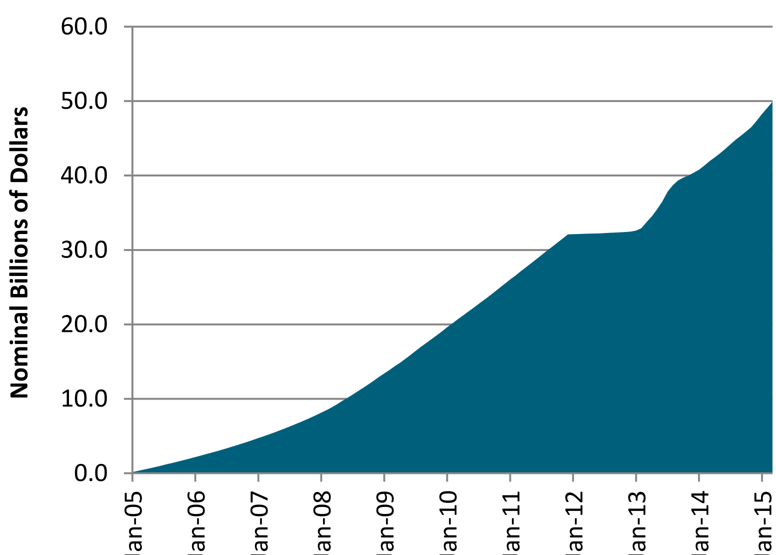
At the local and regional level, bio-refineries – such as corn ethanol refineries – may add some economic stimulus in the form of gross regional production, state and local tax revenues, and direct jobs (construction and operating) along with supply chain jobs and indirect employment opportunities stemming from wages and worker spending.

However, while there are some localized economic benefits to corn ethanol refineries, there also have been widespread economic costs. These costs have taken the form of:

- **Sizable Federal and Market Subsidies:** the now-expired Blender's Tax Credit and Renewable Identification Number ("RIN") program has subsidized the cost of corn ethanol.
- **Bankruptcies:** the large number of ethanol refinery bankruptcies that occurred from the 2008/2009 oil price slide translated into lost investments, jobs and unrealized tax revenues.

Since January 2005, the corn ethanol industry has received almost $50 billion in cumulative taxpayer and market subsidies (Figure 5).[10] And further, since 1982, the total subsidy figures stand even higher at $66 billion.

Figure 5: Cumulative Corn Ethanol Federal and Market Subsidies Paid, 2005–2014



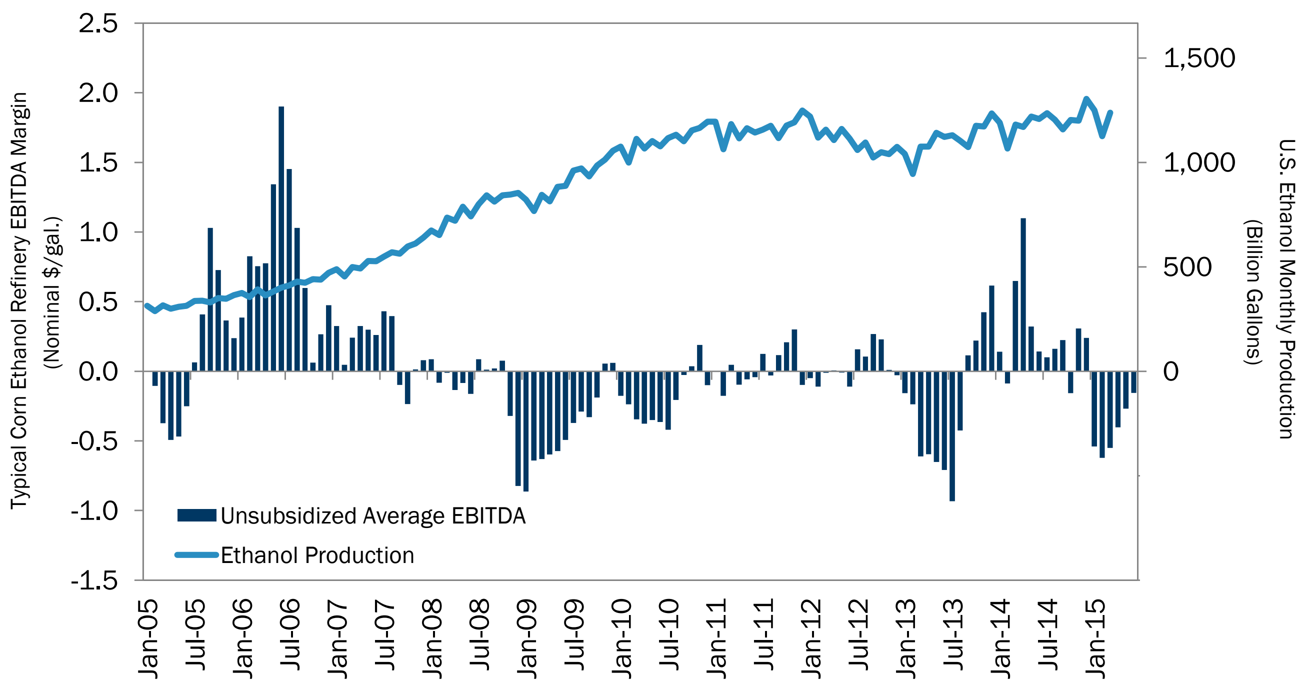
[9] Knoll 2009.

[10] Figure 5 reflects exclusively federal and market subsidies and does not include local and state corn ethanol subsidies.

Our analysis shows that the corn ethanol industry, even with its tremendous growth over the past decade and technology maturity, cannot survive in any real commercial sense without mandated fuel volume requirements.

Figure 6 shows the non-subsidized, monthly EBITDA margin[11] of a typical corn ethanol refinery versus U.S. monthly ethanol production starting from 2005.

Figure 6: Typical Corn Ethanol Monthly Non-Subsidized EBITDA Margin vs. U.S. Monthly Production



From January 2005 to October 2008, corn ethanol's non-subsidized EBITDA averaged $0.28 per gallon in nominal dollars, meaning that corn ethanol production was profitable without subsidies primarily because of the favorable price spread that existed between gasoline and corn prices, a blender's tax credit of $0.51 per gallon, growing fuel demand, and declining MTBE market share.

Since then, the non-subsidized EBITDA margin has averaged negative $0.12 per gallon. A rational investor interested in collecting a reasonable return would not have invested in a new ethanol facility after October 2008.

When considering bankruptcies, their economic cost in the corn ethanol industry has been substantial yet has received little academic attention. As Figure 6 shows, corn ethanol margins dramatically reversed from October to November 2008. This was a result of the 2008/2009 oil price slide, which forced a large number of corn ethanol plants and corn ethanol companies to enter into various forms of bankruptcy.

[11] EBITDA margin is defined as the per gallon earnings before interest taxes, depreciation, and amortization.

In total, corn ethanol bankruptcies over the past 10 years have equated to approximately one-quarter of current, operational corn ethanol capacity. These bankruptcies rocked the industry and caused financial pain for owners, investors [including taxpayers], employees, and surrounding communities.

Corn Ethanol's Impact on Advanced Biofuel Proliferation

While corn ethanol has failed to achieve the environmental objectives envisioned under the RFS, some have continued to support it politically on the basis of its supposed status as a "bridge" to advanced biofuels. Advanced biofuels rely on sustainable feedstocks such as corn stover, dedicated energy crops, and forest residues to produce transportation fuels.

Indeed, former EPA Administrator Lisa Jackson stated that "*[c]orn-based ethanol is a bridge, an extraordinarily important one, to the next generation of ethanol and biofuels*."[12]

Corn ethanol's purported role as an advanced biofuel "bridge", however, is under scrutiny. In fact, we contend that corn ethanol has actually stymied the growth of advanced biofuels by receiving substantial RFS targets (10 percent of fuel by volume), essentially retarding the growth of the advanced biofuels sector.

Advanced biofuel production in 2014 was 131 million gallons, or approximately one percent of total biofuel production. Undoubtedly, advanced biofuels are by their very nature challenging to bring to market given the technology scale-up issues and capital cost intensity.

The RFS2 was intended to help ease the entry of advanced biofuels by subsidizing them through RIN credits. This has not occurred. Instead, the RFS has focused most of the attention on corn ethanol and diverted attention away from advanced biofuels.

The U.S. does not require 14 billion gallons of corn ethanol to be produced on an annual basis. For oxygenate reasons, only 4.34 billion gallons are required.[13] In fact, corn grain ethanol's use as an oxygenate is partially counterproductive since the tailpipe NOx and VOC reductions it provides are offset by other emissions produced over the remainder of its lifecycle.

After 10 years of the RFS and its missed objectives, it is time to re-think the design, structure and practical implementation of the RFS and examine whether other policy designs may be more appropriate for promoting the production and consumption of advanced biofuels.

To illustrate why the promotion of advanced biofuels is critical, this report examines two scenarios where advanced biofuels replace varying portions of corn production over the past 10 years:

---

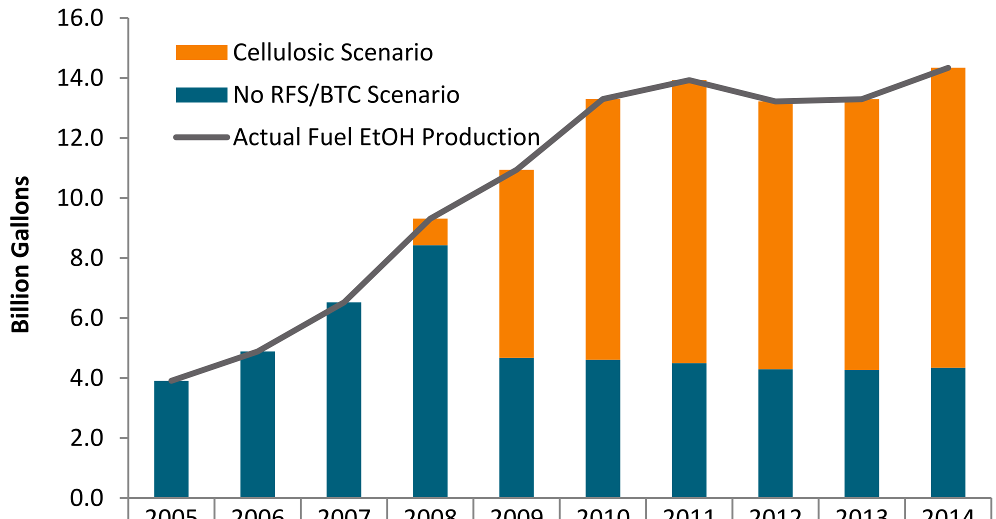
[12] Korosec 2009.

[13] 4.34 billion gallons is based on multiplying current gasoline consumption by the 2005 oxygenate-equivalent ethanol production as a share of total U.S. gasoline consumption prior to the MTBE ban. Without subsidies, no additional ethanol beyond 4.34 billion gallons would have been produced.

- **No RFS/Blenders Tax Credit ("BTC") Scenario:** This scenario examines the economic and environmental impacts if there were No RFS or BTC (i.e., corn ethanol was unsubsidized[14]) and, at a minimum, ethanol was required to meet actual consumer demand for oxygenates. In this scenario, corn ethanol demand is 4.34 billion gallons in 2014 or only 30 percent of actual corn ethanol production.

- **Cellulosic Replacement Scenario:** This scenario examines the economic and environmental impacts if the lost corn ethanol production in the No RFS/BTC scenario were replaced with cellulosic ethanol under a new RFS framework that incentivizes advanced biofuels exclusively. In this scenario, cellulosic ethanol production levels are 10 billion gallons or 70 percent of actual corn ethanol production in 2014. We recognize that this scenario would not have been possible given current technology status, technology costs, and RFS policy design at the time. However, it is an important scenario that develops an understanding of lost opportunities and calls for better policy design.

Figure 7: Corn and Cellulosic Ethanol Production under Scenarios Evaluated



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cellulosic Scenario	0.00	0.00	0.00	0.88	6.27	8.69	9.43	8.93	9.02	10.00
No RFS/BTC Scenario	3.90	4.88	6.52	8.43	4.67	4.61	4.50	4.29	4.27	4.34
Actual Fuel EtOH Production	3.90	4.88	6.52	9.31	10.94	13.30	13.93	13.22	13.29	14.34

We use the Policy Analysis System (POLYSYS) agricultural policy simulation model (De La Torre Ugarte et al. 1998) to examine the economic and environmental impact changes relative to the Business as Usual ("BAU") scenario. The BAU scenario represents the actual production of corn ethanol and its impacts over the last 10 years.

[14] Subsidies excluded were the federal BTC and the RIN values resulting from the RFS. Scenario does not include the removal of any state or local subsidies for corn ethanol.

Our modeling analysis finds that there are significant changes in crop acres planted, commodity prices, environmental emissions, and economic gains in both scenarios relative to the BAU.

In terms of planted acres, both scenarios show a sizable impact on reducing corn plantings as shown in Figure 8. In the No RFS/BTC scenario, corn demand decreases when the RFS' mandated volumes. As a result, there is a demand shift that reduces corn prices and a supply side shift that also reduces prices for wheat and soybeans as corn acreage is transitioned to these crops (Figure 9).

Figure 8: Average Annual Acres Planted by Scenario, 2008-2014

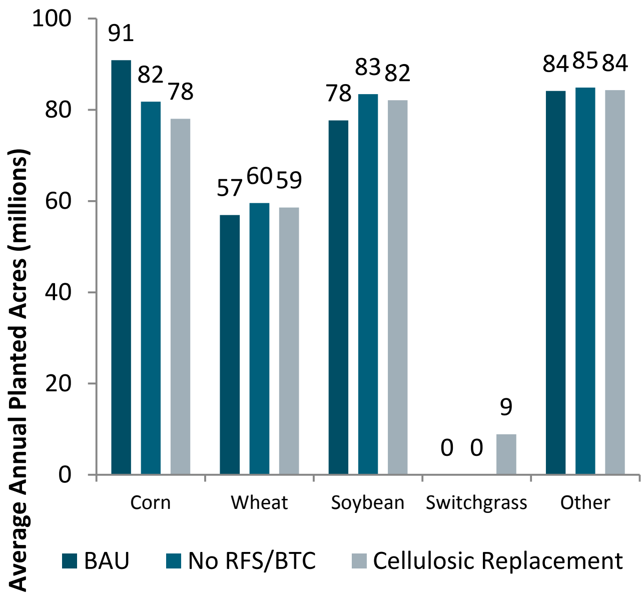
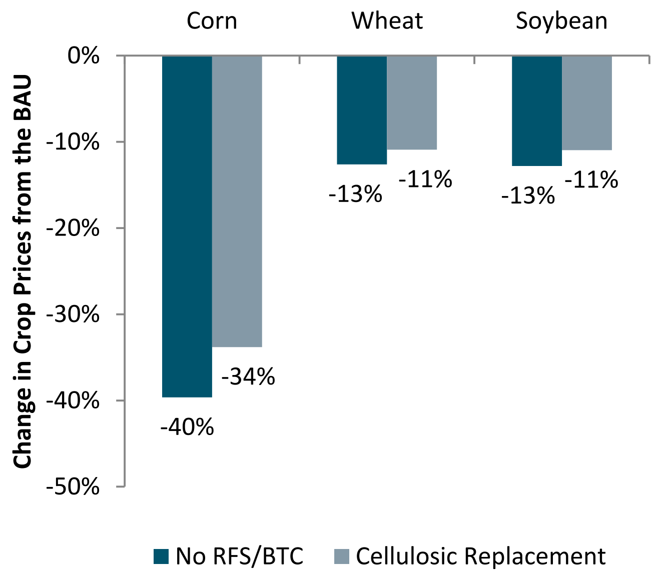


Figure 9: Change in Average Annual Crop Prices by Scenario, 2008-2014



The crop price reductions translate into substantial savings that are passed to value chain participants in terms of higher margins and also to end-consumers in terms of lower food costs. However, low crop prices also translate to lower incomes for farmers. These impacts, derived from the POLYSYS model, are shown in Table 1.

Table 1: Annual Average Direct Economic Impacts by Scenario, 2008–2014[15] (Billions of 2015$'s)

Scenario	U.S. Consumer Wholesale Expenditure Savings	Net Realized Farm Income Loss
No RFS/BTC	$31.6	-$19.7
Cellulosic Replacement	$29.6	-$13.0

Using these two macroeconomic outputs from the POLYSYS model along with other estimations, we approximated the overall net U.S. economic benefits in the two scenarios for 2014. This year was

[15] U.S. Consumer Wholesale Purchase Savings was derived by taking the POLYSYS price changes and multiplying by POLYSYS U.S. crop consumption. Net Realized Farm Income Loss is a result taken directly from POLYSYS.

selected because it is the most recent year where ethanol production is fairly stable and there is very little capacity expansion of ethanol refineries. Table 2 provides the results of this analysis.

Table 2: 2014 Net Economic Benefits by Scenario (Billions of 2015$'s)

Economic Impact	Net Benefit
No RFS/BTC	$28.4
Cellulosic Replacement	$42.1

The Cellulosic Replacement scenario provides the largest economic impact to the overall economy as it lowers crop prices and stimulates advanced biofuel production, benefiting rural communities.

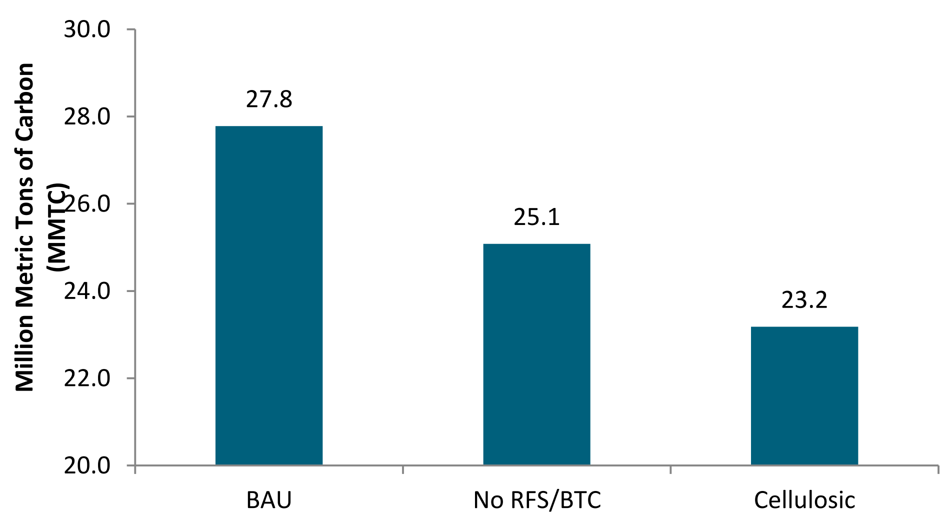
While our analysis does show that the overall economy would have experienced net economic benefits in a scenario without the RFS and BTC, it should be noted that the RFS has provided localized benefits to rural communities due to higher crop prices and volumes, ethanol refinery investment, and ethanol refinery production.

In addition to producing net economic gains to the U.S. economy, both scenarios show significant net environmental improvements for the following:

- Carbon emissions from agricultural production and input use
- Soil erosion
- Chemical and fertilizer usage

For carbon, the POLYSYS model shows that emissions from agricultural production and input use would decline for the scenarios (Figure 10). In the No RFS/BTC and Cellulosic Replacement scenarios, the primary driver for the reduced carbon emissions is the increased soil uptake of carbon as corn acres are replaced with wheat and soybean acres. These crops produce a better soil carbon uptake than corn.

Figure 10: Carbon Emissions from Agricultural Production and Input Use by Scenario, 2014



Soil erosion improves greatly under both scenarios relative to the BAU. In the BAU, U.S. annual soil erosion increased from 807 million tons to 837 million tons, or 3.7 percent, from 2008 to 2014 due to increasing RFS-induced corn plantings (Table 3). During this period, the erosion in the BAU was estimated to total 5.7 billion tons.

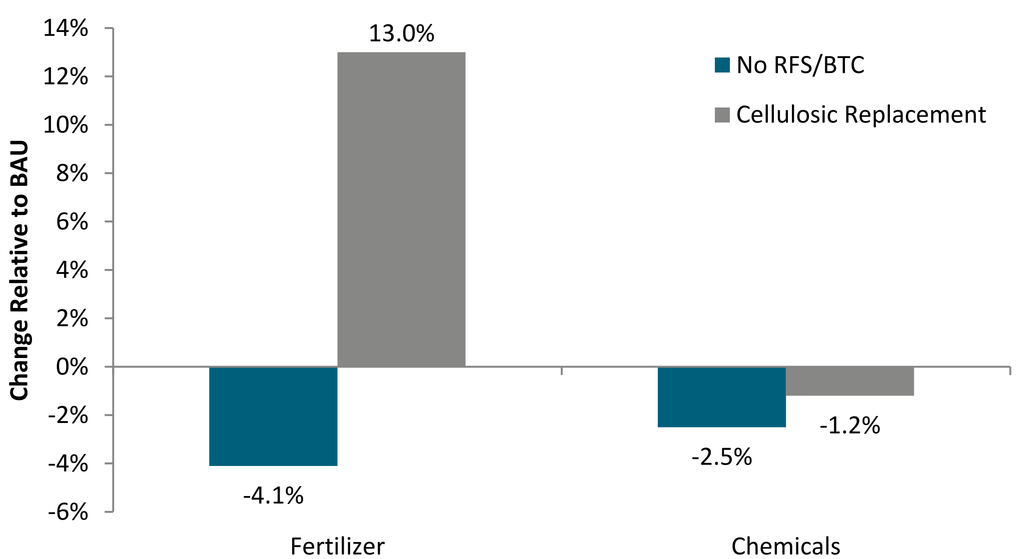
Table 3: U.S. Annual Soil Erosion by Scenario (million tons)

Scenario	2005	2014	Absolute Change	% Change
BAU	807	837	30	3.7%
No RFS/BTC	807	760	-47	-5.8%
Cellulosic Replacement	807	695	-112	-13.8%

In the No RFS/BTC scenario and Cellulosic Replacement scenarios, U.S. annual soil erosion in 2014 decreases to 760 and 695 million tons, or 5.8 percent and 13.8 percent, respectively, from 2008 levels. This is due to corn crops being switched over to crops that are less erosion-prone. Cumulative erosion from 2008 to 2014 declines by 4.1 percent and 9.1 percent in the No RFS/BTC and Cellulosic Replacement scenarios, respectively.

For fertilizer and chemical consumption, the scenario modeling shows decreases in the No RFS/BTC scenario relative to the BAU (Figure 11). This is due to corn acres being replaced with crops, such as wheat and soybeans, which require less fertilizer and chemical application.

Figure 11: Average Change in U.S. Agricultural Fertilizer and Chemical Consumption by Scenario, 2008-2014



The Cellulosic Replacement scenario portrays a different story. While chemical consumption decreases relative to the BAU in the scenario, fertilizer consumption increases relative to the BAU. The scenario's higher fertilizer consumption reflects the requirement to replace the nutrients removed when crop residues are removed and used as energy feedstocks along with the increase in fertilization requirements on existing hay and pasture lands to maintain roughage for livestock as lands shift from hay/pasture to growing dedicated energy crops.

Re-energizing Advanced Biofuels

We believe it is time to create a new policy initiative that delivers on the original intentions of the RFS. The current RFS design is unsuitable for driving advanced biofuels forward. It rewards production from mature technologies while advanced biofuels require a mechanism that overcomes their capital intensity and technology risk.

An investment-based mechanism could be a solution. The mechanism could be designed to support projects that use both crop and forest residues and those requiring dedicated energy crops. In addition, the mechanism could be designed to incorporate the retrofitting of existing plants, which would be supportive of the existing corn ethanol industry.

Investment-based mechanisms, for example, have benefited the renewable electricity industry. Solar installations have grown tremendously as a result. In fact, subsides are now in question. In August, energy secretary Ernest Moniz stated: "*I certainly see solar growing [even] without a subsidy*." [16]

We have had 10 years under the RFS, and a commercially viable, next generation biofuels technology has not emerged. It is time to rethink the design of the RFS2 and develop a new set of policies that places the U.S. on track to achieve significant advanced biofuels market penetration in the next 10 years aimed at achieving meaningful environmental benefits.

[16] Siciliano 2015.

1. Introduction

Over the past 10 years, corn grain ethanol's[17] use as a transportation fuel supply source has risen dramatically. From 2005 to 2014, corn ethanol production grew from 3.9 billion gallons to 14.3 billion gallons, or 267 percent. In 2014, corn ethanol accounted for 87 percent of the nation's total biofuel production and composed 10 percent of the gasoline market sales by volume.

There have been a number of drivers for this growth – the spread between oil and corn prices in the 2005–2008 timeframe, the de facto ban on MTBE as an oxygenate, the Renewable Fuel Standard ("RFS") program, and government incentives for biofuel production.

The RFS program (created by the Energy Policy Act, or EPAct, of 2005 and updated in 2007) has been the principal driver of growth in ethanol use for most of this period. It mandates the use of specific volumes of biofuels by certain years. The primary objectives of the RFS were to make our air cleaner and reduce our dependence on foreign oil, as stated by President George W. Bush at the 2005 signing ceremony.

The supply and demand dynamics of the transportation fuel market today differ markedly from those 10 years ago when the first version of RFS program was enacted. In 2005, U.S. crude production was 1.9 billion barrels, or 34 percent of U.S. crude demand, and U.S. gasoline consumption grew at an annualized rate of 1.6 percent from 1995–2005.

Biofuels appeared at the time, according to some supporters, to be not only the environmental solution to address transportation fuel emissions but also a fix for the problematic gap between domestic oil production and demand, with the goal in mind to put the U.S. on track to become more energy independent.

In contrast, the U.S. is experiencing a transportation fuel glut today. At the end of 2014, annual crude production was 3.2 billion barrels or 56 percent of total crude demand. On the demand side, U.S. gasoline growth has declined at an annualized rate of 0.3 percent from 2005 to 2014. A combination of unexpected events following 2005, particularly the shale oil revolution and a recession-induced reset of fuel demand, has fundamentally altered the supply and demand balance. According to the latest outlook by the Energy Information Administration, the current market landscape is expected to continue for at least the next 10 years.[18]

In addition to natural market disruptions, U.S. and state government actions and lack of actions have disrupted the market, including:

- Enactment of tighter vehicle efficiency standards (via the Corporate Average Fuel Economy or CAFE)

---

[17] For the purposes of this paper, corn grain ethanol and corn ethanol are used interchangeably. The use of corn stover (husks, cobs, stalks left over after the harvest) for conversion into an advanced biofuel is one type of cellulosic biofuel and is discussed later.

[18] Energy Information Administration's Annual Energy Outlook 2015.

- Ban of MTBE among 25 states from 2001 to 2009
- Continued restriction on crude exports
- Enactment of further biofuel production mandates through the Energy Independence and Security Act (EISA) of 2007.

This report examines the rise of corn ethanol use as required by the RFS, the many factors that have impacted the transportation fuel market within the context of the RFS, and in particular, the effect on the environment caused by the use of corn ethanol.

We find that a chief objective of the RFS – cleaner air – has not been met due to the requirement for the use of corn ethanol. Indeed, academic studies show that current corn ethanol production and use could actually contribute to a sharp and overall increase of GHGs. Additionally, a number of other studies show that ethanol production and use emits more particulate matter, ozone (as well as other smog precursors[19]) and other air pollutants than gasoline.

We also find that corn ethanol's net economic benefits have not been accurately represented. While many studies show that ethanol refineries add economic value and jobs to some rural communities, they do not account for corn ethanol's hidden costs, such as the environmental damage caused and the taxpayer and marketplace subsidies that add costs to the economy.

Finally, our analysis shows that the use of corn ethanol has not been the "bridge" to the production and use of advanced biofuels that was anticipated. In fact, the subsidies directed to corn ethanol have increased its production such that it has crowded out advanced biofuel production.

From an environmental and energy independence perspective, the subsidies and mandates for corn ethanol would have been better and more effectively used had they been directed towards advanced biofuels.

[19] As will be discussed in more detail later, a smog precursor is a compound [e.g., nitrous oxides (NOx) or Volatile Organic Compounds (VOCs)] that undergo reactions in sunlight to form smog.

2. The Economics of Corn Ethanol

This section examines the economic drivers and economic impacts of corn ethanol. While the environmental aspects of corn ethanol production are the major aspect of this report, we believe it is important to first understand what factors have driven the fuel's growth in marketplace over the past 10 years.

We then discuss the results of a modeling scenario that examines the economic impacts if there were no RFS and no BTC, which we define as the "No RFS/BTC" scenario. The environmental findings from this scenario are discussed in Section 3.

2.1. Major Drivers of Corn Ethanol Economics and Growth

Over the past 10 years, the primary drivers of corn ethanol economics have included the following:

- **Gasoline-corn price spread ("Spark Spread"):** represents the monthly spread between New York Harbor conventional gasoline regular spot price less the converted monthly spot price of corn in dollars per gallon. A spark spread above $0.50/gallon[20] generally generates a positive EBITDA[21] for an average corn ethanol refinery using natural-gas for heat.
- **MTBE production:** MTBE is an octane enhancer and oxygenate used to reduce CO tailpipe emissions. From 2001 to 2009, twenty-five states banned MTBE use. As a result, production declined by 79 percent with corn ethanol supplying the difference.
- **Federal and market subsidies:** represents the combined value of the Blender's Tax Credit (BTC) and the corn ethanol RIN price. Over the past 10 years, this value has generally been in a range of $0.51 to $0.56/gal except for 2012 when the BTC expired and an excess supply of RINs kept prices near zero.
- **Gasoline demand:** prior to the Great Recession, gasoline demand grew at an annual average rate of 0.6 percent from 2005 through 2007. From 2008 to 2014, domestic gasoline demand has shrunk by 0.6 percent annually, on average due to a combination of weak post-recession GDP growth and CAFE standards.

Figure 12 shows a timeline of an average ethanol refinery's EBITDA (exclusive of federal and market subsidies) and total U.S. ethanol production along with changes in these primary drivers. Drivers shown in green are positive for corn ethanol profits and growth, while drivers shown in red are negative. This timeline and the economic analysis identifying these drivers and their financial impacts were developed as part of this report.

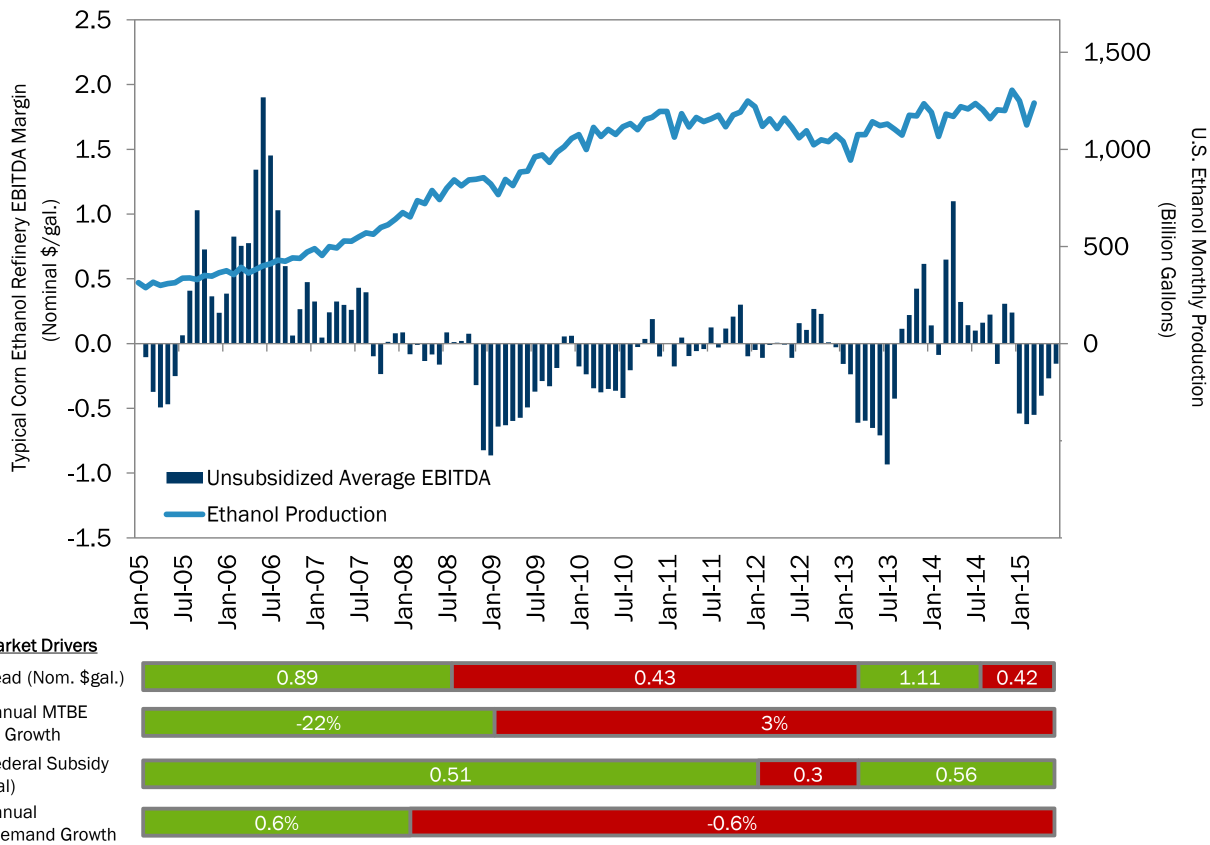
[20] Based on the authors' research

[21] Earnings before interest, taxes, depreciation, and amortization

The figure reveals that the period of January 2005 to October 2008 generally produced a positive, unsubsidized EBITDA for ethanol refineries. During this period all four primary financial/market drivers had positive indicators – spark spread was above $0.50/gallon, MTBE production was decreasing rapidly due to state bans, federal subsidies averaged $0.51/gallon, and fuel demand was growing.

In November 2008, however, the economics of corn ethanol made a sharp reversal as the average WTI oil price dropped to $57.31 per barrel from $76.61 per barrel in October 2008 as part of a steep decline associated with the Great Recession.

Figure 12: Timeline of Ethanol Refinery EBITDA, Total U.S. Ethanol Production, and Financial/Market Drivers



Between November 2008 and June 2015, the average unsubsidized EBITDA of corn ethanol was negative $0.12 per gallon.[22] This negative unsubsidized EBITDA includes the period from September 2013 to December 2014 where the unsubsidized EBITDA turned positive due to a spark spread that was well above the $0.50 per gallon breakeven.

The red bars below the chart in Figure 12 show the market drivers and explain the cause of this EBITDA downturn – the spark spread was below $0.50 per gallon for much of the period, MTBE production growth stabilized and increased slightly, and gasoline demand growth declined. The result was a period of little growth in ethanol production from 2010 onwards.

[22] EBITDA margins were calculated using historical economic data from the USDA and applying assumptions from Iowa State 2015.

If Figure 12 were to include subsidies, the EBITDA generally would have been positive after November 2008, and would have averaged $0.33 per gallon. Incidentally, this is approximately the breakeven EBITDA required to earn a reasonable return on investment for an average, new corn ethanol refinery[23], meaning that there is a 50 percent chance of earning an adequate return on investment. This is poor odds for a rational investor seeking a reasonable return.

Our finding is that, without the artificial demand mandates at the core of the RFS, the corn ethanol industry cannot survive in any real commercial sense and this finding is supported by the many bankruptcies experienced during the past 10 years. When EPAct and EISA were passed, investors poured billions of dollars into corn ethanol refineries. However, as ethanol production has plateaued due to changing market/financial drivers, there have been a large number of bankruptcies in the corn ethanol refining market.

In total, 3.8 billion gallons of ethanol refinery capacity, including plants under construction and in operation, have undergone bankruptcy proceedings (Appendix A). This is a conservative estimate based on a review of news releases and other publicly available financial data. These bankruptcies are equivalent to approximately one-quarter of the current ethanol refinery operating capacity.[24]

The period of 2008 and 2009 represented the peak with 1.7 and 1.5 billion gallons of capacity, respectively, undergoing bankruptcy. Together, 2008-2009 composed 82 percent of the bankruptcies shown in Table 13.

2.2. POLYSYS Modeling of Corn Ethanol's Economic Impacts

As previously described, this report examines a scenario assuming no RFS or BTC during the past 10 years (defined as the "No RFS/BTC" scenario).

The POLYSYS model (De La Torre Ugarte et al, 1998) has the unique ability to provide annual estimates of changes in land use resulting from the demand generated by bioenergy industries. For environmental analysis, the POLYSYS model can inform changes in crop fertilizer consumption, chemical application to crops, soil erosion, and agricultural carbon emissions.

The POLYSYS model was applied to determine the agricultural impacts that would result under such a scenario relative to the BAU scenario. The modeling results show that there are significant changes in crop acres planted and thus commodity prices and broader economic impacts in a No RFS/BTC scenario.

[23] Based on authors' assumption of a new 100 million gallon per year corn ethanol refinery costing $211 million to bring on-line with an economic life of 15 years at a discount rate of 13.2%.

[24] 3.8 billion gallons of capacity that went through bankruptcy divided by 15 billion gallons of capacity available in 2015.

In terms of planted acres, the No RFS/BTC scenario reveals that corn acres planted from 2008-2014, on average, would have decreased by 9 million acres or 10 percent while additional wheat and soybean acres planted would have offset most of this reduction (Figure 13). This crop shift is the direct result of removing the artificial corn demand induced by the RFS and the BTC.

Figure 13: Average Annual Planted Acres by Scenario, 2008-2014

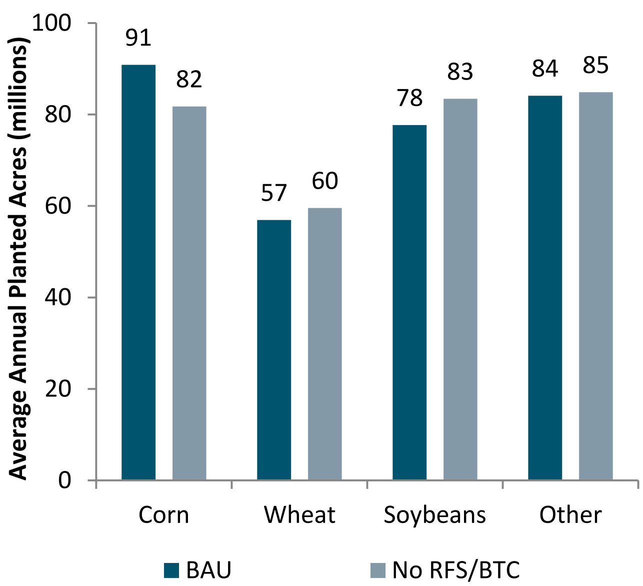
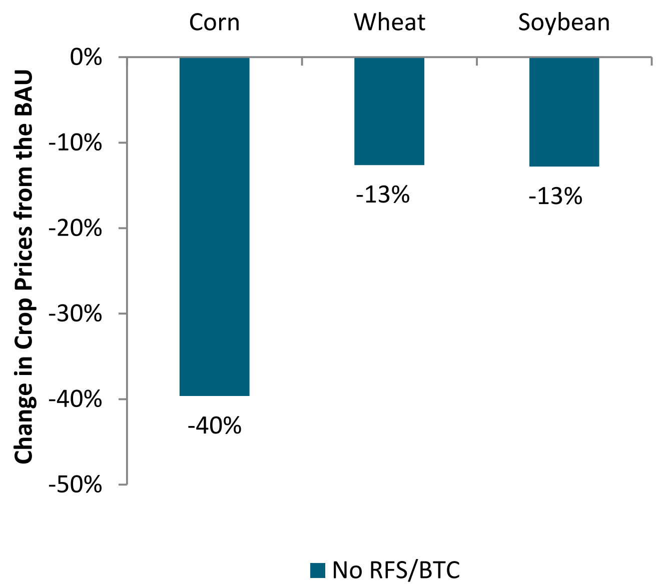


Figure 14: Change in Annual Average Crop Prices by Scenario, 2008-2014



Because corn demand is removed, corn prices are reduced significantly (-40 percent) and a supply side increase in wheat and soybean acreage reduces prices for these commodities (Figure 14).

The POLYSYS model provides two important macroeconomic statistics that show the broader economic impacts of altering policies – Net Realized Farm Income (NRFI) and U.S. Wholesale Crop Expenditure Savings. NRFI is defined as the following:

NRFI = Cash Receipts + Government Payments –Operating Expenses –Depreciation

NRFI differs from Net Farm Income, as it does not include the value of stock (inventory) changes. NRFI is an important statistic as it reveals the aggregate income gain or loss for U.S. farmers.

In the No RFS/BTC scenario, NRFI is reduced by $19.7 billion, on average, from 2008-2014 due to the lower crop prices. This is a direct loss and does not include larger economy-wide impacts.

While NRFI declines in the No RFS/BTC scenario, U.S. Wholesale Crop Expenditure Savings is increased by $31.6 billion on average from 2008-2014 relative to the BAU. Wholesale Crop Expenditure Savings is defined as the change in U.S. crop prices between scenarios multiplied by U.S. crop consumptions (U.S. production less exports and ignoring stock changes). This savings is distributed to value chain participants in terms of increased margins and food cost savings to end-consumers.

Using these two macroeconomic outputs from the POLYSYS model along with other estimations, we are able to approximate the overall net U.S. economic benefits in the No RFS/BTC scenario by applying the IMPLAN model. The IMPLAN model is a general input-output modeling software and data system that tracks the movement of money through an economy, looking at linkages between industries along the supply chain, to measure the cumulative effect of spending in terms of job creation, income, production, and taxes. As such IMPLAN provides the economic ripple effect, or multiplier effect, that tracks how each dollar of input, or direct spending, cycles through the economy to suppliers and ultimately to households.

There are two main economic benefits that we considered under a No RFS/BTC scenario:[25]

- Crop consumption cost savings that are distributed to end-consumers and also to downstream value chain participants in the form of higher profit margins.[26]
- Increased gasoline production to offset lost ethanol volumes

There are three main economic opportunity costs that we considered under a No RFS/BTC scenario:[27]

- Increased farm income via higher crop prices
- Increased farm income via higher crop volumes
- Increased ethanol production due to volume mandates

The net economic benefit or cost of the No RFS/BTC scenario is simply the economic benefits of not having the RFS and BTC in place less the economic benefits of the BAU.

In conducting this analysis, we chose 2014 as the IMPLAN modeling year. This year was selected because it is the most recent year where ethanol production is fairly stable and there is very little capacity expansion of ethanol or oil refineries. Table 4 provides the results of this analysis. It shows that the No RFS/BTC scenario would have produced a $28.4 billion net economic benefit in 2014. The economic impacts shown are in total output, which is defined as value added or GDP plus the value of intermediate inputs. The impacts also include direct, indirect, and induced impacts.[28]

[25] Other economic benefits would include increased investment in oil refining capacity, net consumer fuel price savings (ethanol price on a gasoline equivalent gallon basis less gasoline prices) from not purchasing ethanol blended fuel, and no BTC. To be conservative, these benefits were not considered in our analysis.

[26] Expert judgement is used to assume that end-consumers receive 70% of the benefit and that downstream value chain participants receive 30% of the benefit in terms of higher profit margins.

[27] Increased ethanol capacity investment is another net economic benefit from having the RFS and BTC in place. We did not include this in our analysis because these investments are one-time impacts that offset oil refinery expansion economic impacts.

[28] Direct is defined as impacts directly to the sector being examined. Indirect is defined as impacts to the sector's suppliers. Induced is defined as impacts generated by the sector's and supplier's employee spending.

Table 4: 2014 Net Economic Impacts in a No RFS/BTC Scenario (Billions of 2015$'s)

Economic Impact	Net Benefit	Opportunity Cost
Crop consumption cost savings	$55.0	N/A
Increased gasoline production	$52.6	N/A
Increased farm income via higher crop prices	N/A	$59.0
Increased farm incomes via crop volumes	N/A	$10.0
Increased ethanol production	N/A	$10.2
Total	**$107.6**	**$79.2**
Net Scenario Benefit	**$28.4**	

While our analysis shows that the overall economy would have experienced net economic benefits in a No RFS/BTC scenario in 2014, it also should be noted that there are localized benefits to rural communities due to higher crop prices and volumes, ethanol refinery investment, and ethanol refinery production. For 2014, this economic impact of localized benefits would have been $79.2 billion. In this regard, the RFS has achieved one of its objectives of increasing rural economic viability.

3. Corn Ethanol's Environmental Record

The original intent of the ethanol and biodiesel provisions of the 2005 EPAct was to improve the environment and to reduce the country's dependence on foreign oil. The law included tax incentives for ethanol and biodiesel producers. The RFS program provisions increased the use of these fuels. By 2007, with the signing of the EISA, the White House began to recognize that corn ethanol was not a long term solution.

As President Bush stated at the time:

> *"(W)e're going to spend money on new research for alternative feedstocks for ethanol. We understand the hog growers are getting nervous because the price of corn is up. But we also believe strongly that research will enable us to use wood chips and switchgrass and biomass to be able to develop the ethanol necessary to help us realize the vision outlined in this bill."*[29]

The Obama administration became more vocal and direct about corn ethanol's role as a bridge to advanced biofuels. In 2009, President Obama stated:

> *"I've also said -- and I said during the campaign trail in Iowa, in front of farmers -- that it was important for us to transition to the next generation of biofuels, that we've got to do a much better job of developing cellulosic ethanol, that com-based ethanol, over time, is not going to provide us with the energy-efficient solutions that are needed…So our challenge, I think, is to see our current ethanol technology as a bridge to the biofuels technologies of the future."*[30]

Former EPA Administrator Lisa Jackson echoed this sentiment two months later: *"Corn-based ethanol is a bridge, an extraordinarily important one, to the next generation of ethanol and biofuels."*[31]

While corn ethanol has been touted as a renewable and clean alternative to gasoline, its record is – at best – highly questionable. When all the lifecycle factors from crop growth to refining to fuel combustion are fully considered, the negative side-effects of corn ethanol production and use are far more harmful to human health than previously anticipated and, in the case of some pollutants, are far worse than using gasoline.

Reports touting corn ethanol as a clean fuel typically focus on some of the cleaner tail pipe emissions caused by burning corn ethanol in vehicles rather than on the additional emissions caused by the rest of its lifecycle. In fact, the life-cycle emissions related to the production of corn ethanol actually result in higher pollutant levels than gasoline for a number of contaminants, including fine particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs), nitrogen oxides (NOx), sulfur dioxide (SOx), and ammonia (NH_3). As we will show, the production and use of corn ethanol can actually increase smog levels and GHG emissions.

---

[29] The White House Archives 2007.

[30] White House Office of the Press Secretary 2009.

[31] Korosec, 2009.

3.1. Literature Review of Corn Ethanol Emissions Lifecycle Analysis

3.1.1. Greenhouse Gas Emissions

Lifecycle Greenhouse Gas (GHG) emissions, as defined by the Clean Air Act, are the aggregate emissions related to the full fuel lifecycle.[32] For corn ethanol, this lifecycle includes the full value chain segments and the supply inputs for each segment – cultivation of the corn crop, drying and storage of the corn, transportation to the refinery, conversion of the corn into ethanol, distribution to end-users and combustion by end users of the ethanol fuel. The lifecycle also includes land use changes (LUC), that is, the conversion of land from native habitats or other existing cropland to cropland for corn.

A significant number of academics and government institutions have studied the lifecycle GHG impacts of corn ethanol compared to traditional transportation fuels. There are two distinct sets of findings – those studies that include LUC and those studies that do not.

For those studies not considering LUC, the results mostly vary on refinery-specific factors, such as:

- Process heat source (e.g., natural gas, coal, and biomass)
- Heat source conversion (e.g., boiler vs. combined heat and power)
- Process type (e.g., dry mill vs. wet mill)
- Process technology (e.g., fractionation, membrane separation, hydrolysis)
- Refinery location
- Co-products (e.g., wet vs. dry distillers grain solubles)

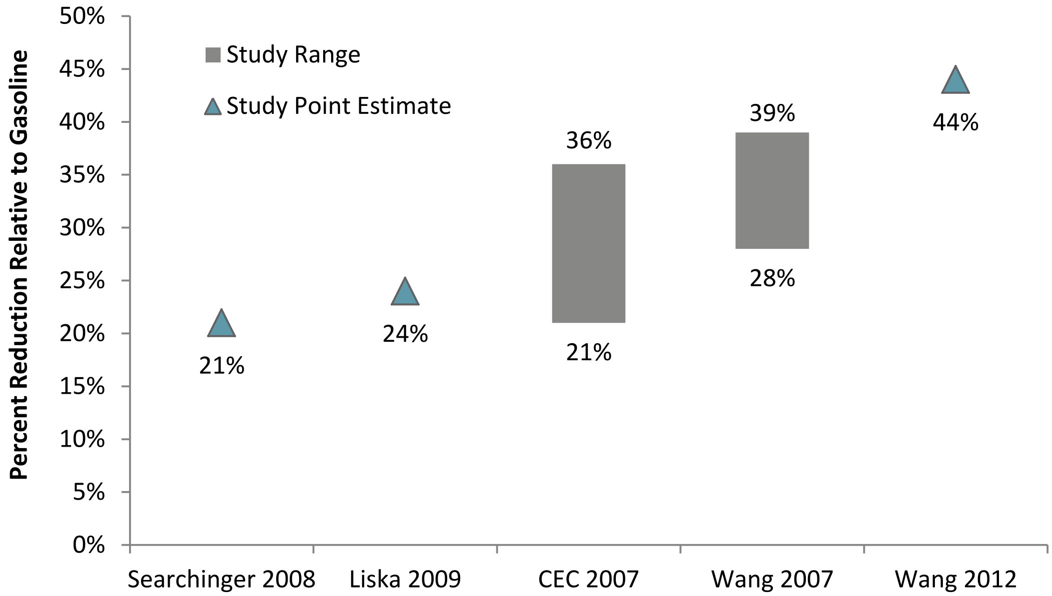
In addition, the findings can depend on the model (e.g., GREET, BESS, BEACCON) and methodology (e.g., LCA vs. ABC) employed by the researchers. Figure 15 provides a sampling of the range of corn ethanol lifecycle GHG emissions from five different studies. The common thread among the studies is that natural gas is the process heat source assumed. The refinery fuel source used is one of the largest factors influencing corn ethanol lifecycle GHG emissions, with coal as an energy source pushing lifecycle GHG emissions higher than gasoline.

If LUC is excluded, Figure 15 shows that studies generally agree that corn ethanol using natural gas for process heat results in a 20% or greater reduction in GHG lifecycle emissions relative to gasoline.

[32] CAA, Section 211(o).

Carbon storage and sequestration or carbon "uptake" that is sacrificed by diverting land from its existing uses – that is, LUC effects – could drive GHG emissions much higher. Including LUC in GHG lifecycle emissions analysis plays an important role from an environmental and scientific parity perspective.

Figure 15: Corn Ethanol Lifecycle GHG Emission Reductions Exclusive of LUC



To produce crops for biofuels, farmers use cropland used in production of other crops, and/or convert forest and grassland to cropland. The shift to other crops may produce more or less GHG emissions depending on the crop it replaces and the practices used. The conversion of forest and grassland to cropland involves clearing through, burning, and/or microbial decomposition that releases carbon previously stored in plants or soil into the atmosphere.[33] This is defined as "Direct" LUC.

Agriculture may also be the source of additional GHG emissions through the market price increase that the additional demand of cropland for biofuels creates. Farmers are induced through market effects to convert formerly unused areas to cropland for food production. This is defined as "Indirect" LUC ("ILUC"). However, the ILUC effects are highly dependent on the methods used to estimate them.

The GHG emissions released from converting existing cropland and existing grassland or forest land to bioenergy crops results in a "carbon debt" that biofuels must eventually repay through displacement of fossil fuels. The work of Fargione et al (2008), illustrates conditions in which "carbon debt" created by LUC can take almost 100 years to repay as shown in Table 5.

---

[33] Fargione 2008 quotes a reference that states "[s]oils and plant biomass are the two largest biologically active stores of terrestrial carbon, together containing ~2.7 times more carbon than the atmosphere."

Table 5: Time to Repay Corn Ethanol Carbon Debt[34,35]

Calculation Process	Calculation Assumptions / Result	Former Ecosystem: Central Grassland	Former Ecosystem: Abandoned Cropland
A	Carbon Debt (Mg CO_2 ha-^{1})	134	69
B	Debt Allocated to Corn Grain Ethanol (%)[36]	83%	83%
C	Corn Grain Ethanol Annual Repayment of Carbon Debt (Mg CO_2e ha-^{1} year-^{1})[37]	1.2	1.2
D = A x B / C	Time to Repay Corn Grain Ethanol Carbon Debt (Years)	93	48

* Based on the study's calculations, Fargione 2008 attributes 83 percent of the carbon debt to ethanol and 17 percent of the carbon debt to distillers dried grains with solubles, a corn ethanol refinery byproduct.
** The value of 1.2 in Calculation Step C represents the assumption that future corn ethanol refineries reduce GHG emissions over their lifecycle by 20 percent relative to gasoline.

When including carbon debts through direct and indirect LUC, the lifecycle GHG benefits of corn ethanol become much less clear as shown in Figure 16. As with Figure 15, the common thread in the studies shown in in Figure 16 is that natural gas is assumed as the process heat source.

The range in outcomes presented in Figure 16 is wide. LCA 2014 and Wang 2012 show a 23–34 percent reduction in GHG emissions while Searchinger 2008 shows the GHG emissions for corn grain ethanol may be up to 93 percent higher than gasoline when including LUC. This range in outcomes has created a highly contested debate about how to factor in LUC in GHG emissions.

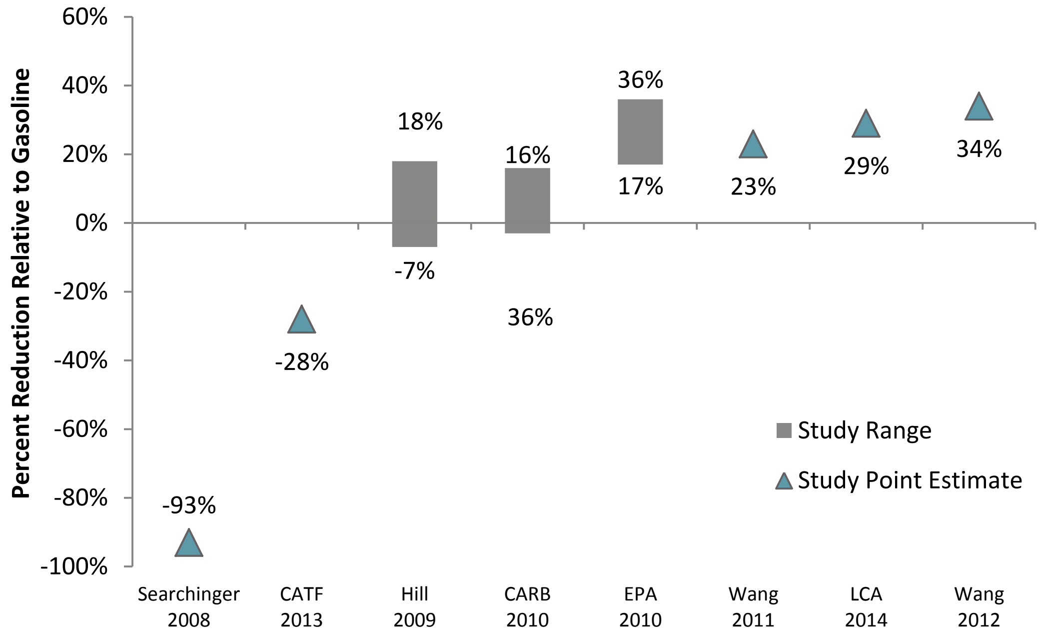
[34] Fargione 2008.

[35] The time to repay the carbon debt due to the conversion of US central grassland and US abandoned cropland to biofuels was estimated to take 93 and 48 years, respectively, in Fargione, 2008.

[36] Based on the study's calculations, Fargione 2008 attributes 83 percent of the carbon debt to ethanol and 17 percent of the carbon debt to distillers dried grains with solubles, a corn ethanol refinery byproduct.

[37] The value of 1.2 in Calculation Step C represents the assumption that future corn ethanol refineries reduce GHG emissions over their lifecycle by 20 percent relative to gasoline.

Figure 16: Corn Ethanol Lifecycle GHG Emission Reductions <u>Inclusive</u> of LUC



While the "life-cycle GHG emissions of bioethanol, especially those of corn-based ethanol, have been subject to debate,"[38] studies typically agree that cellulosic ethanol[39] reduces GHG emissions by more than 75 percent even when including LUC.[40]

Two important questions emerge given the significant LUC impact uncertainty of corn ethanol and the clear benefits of advanced cellulosic biofuels:

- Why should the RFS structure continue to increase corn ethanol volumes as 1) the technology is mature and 2) the environmental benefits are uncertain?
- Why has the RFS mechanism not resulted in promoting the proliferation of advanced biofuels, which clearly has agreement among researchers on their significant GHG emissions reductions?

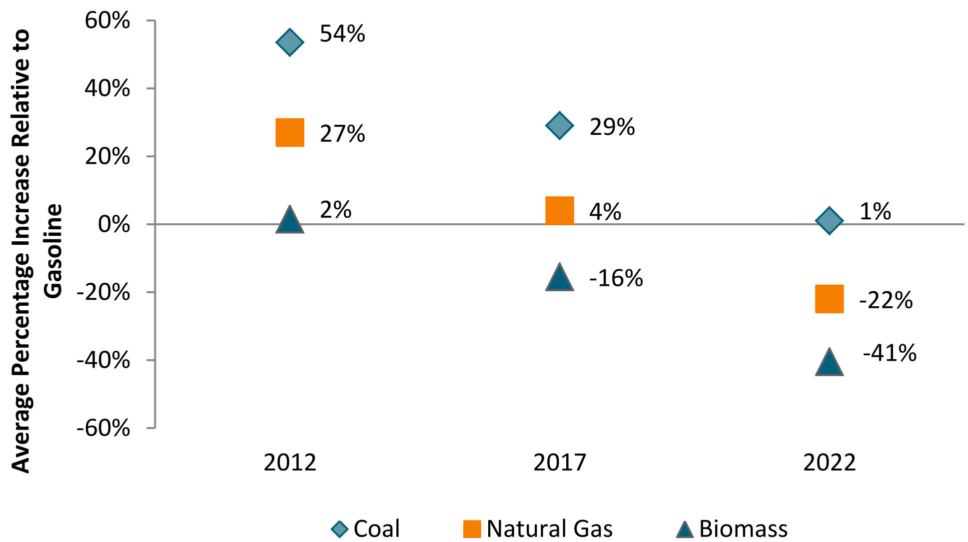
While Figure 16 shows GHG lifecycle estimates for new corn ethanol refineries, relatively little attention has been given to lifecycle emissions of corn ethanol from existing refineries. A 2011 National Academies of Sciences ("NAS") report provides some clue to what these emissions might be relative to a gasoline baseline as it examines near-term (2012 and 2017) corn ethanol refinery technologies. Figure 17 shows that current generation technology generally has lifecycle emissions that exceed gasoline.

[38] Wang 2012.

[39] Ethanol derived from ligno-cellulosic plant material, such as corn stover, switchgrass, or miscanthus.

[40] Based on authors' review of studies examining the lifecycle GHG emissions from cellulosic ethanol facilities.

Figure 17: Corn Ethanol GHG Lifecycle Emission Increase Relative to Gasoline by Refinery Vintage Year as Determined by EPA in the Final Rule for RFS2[41]



In addition, it is worth noting that most lifecycle GHG studies examine emissions in a static environment. A dynamic evaluation of lifecycle emissions would include the feedback or rebound effects from shifting the supply and demand curves for products. As such, an equal displacement of fossil fuels by biofuels is not entirely clear due to market feedback effects.

Biofuels typically are forced into the market by mandates and government incentives at a direct value to consumers that is less than or equal to the market price of fossil fuels.

While in aggregate the costs to consumers are higher due to taxpayer and private industry funding of the mandates and incentives, the consumer reacts to the direct price. A shift in the supply curve can stimulate demand and therefore offset, to some degree, emission reductions from biofuels.

Our research on lifecycle GHGs from corn ethanol refineries can be summarized as follows:

- The GHG lifecycle emissions of corn ethanol are highly uncertain when including LUC, a critical factor for inclusion in a lifecycle assessment. The lifecycle GHG emission reductions of cellulosic ethanol, however, are substantial and more certain.
- Based on the National Academy of Sciences study, the vast majority of ethanol refineries placed in operation by 2017 or earlier will have lifecycle GHG emissions that are higher than gasoline.
- A fossil fuel rebound effect can occur from inserting biofuels into the transportation fuel supply. The rebound effect occurs from shifting the supply curve, which in turn can stimulate demand for fossil fuels. As a result, some amount of lifecycle GHG reductions from biofuels can be offset from this rebound effect.

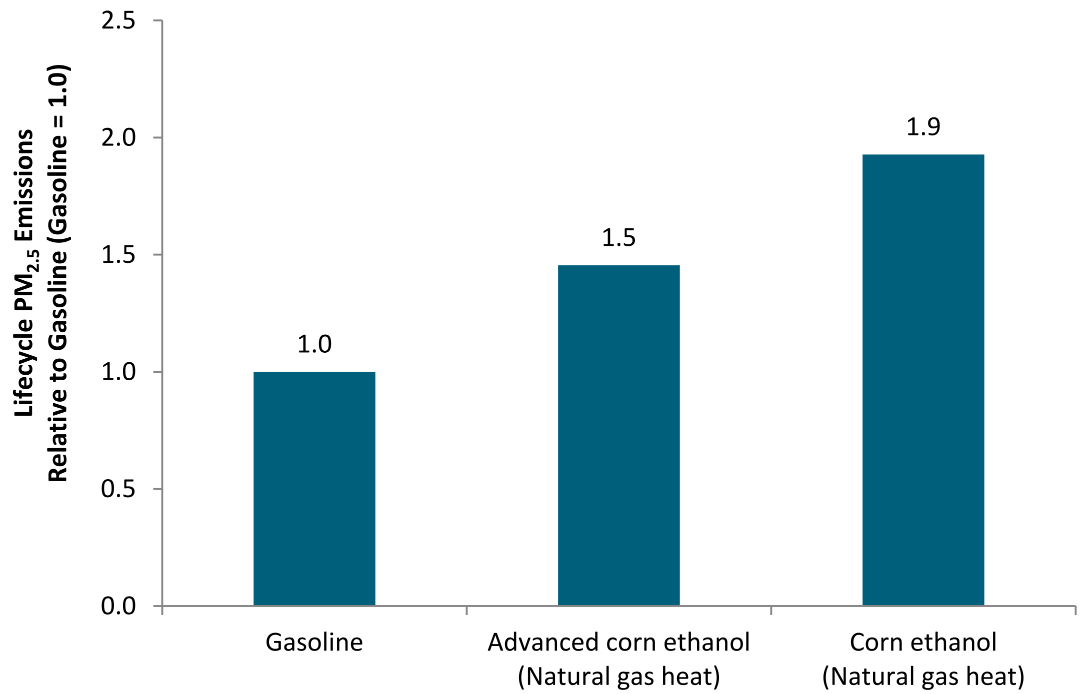
[41] National Academy of Sciences (NAS) 2011; EPA 2010.

3.1.2. Particulate Matter

Particulate matter (PM) is designated as a criteria pollutant by EPA and is defined as a complex mixture of extremely small particles and liquid droplets. It is made up of a number of components, including acids, organic chemicals, metals, and soil or dust particles.[42]

There are two main categories of particulates – $PM_{2.5}$ and PM_{10} – that receive health attention. EPA is concerned about particles that are 10 micrometers in diameter or smaller because they can travel into the lungs and respiratory tract, as well as act as an irritant to the eyes, nose and throat. This can cause increased coughing, sneezing, irritation to mucosal membranes, shortness of breath and exacerbation of symptoms related to asthma and heart disease and can be particularly damaging to children and the elderly.[43]

Figure 18: Corn Ethanol Lifecycle $PM_{2.5}$ Emissions Relative to Gasoline[44,45]



$PM_{2.5}$ are "fine" particles in the 2.5 micrometer size range or less. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries, and automobiles react in the air.

[42] EPA - Particulate Matter (PM).

[43] New York State Department of Health PM 2.5.

[44] Hill 2009.

[45] Hill 2009 defines "advanced corn ethanol" to include 1) 20 percent increase in corn grain yields; 2.) 33 percent decrease in nitrogen fertilization rates; 3.) 19 percent decrease in thermal energy and 79 percent decrease in electricity consumption via the use of combined heat and power technologies in ethanol refineries; and 4.) 10 percent increase in ethanol process improvements, such as converting corn kernel fiber to fermentable sugars.

PM_{10} are considered "inhalable coarse particles" that range in size from 2.5 to 10.0 micrometers. They can be found near roadways and dusty industries. In addition to human health conditions, $PM_{2.5}$ and PM_{10} can contribute to acidic atmospheric conditions that can damage materials and reduce visibility.[46]

While there is some PM_{10} generated in the gasoline and ethanol lifecycles, the main concern is $PM_{2.5}$ as it caused by combustion of fuels, mainly in the refining process and in vehicle operations. According to Hill 2009, corn ethanol produces, at a minimum, 50 percent more $PM_{2.5}$ over its lifecycle than gasoline (Figure 18).

3.1.3. Ozone Precursors

Nitrogen oxides (NOx) and volatile organic compounds (VOC) are the two main precursors to ozone formation. While NOx and VOC emissions naturally occur from biogenic reactions (decomposition of plant materials), they also are created from industrial facilities, electric utilities, motor vehicle exhaust, transportation fuel vapors, and chemical solvents.

According to the EPA, "breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma."[47] EPA also states that ground level ozone can also have harmful effects on sensitive vegetation and ecosystems.

Figure 19: Corn Ethanol Lifecycle VOC and NOx Emissions Relative to Gasoline[48]

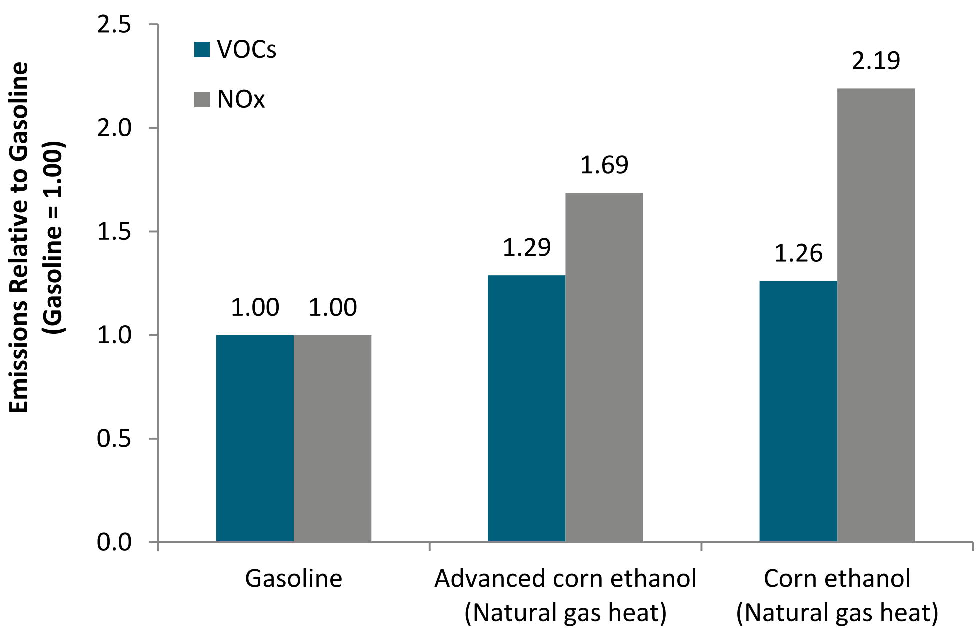


Figure 19 shows the VOC and NOx lifecycle results from the Hill 2009 study for ethanol refineries using natural gas as process heat. Natural gas presented the lowest lifecycle emissions of VOCs and NOx as

[46] EPA 1995.

[47] EPA - Ground Level Ozone.

[48] Hill 2009.

compared to corn stover and coal. Also, natural gas represents the lowest cost option for process heat in the current natural gas pricing environment.

The Hill 2009 study reveals that VOCs emissions from the corn ethanol lifecycle are up to 29 percent higher than emissions from the gasoline lifecycle. The major contributors to higher lifecycle emissions relative to gasoline are "feedstock recovery" and "fertilizer production."[49] Feedstock recovery VOC emissions are defined as the emissions created from harvesting and processing of the feedstock for biofuels production. Fertilizer production VOC emissions are the emissions created during the fertilizer manufacturing process that are attributable to biofuels.

For NOx, the major contributors to higher emissions relative to gasoline are "feedstock recovery" and "nitrogen oxide emissions from soil."[50] Nitrogen oxide (NO) emissions include the increase in NO released from soil due to land use (corn production vs. another crop). NO emissions from soil also include the release of NO into the air due to decomposition of nitrogen fertilizers applied to the soil.

It is possible that lifecycle VOC and NOx emissions could be much higher than reported in the Hill 2009 study. The de Gouw 2015 study examined the downwind air contaminants from an ethanol refinery in Decatur, IL. The study determined that emissions of VOCs were much higher than expected. [51]

The study measured emission levels of NO, NO_2, Nitric Acid (HNO_3), CO_2, SO_2, ethanol, n-hexane, formaldehyde (HCHO), acetaldehyde (CH_3CHO), peroxyacetyl nitrate (PAN), peroxypropionyl nitrate (PPN), and fine particulates in the plume of pollutants for several miles around the refinery. These emissions were expected to be below certain levels based on the National Emissions Inventory study of 2011 (NEI-2011).

SO_2 and NOx were on par with the NEI-2011 study, but even after correcting for several potential sources of error related to surrounding refineries and electricity plants, emissions of VOCs such as ethanol, formaldehyde, and acetaldehyde, were found to be 10-30 times higher than predicted from the NEI-2011 study. NOx emissions were found to react as emissions moved downwind, forming HNO_3, PAN (peroxyacetyl nitrate), and PPN (peroxypropionyl nitrate) as distance from the plant increased.

The de Gouw 2015 study also found that ozone production from the photooxidation of VOCs caused ozone flux to increase with distance downwind from the refinery at a somewhat higher efficiency than what is generally observed downwind from power plants.

3.1.4. Ammonia and Sulfur Dioxide

Ammonia (NH_3) and sulfur dioxide (SO_2) are two other air pollutants that contribute to the creation of particulate matter. A proper assessment of the impact of corn ethanol production must consider these pollutants over the entire production lifecycle as well. Studies taking the ethanol production lifecycle

[49] Huo 2009.

[50] Ibid.

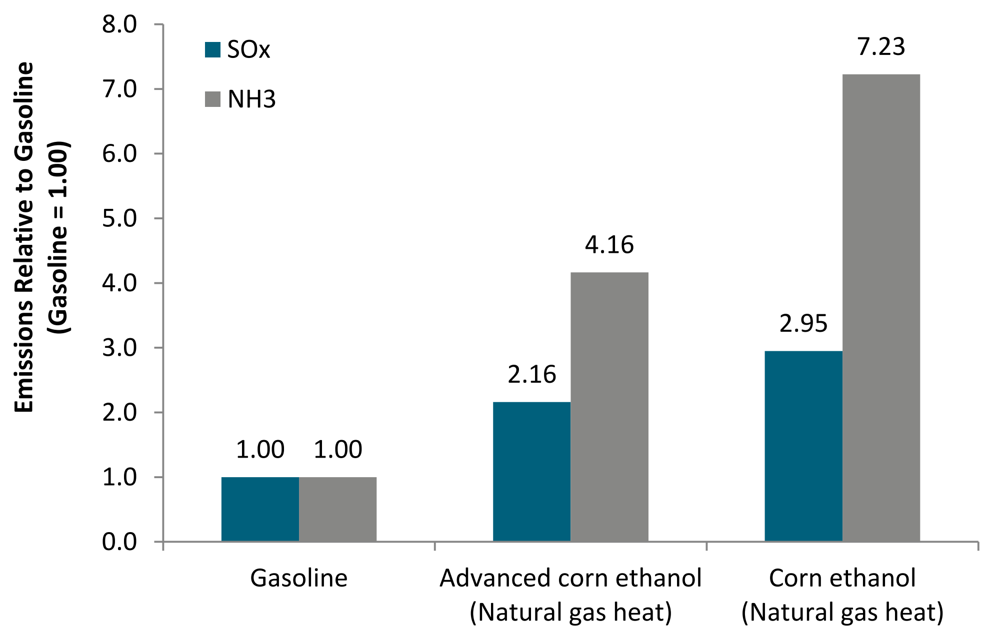
[51] de Gouw 2015

into account indicate that these emissions are likely greater than those associated with traditional transportation fuels.

Ammonia is used by corn ethanol production plants in the early stages of the process to balance pH and improve the action of enzymes used in the slurry system. When ammonia is released into the atmosphere, it mixes with other emissions to form fine particulate emissions, which are linked to heart and lung disease and even death.

Sulfur dioxide is used in ethanol plants in various parts of the production process. SO_2 is linked with the creation of particulates, which have an adverse effect on the respiratory system.[52] Figure 20 shows the results from the Hill 2009 study on the lifecycle SOx and NH_3 from new corn ethanol refineries using natural gas as process heat.

Figure 20: Corn Ethanol Lifecycle SOx and NH_3 Emissions Relative to Gasoline[53]



The figure shows that lifecycle SOx emissions can be 116 to 195 percent higher for corn ethanol than gasoline. For NH_3, the relative emission levels are significantly higher – 316 to 623 percent.

3.2. POLYSYS Modeling of Corn Ethanol's Environmental Impacts

In addition to performing the above literature review of corn ethanol's environmental impacts, we have applied the POLYSYS model to estimate the environmental impacts of corn ethanol over the past ten years. These impacts include agricultural carbon emissions, fertilizer and chemical consumption, and soil erosion.

[52] EPA – Sulfur Dioxide.

[53] Hill 2009.

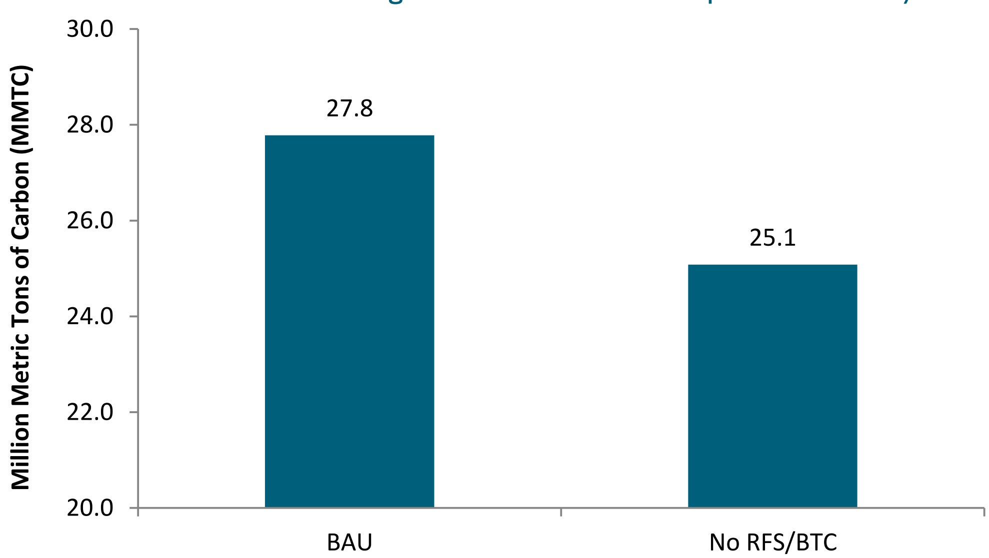
The scenario examined here is the No RFS/BTC scenario, which assumes that the RFS was never implemented and the BTC ended by 2005. As described in Section 2, the net, unsubsidized profit margins for corn ethanol refinery without the RFS and the BTC would have been insufficient after November 2008 to justify investment in new facilities.

3.2.1. Agricultural Carbon Emissions

For carbon, the POLYSYS model computes the emissions from agricultural production and input use and projects that emissions would decline by 10 percent in the No RFS/BTC scenario (Figure 21). The components of the total carbon emissions calculated in the POLYSYS model include the following:

- Soil Carbon Uptake: the amount of carbon pulled from the air and stored in the soil by the crop.
- Direct Carbon: carbon emitted from the process of preparing the cropland, planting the crop, maintaining the crop, and harvesting the crop.
- Fertilizer Carbon: carbon emitted in the process of producing fertilizers for agriculture.
- Chemical Carbon: carbon emitted in the process of producing chemicals, such as herbicides and pesticides, for agriculture.
- Seed Carbon: carbon emitted from the process of preparing the seed for planting (mostly through natural gas or propane drying).
- Nitrogen Carbon: nitrous oxide (N_2O) emitted from the decomposition of fertilizer. N_2O is a GHG.
- Lime Carbon: the carbon emitted from the lime applied to the cropland. Lime reduces the acidity of soils.

Figure 21: 2014 Carbon Emissions from Agricultural Production and Input Use – No RFS/BTC Scenario



In the No RFS/BTC scenario, the primary driver for the reduced carbon emissions is the increased Soil Carbon Uptake as less corn acres are planted and more wheat and soybean acres are planted. These crops produce sequester more carbon in the soil than does corn.

3.2.2. Soil Erosion, Fertilizer Consumption, and Chemical Consumption

It is important to assess the environmental impacts of increased corn plantings due to the RFS as corn presents a number of issues around soil erosion, fertilizer consumption, and chemical consumption. The reason is that the root system and land coverage of corn is not as beneficial to reducing erosion as other crops, such as wheat or hay.

As such, corn plantings have generally been associated with higher levels of erosion. With erosion, fertilizer and chemical contamination of surface and ground waters increase. Also, erosion removes beneficial soil from the cropland, which requires higher levels of fertilizer re-applications in order to boost nutrient levels and sustain yields.

Another concern with the RFS-related corn plantings is the lack of crop rotation that can occur, which also is known as continuous planting. The two issues with continuous planting are increasing fertilizer loads needed to sustain yields and increasing application of pesticides as farmers forfeit the crop rotation benefits of pest control. Again, erosion related to fewer crop rotations impacts surface and groundwater contamination levels.

The extent of surface and ground water contamination directly related to corn ethanol is very much debated. Some have argued that surface water runoff from RFS-induced corn plantings has contributed to a dead zone in Gulf of Mexico.[54] In addition, there is evidence that points toward elevated levels of nitrogen in groundwater linked to areas of corn production.[55]

Others have argued against these types of analyses as there are many methods for controlling the pollutant impacts of erosion and over-application of chemicals. These include constructing grassed waterways, diversions, terraces, and contour buffer strips along with seeding down headlands where erosion is known to occur.[56] The degree of adherence to these abatement methods is not entirely clear and deserves further study.

Regardless of where one stands on the debate, it is commonly accepted that that reducing erosion along with chemical consumption is an environmentally and economically sound action to pursue as it minimizes the possibility of environmental contamination.

[54] Union of Concerned Scientist (UCS) 2011.

[55] USDA 2007.

[56] Ibid.

Soil Erosion Results

Soil erosion decreases in the No RFS/BTC scenario relative to the BAU and to 2008 levels. In the BAU, U.S. annual soil erosion increased from 807 million tons to 837 million tons, or 3.7 percent, from 2008 to 2014 due to increasing corn plantings and its inherent soil damage. During that period, the cumulative erosion in the BAU was estimated to be 5.7 billion tons.

Table 6: U.S. Annual Soil Erosion by Scenario (million tons)

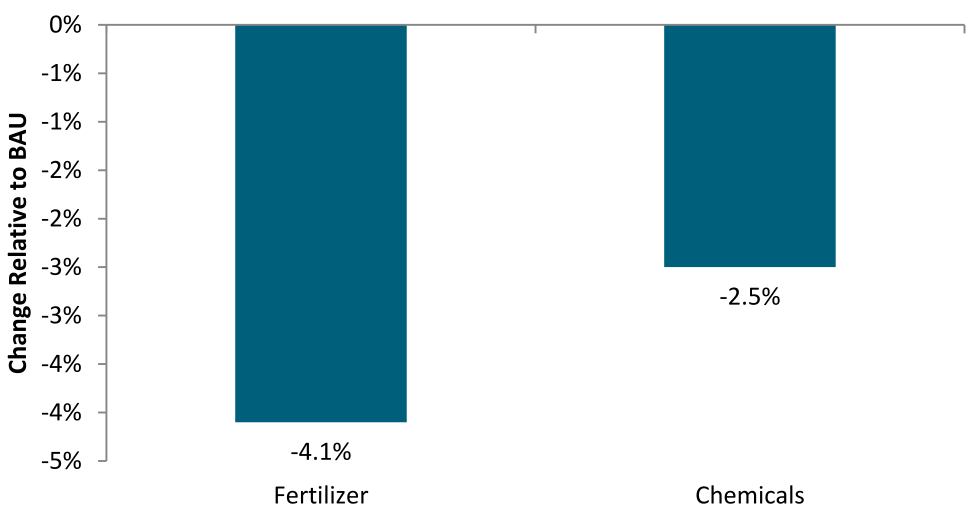
Scenario	2008	2014	Absolute Change from 2008	% Change from 2008
BAU	807	837	30	3.7%
No RFS/BTC	807	761	-47	-5.8%

In the No RFS/BTC scenario, U.S. annual soil erosion decreases from 807 million tons to 760 million tons, or 5.8 percent, from 2008 to 2014 as corn crops are switched over to crops that are less erosion-prone. From 2008 to 2014, the cumulative erosion in the No RFS/BTC scenario was computed 5.5 billion tons. This is a reduction in cumulative erosion of 233 million tons, or 4.1 percent.

Fertilizer and Chemical Consumption

As for fertilizer and chemical consumption, the scenario modeling shows that less is required in the No RFS/BTC scenario relative to the BAU (Figure 22).

Figure 22: No RFS/BTC Annual Average Change in U.S. Agricultural Fertilizer and Chemical Consumption, 2008-2014



Fertilizer consumption declines by almost 5 percent on average, and chemical consumption declines by almost 3 percent on average. This is due to corn acres being replaced with crops, such as wheat and soybeans, which require less fertilizer and chemical application.

4. Developing Advanced Biofuels is the Solution to Corn Ethanol

In the previous two sections, we explained the environmental and economic problems of corn ethanol and how the RFS has artificially created demand for corn ethanol production since the end of 2008. In this section, we examine the solution to corn ethanol – advanced biofuels.

Advanced biofuels are defined by EPA as biofuels that reduce GHG emissions by 50 percent relative to their petroleum-based counterparts. Biodiesel, renewable diesel, cellulosic ethanol, and cellulosic diesel are examples of advanced biofuels per EPA's definition.[57] In this paper, we use the following criteria to define advanced biofuels:

- **Biofuels that rely upon feedstocks that do not compete with food.** Soybean-based or soy-diesel is an example biofuel that is excluded from the advanced biofuels definition in this paper as soybeans are a food crop.
- **Biofuels that reduce GHG emissions by 50% relative to their petroleum counterpart.**

We begin our advanced biofuels assessment by looking at advanced biofuels' current and historical state of affairs. Next, we explain why the RFS has failed at developing advanced biofuels. We then examine the economic impacts that advanced biofuels would have produced if they had filled the gap between natural oxygenate demand and corn ethanol production during the past 10 years. We again use the POLYSYS model to explore these impacts.

4.1. Current Status of Advanced Biofuel Capacity and Production

In 2014, 1.93 billion gallons of advanced biofuels were produced. Of this volume, 1.49 billion gallons or 77 percent was methyl ester biodiesel, which is a mature technology that typically relies on a food crop (soybeans) as a feedstock. The difference of 0.44 billion gallons represents the "other" advanced biofuels that are cellulosic-based or do not require a feedstock that also competes with food. The "other" advanced biofuel production in 2014 was equivalent to 2.7 percent of corn ethanol production on a volume basis.

The advanced biofuels industry clearly has struggled to gain traction for both technical and financial reasons. Researchers have been challenged in accelerating the process of breaking down ligno-cellulosic biomass into starches or sugars for the production of cellulosic biofuels.

Outside of cellulosic biofuels, there are other technologies, such as gasification, that can rapidly transform ligno-cellulosic biomass into useable compounds for producing biofuels; however, the costs are currently prohibitive.

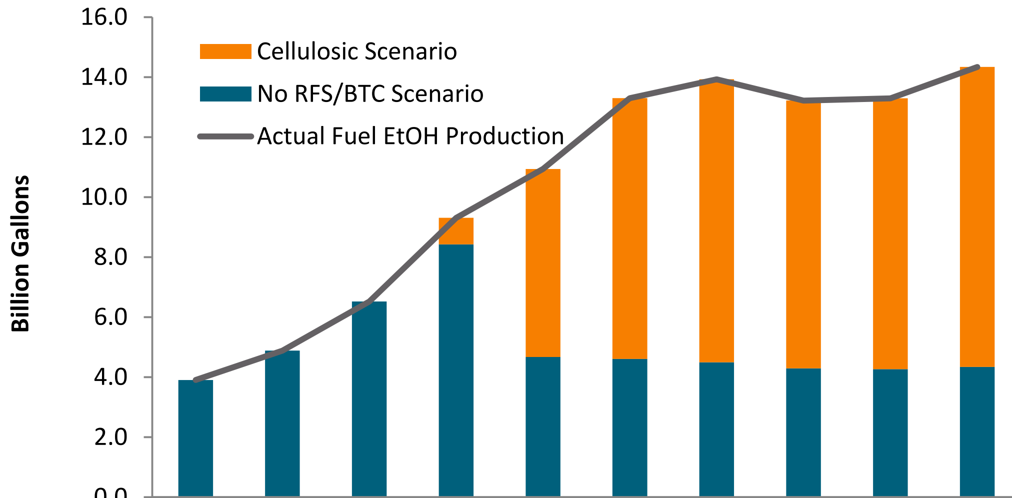
[57] Federal Register 2010.

The costs for cellulosic biofuel plants are relatively high as well. For example, corn stover ethanol plants, which transform the leftover parts of the corn into ethanol, are approximately 300 percent more capital intensive to build than corn ethanol plants.[58]

4.2. Cellulosic Replacement Scenario Results

The Cellulosic Replacement scenario examines the economic and environmental impacts if the lost corn ethanol production in the No RFS/BTC scenario were replaced with cellulosic ethanol under a new RFS framework that incentivizes advanced biofuels exclusively. In this scenario, cellulosic ethanol production levels are 10 billion gallons or 70 percent of actual biomass-based ethanol production in 2014.

Figure 23: Corn and Cellulosic Ethanol Production under Scenarios Evaluated



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cellulosic Scenario	0.00	0.00	0.00	0.88	6.27	8.69	9.43	8.93	9.02	10.00
No RFS/BTC Scenario	3.90	4.88	6.52	8.43	4.67	4.61	4.50	4.29	4.27	4.34
Actual Fuel EtOH Production	3.90	4.88	6.52	9.31	10.94	13.30	13.93	13.22	13.29	14.34

4.2.1. Economic Impacts of Advanced Biofuels

In the Cellulosic Replacement scenario modeled in POLYSYS, we make two key assumptions. The first assumption is that cellulosic ethanol is commercially available and cost competitive with gasoline by 2008. We make this assumption in order to understand how the economy would *benefit* from an economically competitive advanced biofuel fully appreciating that economic costs, principally in the form of subsidies, would have been required to commercialize advanced biofuels by 2008.

The second assumption is that cellulosic ethanol feedstock demand can be met with any number of feedstocks, such as crop residues from corn, wheat, oats, sorghum, and rice; dedicated energy crops

[58] Based on NREL capital cost estimate for a mature cellulosic ethanol plant – $422.5 million (2007$'s) for 61 MM gal/y capacity – versus Iowa State's capital cost estimate for a mature corn ethanol plant - $211 million (2015$'s) for 100 MM gal/y capacity.; Humbird 2011; Iowa State 2015.

such as switchgrass, miscanthus, and forage sorghum along with short rotation woody crops including eucalyptus, poplar, and willow.

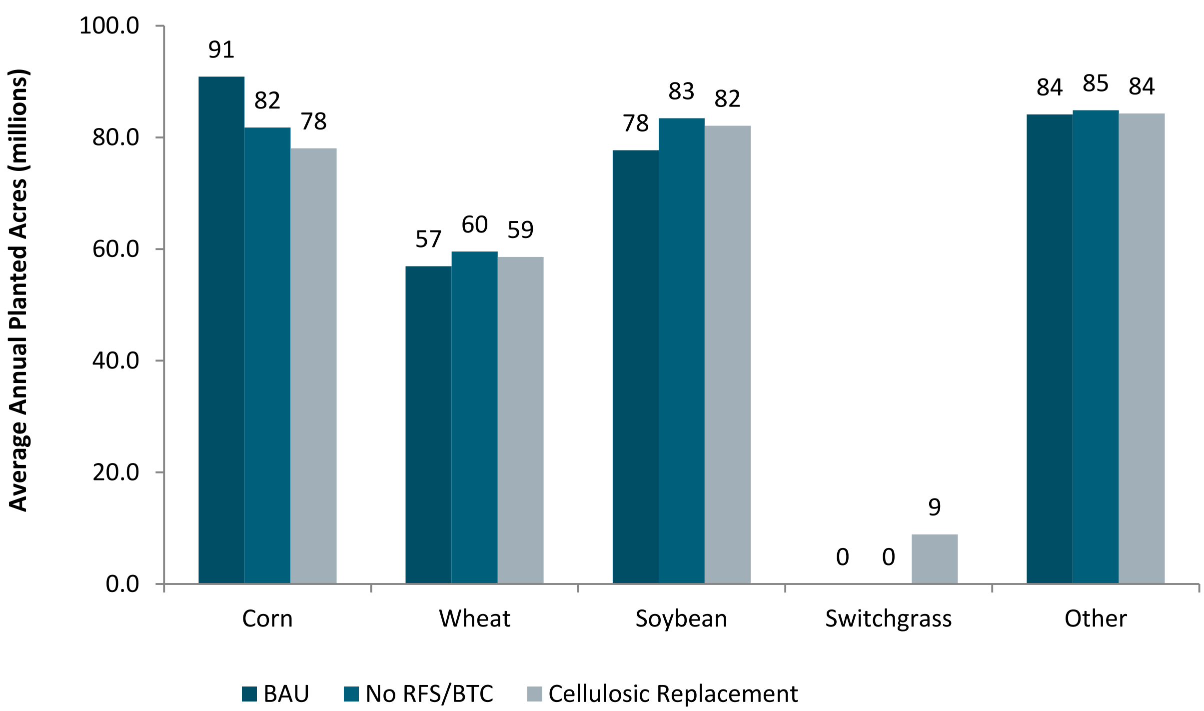
The following discussion is in regards to economic benefits and does not consider economic costs that would translate into *net economic benefits*. We make this distinction as the external costs in economic studies are often ignored or simply not acknowledged.

Cropland Use Change

The biggest economic driver in the Cellulosic Replacement scenario is the change in cropland use. Figure 24 shows the changes in crop land use for the historical (BAU) and the two scenarios modeled. In response to the lower production of corn ethanol, the No RFS/BTC and Cellulosic Replacement scenarios imply a reduction in total acreage planted to corn, falling from 90.9 million acres in BAU to 81.8 (-10 percent) and 78.0 (-14 percent) million acres in the No RFS/BTC and Cellulosic Replacement scenarios, respectively.

The BAU shows that the average planted acreage of corn for the 2008-2014 period was 90.9 million acres; when compared with the average of the 2004-2007 years, it meant an increase of 7.2 (9 percent) million acres. Comparing the two alternative scenarios to each other, one observes that corn acreage is reduced in the Cellulosic Replacement scenario relative to the BAU, but is higher than the No RFS/BTC scenario. The reason is that the Cellulosic Replacement Scenario requires residues such as corn stover as feedstock, which in turn increases the value of corn (and thus supply) relative to other crops.

Figure 24: Average Annual Planted Acres by Scenario, 2008-2014



For soybeans, the comparison of the historical data indicates that there was an 8 percent increase in planted acreage based on the 2004-2007 average versus the 2008-2014 average.

Looking at the impact of the two alternative scenarios, the average planted soybean acreage would have increased by 5.7 million acres (7 percent) and 4.4 million acres (6 percent), on average, for the No RFS/BTC and Cellulosic Replacement scenarios, respectively, relative to the BAU. These changes represent a shift from corn as ethanol demand diminishes.

For wheat, the comparison of the historical data indicates that there was a 3 percent reduction in planted acreage based on the 2004-2007 average versus 2008-2014 average. The average planted wheat acreage would have increased by 2.6 million acres (5 percent) and 1.7 million acres (3 percent), on average, for the No RFS/BTC and Cellulosic Replacement scenarios, respectively, relative to the BAU. Similar to soybeans, these scenario results represent a shift from corn as ethanol demand diminishes.

Within the Cellulosic Replacement scenario, there also is a shift of cropland to the production of cellulosic feedstock, particularly switchgrass. To meet the historical ethanol demand levels, this scenario implies that the addition of 8.9 million acres of switchgrass, on average, is required; moreover, the model results indicate that 15.7 million acres of switchgrass would have been required in 2014 to produce enough feedstock for meeting ethanol production in that year.

The model results indicate that a large share of the switchgrass acreage planted would have come from corn, soybeans, and wheat. An additional 3.4 million acres, though, would be needed by 2014 in order to produce enough feedstock for cellulosic ethanol facilities.

Planting switchgrass in marginal cropland allows for this additional acreage. While not modeled explicitly, the Conservation Reserve Program (CRP) could be a source for some of the additional acres needed. The CRP reached an all-time peak of 27 million acres in 2007. The 2008 Farm Bill reduced the cap on CRP lands from 39 million to 32 million. By 2014, the CRP acreage declined further to 26 million acres. Some of the opened CRP acreage went into crop production along with idled and pastured land to increase the total land area in crop production.

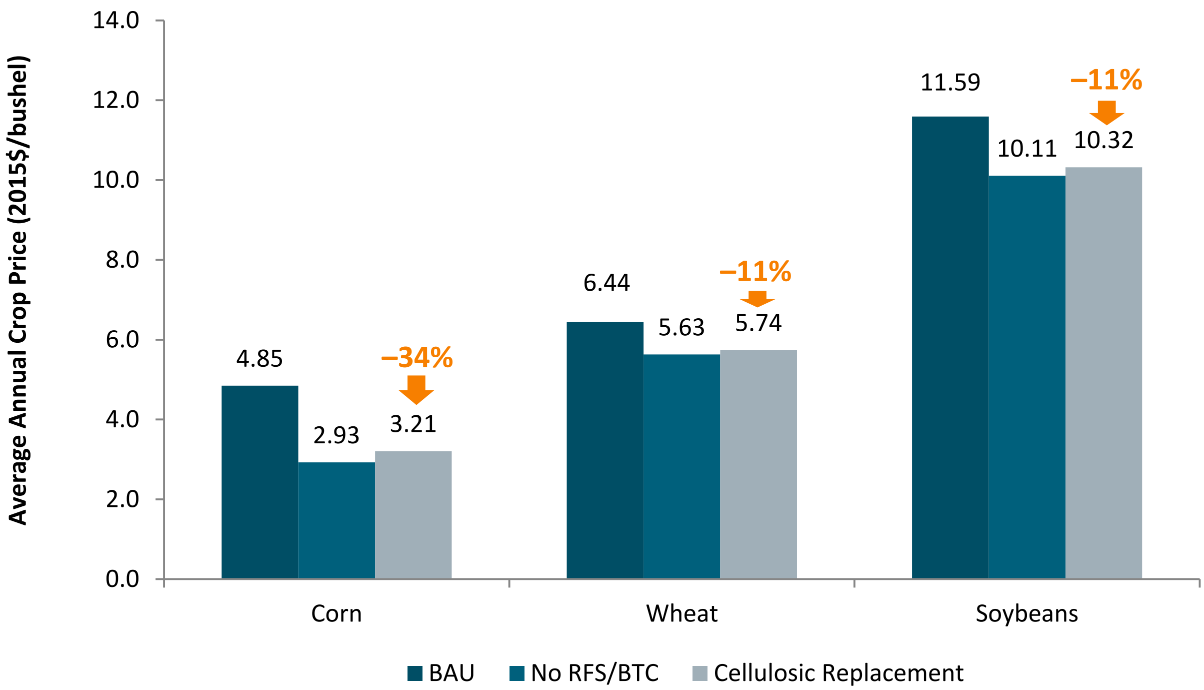
It should be noted that several studies have indicated that these lands would have transitioned to crop production even without RFS due to other drivers pushing up crop prices, such as increased food demand, falling dollar values, oil price increases, and supply shortfalls in other regions of the world.[59]

Crop Price Changes

Another key variable to consider are the changes in crop prices from the BAU. The Cellulosic Replacement scenario results show average annual prices dropping for corn, wheat, and soybeans by 34 percent, 11 percent and 11 percent, respectively, from the BAU scenario (Figure 25).

[59] Tyner 2010; Hochman 2012; Zilberman 2013.

Figure 25: Average Annual Crop Prices and Percent Change by Scenario, 2008-2014



The price reductions in the scenarios reflects the reduced demand for corn ethanol and the increased supply of wheat and soybeans as acreage is shifted away from corn. In addition, price reductions are less than the No RFS/BTC Scenario because of the demand for cropland increased in order to produce dedicated energy crops.

It should be noted that corn still plays an important role in biofuels production in the Cellulosic Replacement scenario. For one, corn starch is used to supply 30 percent of the bio-ethanol market in 2014. Secondly, corn stover is used to help supply the remaining 70 percent of the bio-ethanol market in 2014.

Changes in National Economic Indicators

As discussed in Section 2.2, the POLYSYS model provides two important macroeconomic statistics – NRFI and Wholesale Crop Expenditure Savings.

In the BAU scenario, the average NRFI was $97 billion on average from 2008-2014 as shown in Table 7. For the Cellulosic Replacement scenario, NRFI was reduced to $84.1 billion on average, which is a reduction of $13 billion or 13 percent.

In the Cellulosic Replacement scenario, the drop in corn ethanol demand is substituted by ethanol from cellulosic sources, which imply the use of feedstock already in production (stover, straw, and crop residues). Besides, the conversion rate of cellulosic feedstock to ethanol is higher than the corn to ethanol rate. These two factors resulted in a lower pressure in agricultural demand and cropland.

Table 7: Net Realized Farm Income – Cellulosic Replacement vs. BAU scenario

Scenario	Average Annual Net Realized Farm Income – 2008 to 2014 (Billions of 2015$'s)
BAU	$97.1
Cellulosic Replacement	$84.1
Change (Loss)	–$13.0

Government payments, which include all direct payments to farms from the government (e.g., Loan Deficiency Payments, Contract Payments, Counter-Cyclical Payments, CRP and other conservation/environmental related payments), do not show major change in the scenarios analyzed. They reached an annual average of $11.3 billion for all scenarios and thus were inconsequential to changes in NRFI.

As crop prices rise and fall, consumer purchases increase and decrease, respectively. A decrease in crop prices, while negatively impacting NRFI, reduces consumer expenditures and places dollars back into consumers' pockets to spend on higher-valued items and/or to save.

Table 8 shows the U.S. Wholesale Crop Expenditure Savings for corn, wheat, and soybeans in the BAU and Cellulosic Replacement scenario along with the change from the BAU.

Table 8: Average Annual U.S. Wholesale Crop Expenditures of Select Harvest Products (Corn, Wheat, and Soybeans) – Cellulosic Replacement vs. BAU

Scenario	Average Annual Wholesale Crop Expenditures – 2008 to 2014 (Billions of 2015$'s)
BAU	$89.8
Cellulosic Replacement	$60.5
Change (Savings)	$29.3

Table 8 shows that Wholesale Crop Expenditure Savings are increased by $29.3 billion annually under the Cellulosic Replacement scenario.

Using these two macroeconomic outputs from the POLYSYS model along with other estimations, we are able to approximate the overall net U.S. economic benefits in the Cellulosic Replacement scenario by applying the IMPLAN model.

There are five main economic benefits that we considered in this scenario:

- Dedicated Energy Crop Management, which is the management of crops planted as feedstocks for advanced biofuels

- Dedicated Energy Crop Growers Payments, which are the payments to growers for the value of the crop
- Crop Residues Collection, which is the payment for crop residues, such as corn stover, that are collected from fields
- Cellulosic Ethanol Production to offset lost corn ethanol volumes
- Wholesale Crop Expenditure Savings, which are distributed to end-consumers and also to downstream value chain participants in the form of higher profit margins.[60]

There are three main economic opportunity costs that we considered in scenario:

- Increased Farm Income via higher crop prices in the BAU
- Increased Farm Income via higher crop volumes in the BAU
- BAU Ethanol Production that is substituted by cellulosic ethanol in the Cellulosic Replacement scenario

The net economic benefit or cost of the Cellulosic Replacement scenario is simply the economic benefits of Cellulosic Replacement scenario less the economic benefits of the BAU.

Table 9: 2014 Net Economic Impacts in a No RFS/BTC Scenario (Billions of 2015$'s)

Economic Impact	Net Benefit	Opportunity Cost
Dedicated Energy Crop Management	$11.0	N/A
Dedicated Energy Crop Growers Payments	$1.2	N/A
Crop Residues Collection	$11.1	N/A
Crop Residue Growers Payments	$8.9	
Cellulosic Ethanol Production[61]	$32.1	N/A
Wholesale Crop Expenditure Savings	$51.5	N/A
Increased Farm Income via Price	N/A	$40.0
Increased Farm Income via Crop Volumes	N/A	$23.5
BAU Corn Ethanol Production	N/A	$10.2
Total	**$115.8**	**$73.7**
Net Scenario Benefit	**$42.1**	

[60] We assume that end-consumers receive 70% of the benefit and that downstream value chain participants receive 30% of the benefit.

[61] The operating cost of cellulosic ethanol production less the feedstock is estimated to be three times the cost of a corn ethanol

In conducting this analysis, we chose 2014 as the IMPLAN modeling year. This year was selected because it is the most recent year where ethanol production is stable as there is very little capacity expansion. Table 9 provides the results of this analysis.

It shows that the Cellulosic Replacement scenario would have produced a $42.1 billion net economic benefit in 2014. The economic impacts shown are in total output, which is defined as value added or GDP plus the value of intermediate inputs. The impacts also include direct, indirect, and induced impacts.

4.2.2. Environmental Benefits of Advanced Biofuels

Advanced biofuels have significant environmental benefits as compared to corn ethanol. To illustrate this, we have conducted two analyses.

The first analysis is a summary of our findings based on a literature review of lifecycle emissions assessments for a range of emission types. The literature review includes both EPA assessments and academic studies.

The second analysis is based upon our deployment of the POLYSYS model for a second scenario ("Cellulosic Scenario") in which advanced, cellulosic ethanol composes the difference between actual corn ethanol production and oxygenate demand. We assume oxygenate is met by corn ethanol (Figure 23).

The second scenario builds upon the first POLYSYS modeling scenario discussed in the Section 2.2 where we examine a world without the RFS. The first scenario is premised on our economic analysis that corn ethanol production would not have occurred absent the RFS and federal subsidies from 2005 to 2008 due to natural market conditions. Existing ethanol refineries as of 2008 would have been capable of supplying gasoline oxygenate demand through 2014 and thus the difference between actual ethanol production and oxygenate demand would not have occurred with artificial demand drivers.

The second scenario is premised upon two key assumptions:

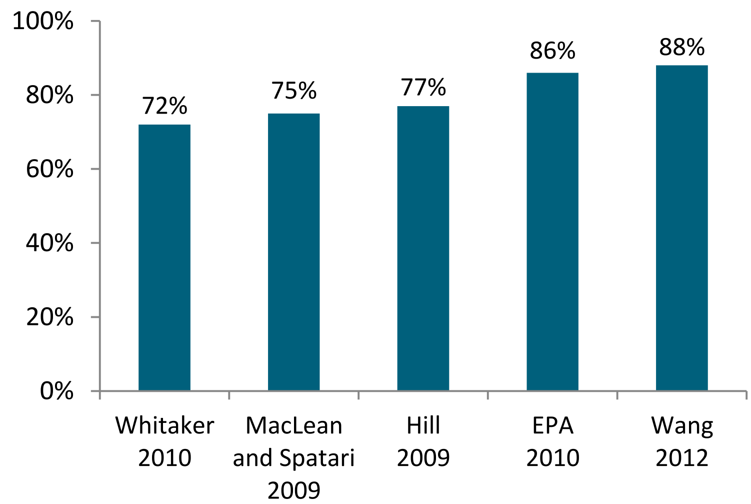
- Cellulosic biofuel technology would have been successfully commercialized by 2008
- The cost of cellulosic ethanol would have been marginally better than gasoline, such that production would have ramped up to the blendwall of 10 percent ethanol.

4.2.3. Agricultural Carbon Emissions

While studies disagree about the GHG emission impacts of corn ethanol, studies generally agree that advanced biofuels have a tremendous impact on reducing GHG emissions. The debate shifts from whether there is any benefit to whether advanced biofuels remove carbon from the atmosphere (i.e., they have a negative carbon footprint).

Figure 26 provides an example of the alignment around various academic studies showing that cellulosic ethanol significantly reduces GHG emissions relative to gasoline.

Figure 26: Cellulosic Ethanol Lifecycle Emission Reductions Relative to Gasoline



The benefits of advanced biofuels can be further illustrated from the results of the POLYSYS model. In the Cellulosic Scenario, we assume that total production of ethanol is equal to the historical. To meet that goal, the use of corn for ethanol is kept at the No RFS/BTC scenario level, and the additional feedstock comes from cellulosic sources.

The simulation results indicated that an average of 127 million dry tons of cellulosic feedstock would be needed. From this total, 54 percent would come from corn stover, 33 percent from switchgrass, 12 percent from wheat straw, and the remaining 1 percent from residues of other crops.

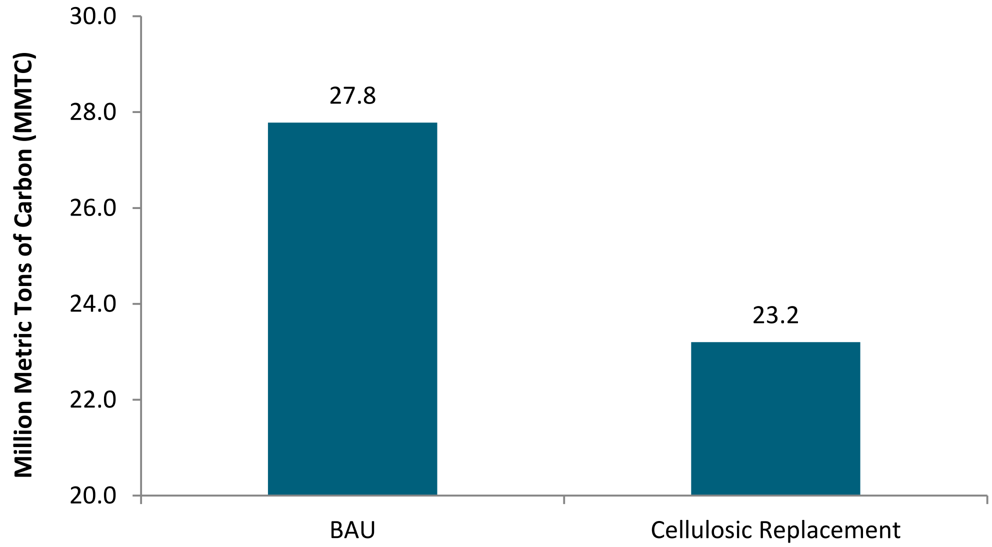
While the total demand for cellulosic feedstock is the result of the construction of the scenario, the participation of each source is endogenously calculated by POLYSYS, comparing the cost of collection and the acreage yield.

While the POLYSYS model does not calculate lifecycle emissions, it does determine at a very detailed level the carbon emissions and reductions for the U.S. agriculture sector. Agriculture emits carbon to the atmosphere through the production and use of fossil fuel intensive inputs such as fertilizers and chemicals, but agriculture also sequesters carbon from the atmosphere and into soils through carbon-friendly production practices such as no-tillage or growing perennial grasses. Although there are always net emissions from agriculture, sequestration lessens carbon emissions from U.S. agriculture.

In 2014, under the BAU, agriculture had net carbon emissions totaling 28 million metric tons of carbon (MMtC), with 40 MMtC emissions from input use less 12 MMtC from sequestration into the soil. Net agriculture carbon emission dropped in the Cellulosic Replacement scenario to 23 MMtC in 2014. The

Cellulosic Replacement scenario has slightly less emission from input use, but a significantly higher rate of carbon sequestration occurring due to the planting of perennial grasses for biofuel feedstock.[62]

Figure 27: 2014 Carbon Emissions from Agricultural Production and Input Use – Cellulosic Replacement Scenario



4.2.4.Soil Erosion, Fertilizer Consumption, and Chemical Consumption

Soil Erosion Results

In the BAU Scenario, erosion increased from 807 million tons to 837 million tons between 2008 and 2014. As corn acreage increased, erosion increased in the model simulation. Soil erosion decreases in the Cellulosic Replacement scenario relative to the BAU (Table 10).

Table 10: U.S. Annual Soil Erosion in the Cellulosic Replacement Scenario (million tons)

Scenario	2008	2014	Absolute Change	% Change
BAU	807	837	30	3.7%
No RFS/BTC	807	760	-47	-5.8%
Cellulosic Replacement	807	695	-112	-13.8%

From 2008 to 2014, U.S. annual soil erosion decreases in the Cellulosic Replacement scenario from 807 million tons to 695 million tons, or almost 14 percent. This is due to corn crops being switched over to perennial crops for bioenergy production that are less erosion-prone.

[62] Perennial grasses pulse carbon into the soil by growing and shedding roots every year. The carbon remains in the soil because the ground does not need to by tilled and planted yearly.

From 2008 to 2014, we calculated the cumulative erosion in the No RFS/BTC scenario to be 5.2 billion tons. This is a reduction in cumulative erosion of 0.53 billion tons from the BAU, or 9.2 percent. Furthermore, the decrease in erosion occurs in the heart of the Corn Belt region (Figure 27). Spatially, as corn stover[63] and dedicated energy crops are used for energy feedstocks, the decrease in erosion occurs over more areas (Figure 28).

Under the No RFS/BTC Scenario, erosion decreased to 760 million tons in 2014 and in the Cellulosic Ethanol Scenario, erosion decreased to 695 million tons in 2014. Over the ten year period, the erosion in the historical baseline is estimated to be 8,088 million tons. When ethanol production is reduced, erosion decreases over the 10 years by 233 million tons or 2.9 percent, when the ethanol is replaced by cellulosic ethanol, an additional decrease occurs. Erosion, over the ten years, will decrease by 524.8 million tons or a 6.5 percent decrease. The change in erosion occurs in the latter years of the analysis. A steady decrease in erosion occurs 2009 to 2014 in both scenarios when compared to the base. By 2014, there is a 9 percent and nearly 17 percent decline in the no RFS/BTC and Cellulosic Replacement scenarios, respectively.

Figure 29: A Spatial Estimation of Changes in Sheet and Rill Erosion Comparing the BAU with the No RFS/BTC Scenario, 2014, tons

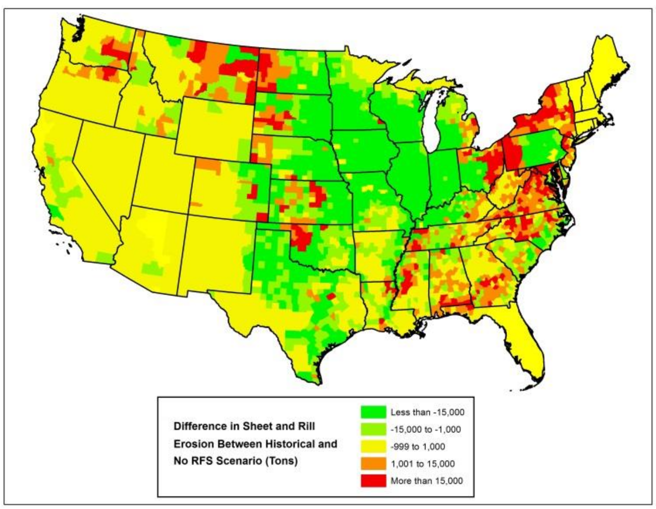
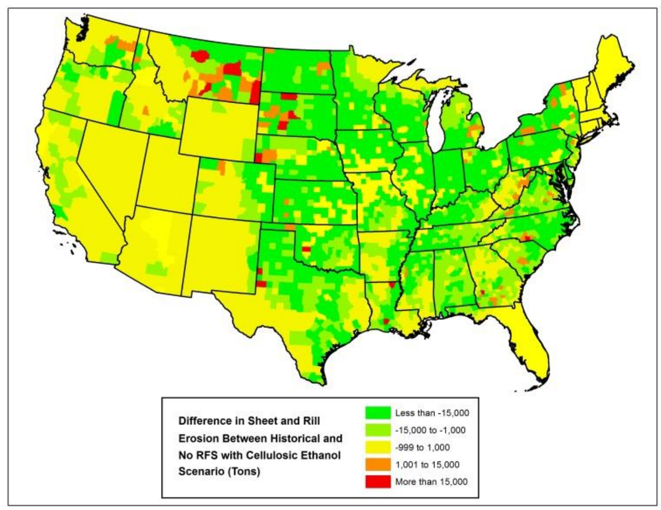


Figure 28: A Spatial Estimation of Changes in Sheet and Rill Erosion Comparing the BAU Scenario with the Cellulosic Replacement Scenario, 2014, tons

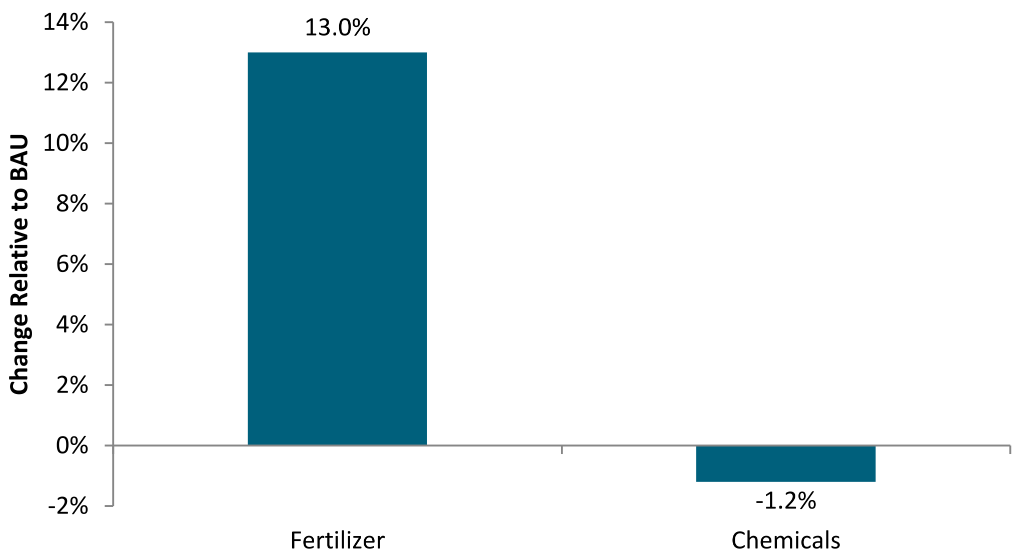


[63] It is assumed that Best Management Practices are employed when removing residues from the fields; thereby leaving sufficient residues so that erosion does not increase.

Fertilizer and Chemical Consumption

The Cellulosic Replacement scenario portrays a slightly different story from the No RFS/BTC Scenario. While chemical consumption decreases relative to the BAU in the scenario, fertilizer consumption increases relative to the BAU.

Figure 30: Average Annual Change in U.S. Agricultural Fertilizer and Chemical Consumption for the Cellulosic Replacement Scenario Relative to the BAU, 2008-2014



The scenario's higher fertilizer consumption reflects the requirement to replace the nutrients removed when crop residues are removed and used as energy feedstocks along with the increase fertilization requirements on existing hay and pasture lands to maintain roughage for livestock as lands shift from hay/pasture to growing dedicated energy crops (Figure 31 and Figure 32).

Figure 31: Change in Fertilizer Consumption by Scenario

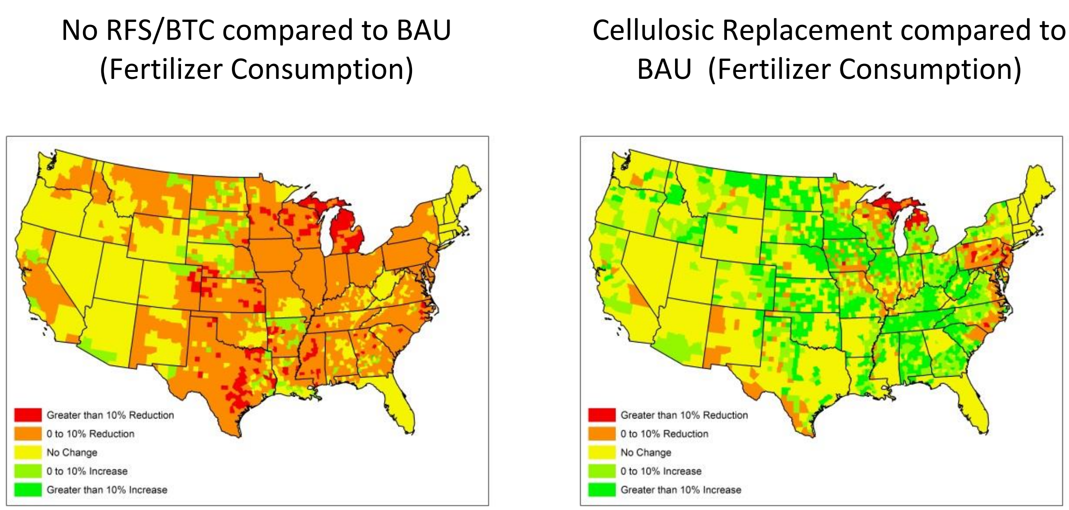
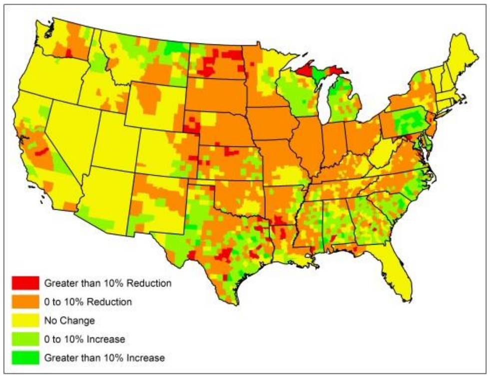
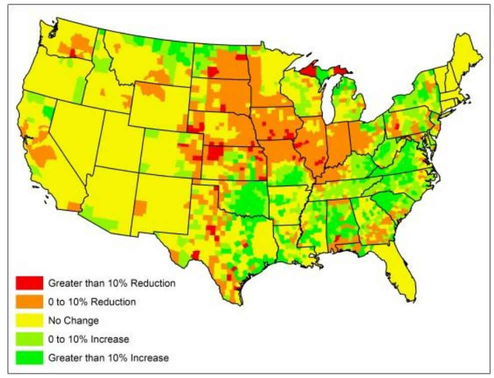


Figure 32: Change in Chemical Consumption by Scenario

No RFS/BTC compared to BAU (Chemical Consumption)



Cellulosic Replacement compared to BAU (Chemical Consumption)



5. Re-energizing Advanced Biofuels

In this section, we examine why corn ethanol has flourished but advanced biofuels have not during the past 10 years of the RFS. We then propose the main tenant of a restructured RFS or RFS3 that gets advanced biofuels back on track to meeting the original intentions of the RFS, which include to following:

- Improve air quality by introducing additional oxygenates to the country's fuel supply;
- Lower greenhouse gas ("GHG") emissions;
- Increase rural economic viability; and
- Reduce U.S. dependence on foreign oil

5.1. Background on the RFS2

The EISA created the RFS2, which changed the structure of the RFS in four meaningful ways:[64]

1. RFS2 increased the mandated usage volumes and extended the time frame over which the volumes ramp up through at least 2022.
2. RFS2 subdivides the total renewable fuel requirement into four separate but nested categories—total renewable fuels, advanced biofuels, biomass-based diesel, and cellulosic biofuels—each with its own volume requirement or standard.
3. Biofuels qualifying under each nested RFS2 category must achieve certain minimum thresholds of lifecycle GHG emission performance.
4. Under RFS2 all renewable fuels must be made from feedstocks that meet a revised definition of renewable biomass, including certain land use restrictions.

As stated earlier, advanced biofuels include any biofuel that meets a GHG emissions reduction target of 50 percent or greater. Thus, biomass-based biodiesel and cellulosic biofuels (for the most part) fall under the definition of advanced biofuels and are part of the "nesting" structure of the RFS2.

Table 11 shows the statutory, final, and proposed targets for each biofuel category in the RFS. Advanced biofuels in the table includes cellulosic biofuels, biomass-based diesel, and other advanced biofuels.

[64] CRS 2013.

Table 11: Statutory, Final, and Proposed RFS Targets (billions of gallons)[65]

Year	Renewable Fuel		Corn Ethanol		Cellulosic Biofuels		Biomass-based Diesel		Other Advanced Biofuels	
	S	F/P	S	F/P	S	F/P	S	F/P	S	F/P**
2006	4.00		4.00						0.00	
2007	4.70		4.70						0.00	
2008	9.00		9.00						0.00	
2009	11.10		10.50				0.50		0.10	
2010	12.95	12.95	12.00	12.00	0.10	0.0065	0.65	1.15	0.20	N/A
2011	13.95	13.95	12.60	12.60	0.25	0.0060	0.80	0.80	0.30	0.54
2012	15.20	15.20	13.20	13.20	0.50	0.0105	1.00	1.00	0.50	0.99
2013	16.55	16.55	13.80	13.80	1.00	0.0008	≥1	1.28		1.47
2014*	18.15	15.93	14.40	13.25	1.75	0.0330	≥1	1.63		1.02
2015*	20.50	16.30	15.00	13.40	3.00	0.1060	≥1	1.70		1.09
2016*	22.25	17.40	15.00	14.00	4.25	0.2060	≥1	1.80		1.39
2017*	24.00	TBD	15.00	TBD	5.50	TBD	≥1	1.90		TBD
2018	26.00		15.00		7.00					
2019	28.00		15.00		8.50					
2020	30.00		15.00		10.50					
2021	33.00		15.00		13.50					
2022	36.00		15.00		16.00					

S = Statutory
F/P = Final/Proposed
TBD = To be determined
* 2014-2017 are years with proposed targets; years prior to this range have final targets.
** Implied volume of Other Advanced Biofuels is calculated by subtracting Corn Ethanol, Cellulosic Biofuels, and Biomass-based Diesel from Renewable Fuels

[65] Congressional Research Service 2015.

In order to support the biofuels industry in meeting its targets, the RFS2 establishes Renewable Volume Obligations (RVO) for different biofuel categories. The RVO forces obligated parties – refiners, importers, and blenders – to purchase mandated biofuel volumes or instead purchase credits.

These credits are called Renewable Identification Numbers or RINs. The price of a RIN is determined by the marketplace and fluctuates. If the market views that obligated parties will have a difficult time procuring biofuels to meet their targets, then RIN prices will increase. This, in turn, will incentivize suppliers to produce more biofuels to meet demand. The opposite is true if the marketplace views obligated parties as having an easier time meeting their RVOs.

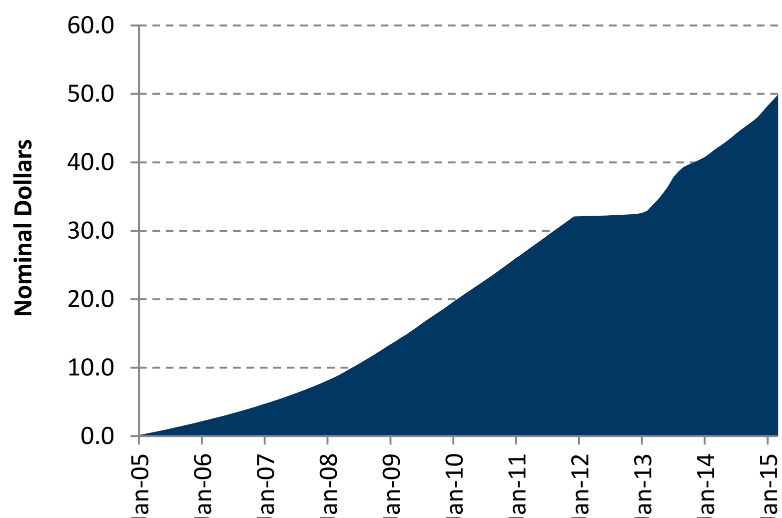
A producer receives a RIN credit (or some multiple depending on the biofuel type) for each gallon of biofuel produced. The producer can then sell the RINs into the marketplace to obligated parties looking to meet their RVOS. RINs essentially are a compliance fee imposed on obligated parties.

5.2. Advanced Biofuels Have Been Slow to Emerge

The RIN market was designed to incentivize production when production shortages occur. This form of mechanism has worked well for mature technologies such as corn ethanol because construction costs and timelines have a high degree of certainty and facilities can come on-line quickly to arbitrage sustained, higher RIN values.

Before 2013 when the BTC ended (in 2012) and banked RINs were depleted, RIN prices for corn ethanol averaged around five cents per gallon. From January 2013 to June 2015, RIN prices have average 56.5 cents per gallon, which is slightly above the value of the expired BTC. [66]

Figure 33: Cumulative Corn Ethanol Subsidies Paid, 2005–2014



Between the BTC and RIN values, the corn ethanol industry has received almost $50 billion in cumulative subsidies from January 2005 to June 2015 (Figure 33). During this time, corn ethanol production has grown from just over 3.8 billion gallons to 14.8 billion gallons on an annualized basis.

It is clear that RINs, however, have not been a helpful incentivizing mechanism for advanced biofuels. This can be seen from Table 11 starting in 2010 when the first cellulosic target was adjusted downward to 6.5 million from 100 million gallons per year. In subsequent years, the EPA continued to adjust cellulosic

[66] Average RIN prices are based on authors' review of corn ethanol RIN prices from OPIS.

biofuel targets downward. The proposed 2016 target is 206 million gallons or only 4.8 percent of the originally statutory target of 4.25 billion gallons.

The question then is the following – why has the RFS worked for corn ethanol but not for advanced biofuels? The first answer is that the RFS rewards production, not investment, as it is a production-based incentive targeting specific volumes. Rewarding production is good for mature technologies that have a relatively low capital cost, but need a subsidy mechanism for making production economic.

The second answer is that RIN have been highly volatile. For example, the annualized price volatility of a corn ethanol RIN has average 128 percent from 2008 to 2014 (Table 12).

Table 12: Annualized Corn Ethanol RIN Volatility[67]

Year	Corn Ethanol RIN Annualized Volatility
2008	94.0%
2009	76.9%
2010	142.3%
2011	155.0%
2012	193.6%
2013	181.0%
2014	54.2%

As a point of comparison, Henry Hub natural gas prices and crude oil have averaged about one-third and one-fifth of corn RIN price volatility, respectively, from 2008 to 2014.

Price volatility or uncertainty is not an enticing characteristic for advanced biofuel technology and plant investors. Faced with a number of uncertainties in cost and performance already, advanced biofuel investors view RINs as simply another layer of volatility with which to contend.

5.3. Proposal to Restructure the RFS

Based on our review of the past 10 years under the RFS, we believe it is time to restructure the RFS such that it delivers on the original intentions of the RFS1 and RFS2. To do so, promoting advanced biofuels will be critical.

One of the major challenges that advanced biofuels faces is its capital intensity. For example, a cellulosic ethanol plant has a capital intensity of $5-6 per gallon of capacity, whereas a corn ethanol refinery has a capital intensity that is approximately one-third of that value.

[67] Monthly corn ethanol RIN data from OPIS was analyzed to develop the annualized values.

For advanced biofuels to enter the market, an investment-based mechanism is necessary to overcome their capital intensity and technology risk. These mechanisms have worked well in the electricity market as they have helped renewable technologies, such as wind and solar, quickly penetrate the market. In fact, Energy Secretary Ernest Moniz stated in late August that "I certainly see solar growing [even] without a subsidy."[68]

An investment-based mechanism has two distinct advantages over the RIN-based market design. The first is certainty as the amount will be clear to an investor. The second is declining costs per unit of capacity over time. As the technology matures, capital costs will decline, and so will the value of the investment mechanism per unit of capacity.

Another benefit of an investment-based mechanism is that it can supportive of the existing corn ethanol industry. Existing plants can be retrofitted to include cellulosic materials as a feedstock. The benefits are clear as these plants can leverage their existing design and infrastructure to provide lower capital costs relative to a greenfield cellulosic refinery.

We have had 10 years under the RFS, and a commercially viable, next generation biofuels technology has not emerged. It is time to rethink the design of the RFS2 and develop a new set of policies that places the U.S. on track to achieve significant advanced biofuels market penetration in the next 10 years that are aimed at achieving meaningful environmental benefits.

[68] Siciliano, J. "Energy chief says solar doesn't need subsidies to grow", *Washington Examiner*, August 24, 2015, available from http://www.washingtonexaminer.com/energy-chief-says-solar-doesnt-need-subsidies-to-grow/article/2570740

APPENDIX A: Corn Ethanol Bankruptcies

Table 13: Ethanol Refinery Bankruptcies – Operational and Under Construction Plants

Plant (City, State)	Year	Bankruptcy Type	Capacity (MM Gallons per Year)
Canton, IL	2007	Chapter 11	37
Mead, NE	2007	Chapter 11	25
Basehor, KS	2008	Chapter 7	0
Hereford, TX	2008	Chapter 11	105
Heyburn, ID	2008	Chapter 11	20
Lima, OH	2008	Chapter 11	54
Pratt, KS	2008	Chapter 11	50
Steamboat Rock, IA	2008	Chapter 11	30
Verasun and 24 Subsidiaries at Various Locations	2008	Chapter 11	1400
Aurora East, NE	2009	Chapter 11	45
Aurora West, NE	2009	Chapter 11	110
Boardman, OR	2009	Chapter 11	40
Burley, ID	2009	Chapter 11	60
Cambridge, NE	2009	Chapter 11	44
Carleton, NE	2009	Chapter 11	110
Fairbanks, IA	2009	Chapter 11	115
Fulton, NY	2009	Chapter 11	100
Hereford, TX	2009	Chapter 11	100
Iowa Falls, IA	2009	Chapter 11	110
Jefferson, WI	2009	Chapter 11	110
Madera, CA	2009	Chapter 11	40
Mt. Vernon, IN	2009	Chapter 11	110
Pekin, IL	2009	Chapter 11	90
Plainview, TX	2009	Chapter 11	110
Port Westward, OR	2009	Chapter 7	108
Stockton, DA	2009	Chapter 11	60
Levelland, TX	2010	Chapter 11	40
Albany, GA	2011	Chapter 11	100
Clearfield, PA	2011	Chapter 7	110
Raeford, NC	2011	Chapter 11	60
South Bend, IN	2012	Chapter 11	100
Buffalo Lake, MN	2013	Chapter 11	20
New Stanton, PA	2014	Chapter 11	200
Total			**3,813**

REFERENCES

California Air Resources Board (CARB). 2010. Final Regulation Order. Subchapter 10. Climate Change, Article 4. Regulations to Achieve Greenhouse Gas Emission Reductions; Subarticle 7. Low Carbon Fuel Standard

California Energy Commission (CEC). 2007. Full Fuel Cycle Assessment: Well-to-Wheels Energy Inputs, Emissions, and Water Impacts; State Plan to Increase the Use of Non-Petroleum Transportation Fuels, AB 1007 (Pavley) Alternative Transportation Fuels Plan Processing. California Energy Commission. June 2007

Clean Air Act (CAA)

Clean Air Task Force (CATF). 2013. Corn Ethanol GHG Emissions Under Various RFS Implementation Scenarios, April 2013

Congressional Research Service (CRS). 2010. Bracmort, K. and Yacobucci, B. "Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard (RFS). March 12, 2010.

Congressional Research Service (CRS). 2013. Schenpf, R. and Yacobucci, B. 2013. "Renewable Fuel Standard (RFS): Overview and Issues," March 14, 2013.

Congressional Research Service (CRS) 2015. Bracmort, K. "The Renewable Fuel Standard (RFS): In Brief,", June 29, 2015

de Gouw, J.A., et. al. 2015. Airborne Measurements of the Atmospheric Emissions from a Fuel Ethanol Refinery, J. Geophys. Res. Atmos., 120, 4385-4397, doi:10.1002/2015JD023138

U.S. Environmental Protection Agency (EPA). Ground Level Ozone, available from http://www3.epa.gov/ozonepollution/

U.S. Environmental Protection Agency (EPA). Particulate Matter (PM), available from http://www3.epa.gov/pm/

U.S. Environmental Protection Agency (EPA). Sulfur Dioxide, available from http://www.epa.gov/airquality/sulfurdioxide/

U.S. Environmental Protection Agency (EPA). 1995. AIRTrends 1995 Summary, Particulate Matter (PM-10), available from http://www.epa.gov/airtrends/aqtrnd95/pm10.html

U.S. Environmental Protection Agency (EPA). 2010. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis, February 2010

U.S. Environmental Protection Agency (EPA). 2015. MTBE (methyl-t-butyl ether) in Drinking Water, Environmental Protection Agency Office of Water, September 2015, available from http://water.epa.gov/drink/contaminants/unregulated/mtbe.cfm

Fargione, J, et al. 2008. Land Clearing and the Biofuel Carbon Debt. Science. Vol. 319. February 29, 2008

Federal Register. 2010. Vol. 75, No. 5, Rules and Regulations, pg. 14675, Friday, March 26, 2010

Gustafson, C. 2015. History of Ethanol Production and Policy, North Dakota State University. September 2015, available from https://www.ag.ndsu.edu/energy/biofuels/energy-briefs/history-of-ethanol-production-and-policy.

Hill, J, et al. 2009. Climate change and health costs of air emissions from biofuels and gasoline. Proceedings of the National Academy of Sciences of the United States of America

Hochman, G. et al. 2012. Biofuel and Food-Commodity Prices. Agriculture 2012, 2, 272-281. September 2012

Humbird, et al. 2011. "Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover," National Renewable Energy Laboratory, Technical Report NREL/TP-5100-47764, May 2011.

Huo, H. et al. 2008. Total versus urban: Well-to wheels assessment of criteria pollutant emissions from various vehicle/fuel systems. Center for Transportation Research, Argonne National Laboratory. December 2008

Iowa State University. 2015, Iowa State economic model accessed in July 2015: https://www.extension.iastate.edu/agdm/energy/xls/d1-10ethanolprofitability.xlsx

Knoll et al. 2009. "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated," National Renewable Energy Laboratory (NREL), February 2009.

Korosec, K. 2009. Does EPA Biofuels Proposal Really Threaten Corn-based Ethanol?, CBS MoneyWatch, May 6, 2009, available from http://www.cbsnews.com/news/does-epa-biofuels-proposal-really-threaten-corn-based-ethanol/

Life Cycle Associates (LCA). 2014. Carbon Intensity of Marginal Petroleum and Corn Ethanol Fuels. January 2014

Liska, A.J., et al. 2009.Improvements in life cycle energy efficiency and greenhouse gas emissions of corn-ethanol. Journal of Industrial Ecology

MacLean, H. and Spatari, S. 2009. The contribution of enzymes and process chemicals to the life cycle of ethanol. Environ. Res. Lett. 4 (2009) 014001.

National Academy of Sciences (NAS). 2011. Renewable Fuel Standard: Potential Economic Environmental Effects of U.S. Biofuel Policy.

New York State Department of Health, Fine Particles (PM 2.5) Questions and Answers, available from https://www.health.ny.gov/environmental/indoors/air/pmq_a.htm

Searchinger, T. et al. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science Vol. 319 (5867). February 29, 2008.

Siciliano, J. 2015. "Energy chief says solar doesn't need subsidies to grow", *Washington Examiner*, August 24, 2015, available from http://www.washingtonexaminer.com/energy-chief-says-solar-doesnt-need-subsidies-to-grow/article/2570740

Tyner, W. et al. 2010. Land Use Changes and Consequent CO_2 Emmissions due to US Corn Ethanol Production: A Comprehensive Analysis. July 2010

Union of Concerned Scientists (UCS). 2011. "Corn Ethanol's Threat to Water Resources", October 2011 available from http://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/ew3/corn-ethanol-and-water-quality.pdf

United States Department of Agriculture (USDA). 2007. "Soil and Water Issues Related to Corn Grain Ethanol Production in Wisconsin", USDA Natural Resources Conservation Service, April 2007

Wang, M. et al. 2007, Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types, Environ. Res. Lett. 2 (2007)

Wang, M. et al. 2011. Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes. Biomass and Bioenergy, Vol. 35, Issue 5, May 2011, Pages 1885-1896.

Wang, M. et al. 2012. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environ. Res. Lett. 7 (2012).

Whitaker, J, et al. 2010. Sources of variability in greenhouse gas and energy balances for biofuel production: a systematic review. GCB Bioenergy, Volume 2, Issue 3, June 2010.

White House Office of the Press Secretary. 2009. "President Obama Talks with Regional Reporters at the White House," *The Washington Post*, March 2009.

White House Archives. 2007. President George W. Bush, President Bush Signs H.R. 6, the Energy Independence and Security Act of 2007, December 2007, available from http://georgewbush-whitehouse.archives.gov/news/releases/2007/12/20071219-6.html

Zilberman, D. et al. 2012. The Impact of Biofuels on Commodity Food Prices: Assessment of Findings, available from http://ajae.oxfordjournals.org/