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10-YEAR REVIEW OF RENEWABLE FUEL STANDARD IMPACTS TO THE ENVIRONMENT, THE ECONOMY, AND ADVANCED BIOFUELS DEVELOPMENT: AN UPDATE

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Executive Summary[1]

In December 2015, the Environmental Protection Agency (EPA) published its Renewable Fuel Standard (RFS) rule, setting renewable fuel volume requirements retroactively for the years 2014 and 2015, and in a forward-looking context for 2016.

On May 18, 2016, the EPA published its proposed mandate volumes for 2017, increasing by 300 million gallons the volume of largely corn-based ethanol that will need to be blended into the nation's fuel supply relative to 2016. Although EPA increased these requirements in 2016 and is seeking to do so again in 2017, the agency in both cases chose to keep these levels below those called for by Congress, thus acknowledging that the volumes envisioned by Congress nearly a decade ago no longer align with the realities of the present marketplace.

While the RFS has functioned as a farm support mechanism heretofore, it seems reasonable to consider, with more than a decade's worth of data and experience available on which to draw, whether the policy has helped produce the kinds of economic and environmental outcomes that it was designed to support.

Given the serious environmental and economic impacts of the RFS, highlighted in my research findings as well as many others, I continue to believe now is the time to create more modernized and efficient policy aimed at promoting advanced biofuels. With a policy objective that is focused on lowering GHG emissions, advanced biofuels can play an important role in meeting this objective.[2] Yet, it is clear that the focus of the RFS thus far – for more than a decade – has been on corn ethanol.

In this report, I set out to examine how the United States is affected environmentally and economically from the EPA's final RFS volumes for 2014–2016.[3] In summary, my findings are:

1) Corn ethanol demand would have been 4.56 billion gallons in 2016 (or 30 percent of projected production) under a scenario in which we did not have a federal RFS policy in place (referred to throughout this paper as "No RFS/BTC scenario"). Cellulosic ethanol demand would have been 10.43 billion gallons in 2016 (or 70 percent of projected ethanol production) under a scenario in which resources and mandates that have otherwise been used to support corn ethanol development had been redirected instead to cellulosic ethanol (referred to as "Cellulosic Replacement scenario").
2) The total number of acres planted to support corn development would have been reduced significantly, between 10-15 percent, under the two alternative scenarios when compared to the business-as-usual scenario ("BAU scenario") we have in place today. This results in a 33-41 percent reduction in corn prices as the demand reduction far outstrips the supply reduction. The reduced corn plantings are replaced mostly with wheat and soybeans, which increases supply and generates a 12-13 percent decrease in wheat prices and a 9-12 percent drop in soybean prices;
3) Corn, soybeans, and wheat price reductions would have translated to approximately $12.9 billion and $10.0 billion of annual consumer wholesale expenditure savings, but a loss of $18.2 billion and $12.1 billion in net realized farm income in the No RFS/BTC and Cellulosic Replacement scenarios, respectively;
4) The overall, net economic benefit of the No RFS/BTC and Cellulosic Replacement scenarios in 2016 would have been $29.2 billion and $42.4 billion, respectively;
5) In 2016, carbon emissions from agricultural production and input use would have been 3.4 million metric tons lower in the No RFS/BTC scenario as compared with the BAU – equivalent to taking 716,000 cars off the road for a year. Under the Cellulosic Replacement scenario, carbon emissions from agricultural production and input use would have been 6.2 million metric tons lower –equivalent to taking 1.3 million cars off the road;
6) If the 2017 proposed corn ethanol volumes were to become final, statutory corn ethanol volumes would increase by approximately two percent over 2016 volumes. As such, I would expect to see emissions reduced by a

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[2] Advanced biofuels include any biofuel that meets a GHG reduction target of 50 percent or greater. Biomass-based diesel and cellulosic biofuels (for the most part) fall under the definition of advanced biofuels.

[3] While the new proposed volumes for 2017 have recently been released, these requirements are not expected to be finalized until November 30, 2016. As such, my analysis only covers the final volume requirements through 2016.

proportional amount in the scenarios that exclude the business-as-usual case – that is, 730,000 and 1.33 million cars off the road annually in the No RFS/BTC and Cellulosic Replacement scenarios, respectively;

7) The amount of soil erosion that takes place under both non-BAU scenarios decreases significantly relative to BAU. Annual soil erosion between 2008 and 2016 would have decreased in the No RFS/BTC and the Cellulosic Replacement by 94 and 204 million metric tons of soil, respectively; and

8) Fertilizer and chemical consumption decreases relative to the BAU in the No RFS/BTC scenario by 4.4 percent and 2.8 percent, respectively. The Cellulosic Replacement scenario shows a 12 percent increase in fertilizer and a 1.4 percent decrease in chemical consumption compared with the BAU.

1. Introduction

The Renewable Fuel Standard (RFS) has entered its 10th year now of existence. The first version of the RFS, or RFS1, was enacted just over a decade ago in 2005. RFS1 and its successor, RFS2, enacted in 2007 under the Energy Independence and Security Act, were intended 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 October 2015, I published a report reviewing the past 10 years of the RFS, analyzing the program's impacts to the environment, the economy, and the development of advanced biofuels.[4]

Using the Policy Analysis System (POLYSYS) agricultural policy simulation model, the report examined the impacts of the actual history of the RFS compared with a scenario without the RFS or Blender's Tax Credit (BTC) – "No RFS/BTC" – and a scenario with the RFS but where advanced biofuels replace a majority of corn ethanol production – "Cellulosic Replacement."

Ultimately, the data's findings demonstrated that the RFS had failed to meet most of its objectives, particularly on its intended environmental benefits. The findings of my analysis included the following:

1) Corn ethanol demand would have been 4.34 billion gallons in 2014 (or 30 percent of actual production) in the No RFS/BTC scenario. Cellulosic ethanol demand would have been 10.0 billion gallons in 2014 (or 70 percent of actual ethanol production) in the Cellulosic Replacement scenario;
2) Both scenarios show that corn acres planted would have been reduced significantly relative to the BAU, resulting in a 34-40 percent reduction in corn prices, along with an 11-13 percent decrease in wheat and soybean prices;
3) Crop price reductions would have translated to approximately $31.6 billion and $29.6 billion of annual consumer wholesale expenditure savings but a loss of $19.7 billion and $13.0 billion in net realized farm income in the No RFS/BTC and Cellulosic Replacement scenarios, respectively;
4) The overall net economic benefits of the No RFS/BTC and Cellulosic Replacement scenarios in 2014 would have been $28.4 billion and $42.1 billion, respectively;
5) In 2014, carbon emissions from agricultural production and input use would have been 2.7 million metric tons lower in the No RFS/BTC scenario and 4.6 million metric tons lower in the Cellulosic Replacement scenario as compared with the BAU;
6) Soil erosion under both scenarios improves greatly compared with the BAU. Annual soil erosion increased in the BAU by 3.7 percent between 2008 and 2014, whereas the No RFS/BTC and the Cellulosic Replacement scenarios see a 5.8 percent and 13.8 percent decrease, respectively; and
7) Fertilizer and chemical consumption decreases relative to the BAU in the No RFS/BTC scenario by 4.1 percent and 2.5 percent, respectively. The Cellulosic Replacement scenario shows a 13 percent increase in fertilizer and a 2.5 percent decrease in chemical consumption compared with the BAU.

This study provides an update to my prior analysis. Specifically, I update renewable fuel volumes produced with real-world data through 2015 and apply a projection for renewable fuel volumes for 2016. I then run these figures through the POLYSYS model to understand the environmental impacts and also apply an economic model to understand the economic impacts of the RFS under both No RFS/BTC and Cellulosic Replacement scenarios.

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[4] De La Torre Ugarte, D. and English, B., "10-Year Review of the Renewable Fuels Standard: Impacts to the Environment, the Economy, and Advanced Biofuel Development", University of Tennessee Institute of Agriculture, October 14, 2015.

2. Regulatory Changes and Challenges to the RFS

In December 2015, the EPA published its final RFS rule, setting the volume standards for 2014, 2015, and 2016 and the biomass-based diesel volume for 2017.[5] Additionally, on May 18, 2016, the EPA announced its proposed volumes for 2017.[6] The figure below shows the finalized volumes for 2014-2016 and the proposed volumes for 2017.

Table 1: RFS Volume Requirements, 2014-2017[7] (billion gallons)

Fuel Type	2014	2015	2016	2017
Cellulosic Biofuel	0.033	0.123	0.230	0.312
Biomass-based Diesel	1.63	1.73	1.90	2.00
Other Advanced Biofuel	1.01	1.03	1.48	1.69
Corn Ethanol	13.61	14.05	14.50	14.8
Total Renewable Fuel	16.28	16.93	18.11	18.8

Source: EIA. Other Advanced Biofuel equals total Advanced Biofuels less Cellulosic Biofuel and Biomass-based Diesel. Corn Ethanol equals Total Renewable Fuel less total Advanced Biofuels.

Prior to the EPA's final ruling on volumes for 2014-2016, the agency's Office of Inspector General (OIG) announced plans to begin preliminary research on the lifecycle impacts of the EPA's renewable fuel standard.[8]

The OIG's stated objectives are to:

> "*determine whether the EPA: 1) complied with the reporting requirements of laws authorizing the Renewable Fuel Standard (RFS); and 2) updated the lifecycle analysis supporting the RFS with findings from the statutorily mandated National Academy of Sciences 2011 study on biofuels, the EPA's 2011 Report to Congress on the Environmental Impacts of Biofuels, as well as any subsequent reports or relevant research on lifecycle impacts of biofuels*."[9]

In addition to the OIG's ongoing investigation, a number of RFS-related lawsuits in the last several months have also been filed in the U.S. Court of Appeals for the D.C. Circuit against the EPA. In February 2016, the American Petroleum Institute (API) filed suit against the EPA for its "failure to meet the deadlines for the 2014 and 2017 biomass-based diesel standards and for mandating more cellulosic ethanol in 2016 than exists."[10]

Similarly, the American Fuel & Petrochemical Manufacturers (AFPM) filed a petition for review regarding "certain aspects of the final RFS rule…[in which the] EPA failed to provide obligated parties with requisite lead time and used flawed methodologies in establishing volume requirements."[11]

It's worth noting that opponents of the RFS are not the only groups filing suit against the EPA. In January 2016, eight trade groups, including the Renewable Fuels Association and the National Corn Growers Association, sued the EPA claiming "it had failed to consider the entire scope of the regulatory scheme when it set ethanol levels below those prescribed in 2007."[12] Other organizations on both sides also have followed similar actions, filing separate suits against the EPA.[13]

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[5] Federal Register, 40 CFR Part 80, No. 239, December 14, 2015.

[6] EPA, *Notice of Proposed Rulemaking*, May 18, 2016. Available at: https://www.epa.gov/sites/production/files/2016-05/documents/rfs-2017-standards-nprm-2016-05-18_0.pdf

[7] Volume requirements for 2014-2016 were finalized in the EPA's December 2015 ruling, while the volumes for 2017 are proposed as of May 2016.

[8] Office of Inspector General, *Memorandum: Lifecycle Impacts of Renewable Fuel Standard*, October 15, 2015.

[9] *Ibid.*

[10] *Oil group API sues U.S. EPA over biofuels policy*. (2016). *Reuters*. Retrieved 14 April 2016, from http://www.reuters.com/article/us-usa-biofuels-lawsuit-idUSKCN0VK2IO

[11] Press Release. *AFPM Files Lawsuit Challenging the Renewable Fuel Standard,* February 10, 2016, from https://www.afpm.org/news-release.aspx?id=5223

[12] *Valero asks EPA to redefine RFS definition of obligated party.* (2016). *Ethanolproducer.com*. Retrieved 14 April 2016, from http://www.ethanolproducer.com/articles/13073/valero-asks-epa-to-redefine-rfs-definition-of-obligated-party. See also, Osborne, J. (2016). *Valero sues EPA over ethanol standard*. *Fuel Fix*. Retrieved 14 April 2016, from http://fuelfix.com/blog/2016/02/12/valero-sues-epa-over-ethanol-standard/

[13] *Ibid.*

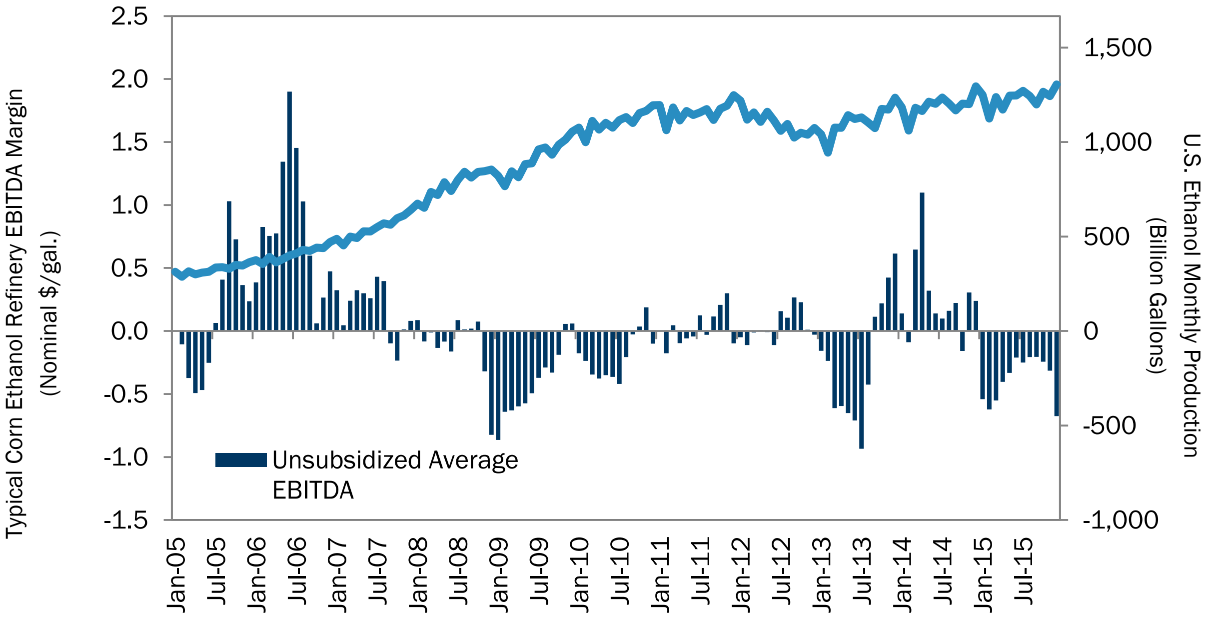
3. Data Updates for 2015 and 2016

There have been several data-related updates since my last report in October 2015. These include a revision to EIA's ethanol production and consumption data from 2014, actual data for 2015, and final volume requirements for 2016. In this section, I provide an update to my original analysis.

Corn Ethanol's Economic Performance

In my prior study, I examined the corn ethanol industry's financial performance from 2005 through 2014. I found that corn ethanol profit margins exclusive of subsidies or "non-subsidized monthly EBITDA[14] margin" had been negative since 2008. The figure below provides an update to this analysis with actual 2015 data of a typical corn ethanol refinery. Although production increased in 2015, the average non-subsidized EBITDA margin averaged negative $0.38 per gallon.

Figure 1: Typical Corn Ethanol Monthly Non-Subsidized EBITDA Margin vs. U.S. Monthly Production, 2005-2015



During the second half of 2015, the average non-subsidized EBITDA margin continued to be negative and reflective of the variability in margin since 2008. In 2015, Abengoa, a provider of solutions for sustainability in the energy and environment sectors (such as creating biofuels) filed for Chapter 11 bankruptcy.[15] Overall, the ethanol industry has voiced its concerns about low ethanol prices and their impact on smaller producers.[16]

Corn Ethanol's Impact on Advanced Biofuel Proliferation

The RFS has been marketed as a "bridge" to the development, manufacture and marketing of advanced biofuels. Advanced biofuels, as defined by the RFS, achieve lifecycle greenhouse gas emissions reductions of 50 percent or more relative to comparable fossil fuels. Advanced biofuels typically rely on feedstocks such as corn stover, dedicated energy crops, and forest residues.

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

[15] See for example, *Abengoa files for Chapter 11 bankruptcy in US.* (2016). *Ethanolproducer.com*. Retrieved 14 April 2016, from http://www.ethanolproducer.com/articles/13082/abengoa-files-for-chapter-11-bankruptcy-in-us

[16] *Small ethanol plants struggle for an edge.* (2016). *Star Tribune.* Retrieved 14 April 2016, from http://www.startribune.com/small-ethanol-plants-struggle-for-an-edge/294436781/

As we know, advanced biofuels continue to represent a negligible amount of the total biofuels market. In fact, advanced biofuel production in 2015 accounted for only 135 million gallons, or less than one percent of total biofuel production.[17]

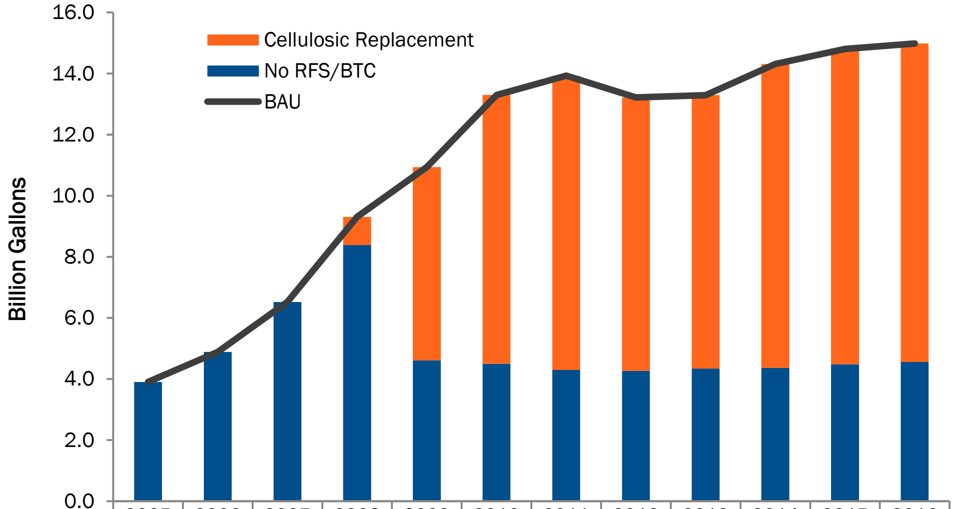
One goal of the RFS2 was to help ease the entry of advanced biofuels by subsidizing them through Renewable Identification Number (RIN) credits. The RIN credit market, however, has benefited mature technologies, like corn ethanol, more so than emerging ones because it provides credits on the basis of production. Advanced biofuels, on the other hand, require credits towards investment, as the initial capital cost is often their most difficult hurdle to surmount.

The RIN credit market that has developed out of the RFS has propelled the production of corn ethanol far beyond where the market would have otherwise taken it. I find that the United States would have mandated the use of only 4.49 billion gallons of corn ethanol for oxygenate reasons[18] compared to the almost 15 billion gallons of actual production in 2015 (as shown in the figure below).

As with my prior analysis, two scenarios relative to the BAU are examined where advanced biofuels replace varying portions of corn production since 2005:

- **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[19]) and, at a minimum, ethanol was required to meet actual consumer demand for oxygenates. In this scenario, corn ethanol demand is 4.49 billion gallons in 2015 and 4.56 billion gallons projected for 2016 or only 30 percent of actual/projected corn ethanol production in both years.
- **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 10.32 billion gallons in 2015 and 10.43 billion gallons projected in 2016 or 70 percent of actual/projected corn ethanol production in 2015 and 2016, respectively. We recognize that this scenario would likely not have been possible given current technology status, technology costs, and RFS policy design at the time. However, it's an important scenario to consider insofar as it helps us better understand and quantify lost opportunities.

Figure 2: Corn and Cellulosic Ethanol Production under Scenarios Evaluated[20]



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cellulosic Replacement	0.00	0.00	0.00	0.92	6.33	8.80	9.64	8.95	8.95	9.95	10.32	10.43
No RFS/BTC	3.90	4.88	6.52	8.39	4.61	4.50	4.29	4.27	4.34	4.36	4.49	4.56
BAU	3.90	4.88	6.52	9.31	10.94	13.30	13.93	13.22	13.29	14.31	14.81	14.99

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[17] EPA. See https://www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel

[18] The oxygenate volumes are 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, I assume no additional ethanol beyond these levels would have been produced.

[19] 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.

[20] As noted above, my analysis focuses on final volumes through 2016. However, due to the recent release of proposed volumes for 2017, I display an estimate in this figure as well, as noted by "2017P."

4. Overview of Models and Outputs

To understand the full environmental economic impacts of these two alternative scenarios compared with the BAU (representing actual corn ethanol production levels today), I employ the POLYSYS agricultural policy simulation model (De La Torre Ugarte et al. 1998) and the IMPLAN model. The methodologies and models employed have not changed since my October 2015 study, but new production and consumption data for 2015 and a forecast for 2016 provide inputs to estimate the impacts on and of these two years.

POLYSYS Model

The POLYSYS model has the unique ability to provide annual estimates of changes in crop land use and crop prices resulting from the demand generated by bioenergy industries. The model also estimates the changes in crop fertilizer consumption, chemical application to crops, soil erosion, and agricultural carbon emissions.

For carbon emissions, the POLYSYS model computes the emissions from agricultural production and input use and provides a projection of emissions that can be compared to the BAU. 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 (N2O) emitted from the decomposition of fertilizer. N2O is a GHG.
- Lime Carbon: the carbon emitted from the lime applied to the cropland. Lime reduces the acidity of soils.

The agricultural carbon emissions results, along with the other environmental impacts (fertilizer and chemical use, corn acres planted, and soil erosion), are discussed in the results section of this study.

In this report, the overall lifecycle GHG impacts of corn ethanol are not discussed, instead focusing solely on the agricultural part of the ethanol value chain. Of course, there are varying levels of research and analysis that have gone into measuring the total lifecycle environmental impacts of corn ethanol and biofuels in general. As previously noted, the EPA's Office of Inspector General is investigating whether EPA is using the best and most up-to-date lifecycle analyses for corn ethanol in its implementation of the RFS. This investigation underscores the level of controversy that exists when it comes to asking and answering the objective, but contentious, question of whether corn ethanol use meets the GHG reduction requirements established under the RFS.

In addition to environmental impacts, 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. We show the aggregate impacts of the No RFS/BTC scenario of both of these macroeconomic impacts in the results section of this study.

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.

IMPLAN Model

The IMPLAN model is an input-output modeling software and data system that tracks the movement of capital and investment through an economy, looking at linkages between industries along the supply chain, and measuring 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.

For this modeling exercise, there are two main economic benefits we considered under the No RFS/BTC scenario:[21]

- Crop consumption cost savings that are distributed to end-consumers and also to downstream value chain participants in the form of higher profit margins.[22]
- Increased gasoline production to offset lost ethanol volumes

There are three main economic opportunity costs that we considered under a No RFS/BTC scenario:[23]

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

For the Cellulosic Replacement scenario, the same economic benefits and opportunity-costs exist, in addition to following economic benefits from the cellulosic value chain:

- 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 the 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.[24]

The net economic benefit of both scenarios is simply the economic benefits less the economic costs. I then compare the scenarios' net economic benefit to the BAU. In conducting this analysis, I chose the projected results for 2016, obtained from POLYSYS and process them through the IMPLAN modeling system. As the 2016 ethanol production is "already known" and existing production capacity aligns with projected (though artificial) "demand" numbers, 2016 represents a good benchmark for comparing the economy wide impacts of the scenarios. The results from this analysis are included in the following section.

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[21] 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 the analysis.

[22] 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.

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

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

5. Modeling Results

In this section, I provide the results of the updated analysis, using new data for 2015 and 2016. Following the conclusions of my previous study, I find that there are negative environmental and economic impacts associated with the increased production and consumption of corn ethanol in 2015 and 2016.

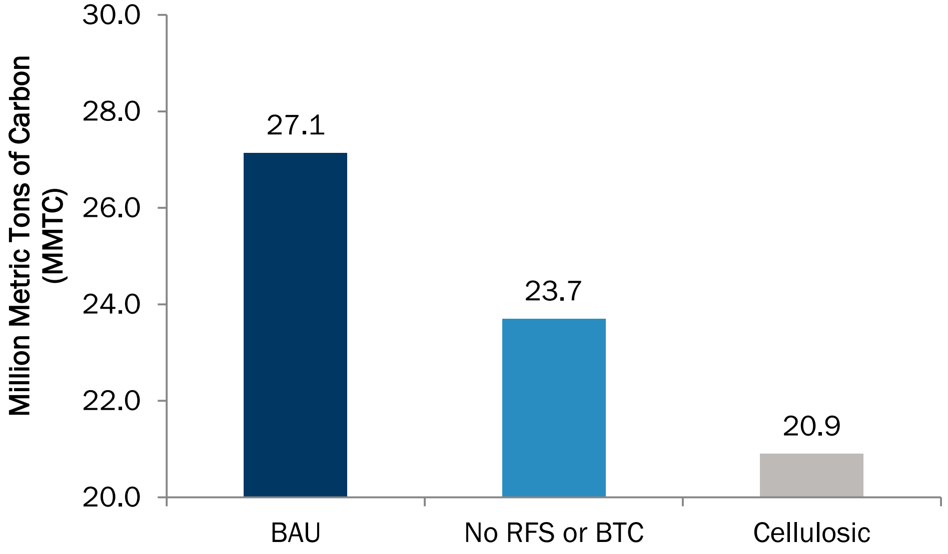
Agricultural Carbon Emissions

The October 2015 report showed that 2014 carbon emissions from agricultural production and input use would have been 10 percent and 17 percent lower than the BAU in the No RFS/BTC and Cellulosic Replacement scenarios, respectively.

With updated data through 2016, I applied the POLYSYS model to compute the emissions from agricultural production and input use. This modeling estimates that emissions would decline by 13 percent in the No RFS/BTC scenario and 23 percent in the Cellulosic Replacement scenario by 2016 (as shown in the figure below). 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 3: Carbon Emissions from Agricultural Production and Input Use, 2016



We note that the primary driver of the reduction in GHG emissions is related to the increased soil uptake of carbon as corn acres are replaced with wheat and soybean acres, which produce better soil carbon uptake. And 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 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.

It is not surprising that 2016 carbon emissions are higher than the 2014 results given the increase in corn ethanol production. To put the 2016 carbon emissions into perspective, the carbon emissions reduced under a No RFS/BTC scenario (i.e., carbon emissions from BAU *less* No RFS/BTC scenario) are equivalent to taking nearly 716,000 cars off the road for a year. Similarly, the carbon emissions reduced under a Cellulosic Replacement scenario in 2016 are equivalent to taking 1.3 million off the road.[25]

It's worth noting that with 2017 proposed corn ethanol volumes increasing by approximately 2 percent over 2016 volumes, I would expect to see emissions reduced by a proportional amount in the scenarios. That is, the No RFS/BTC and Cellulosic Replacement scenarios would amount to taking 730,000 and 1.33 million cars off the road, respectively.

Soil Erosion, Fertilizer Consumption, and Chemical Consumption

In addition to the GHG emissions impacts of corn ethanol, I also examined how the RFS influences soil erosion, fertilizer consumption, and chemical consumption. All three of these metrics provide additional insight of the RFS' overall environmental impact. With increased corn plantings, a number of issues arise, namely:

- Corn's root system does not reduce erosion as well as other crops, such as wheat or hay. With higher levels of corn plantings, erosion potential increases.
- As erosion increases, beneficial soil is removed from the cropland, which increases fertilizer consumption as farmers try to maintain nutrient levels and sustain crop yields.
- Chemical consumption increases due to a lack of crop rotation, as farmers lose the pest control benefits from crop rotation.
- Higher volumes of fertilizer and chemical consumption create issues associated with surface water contamination, which is exacerbated by the increased soil erosion.

We note that these issues are not hypothetical in nature, but a reality of the RFS. For example, in April 2016, one report from Iowa State University shows that as the demand for corn ethanol continues to grow, "farmers have begun to eliminate buffer strips between their farms and waterways."[26] This practice results in "more runoff and environmental degradation."[27] Other studies, such as those from the Proceedings of the National Academy of Sciences, [28] the USDA,[29] and the Union of Concerned Scientists,[30] have made similar conclusions.

Thus, when I modeled the soil erosion effects of increased corn ethanol production in 2016, I find that annual soil erosion would have been greatly improved under both scenarios relative to the BAU. The table below shows that annual soil erosion increased from 807 million to 816 million (or a 1.1% increase) between 2008 and 2016 in the BAU. In the No RFS/BTC scenario, the annual soil erosion decreases by 13.2% between 2008 and 2016. Similarly, I see a 33.7% decrease in annual soil erosion in the Cellulosic Replacement scenario between this time periods.

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[25] Assumes that the average car produces 4.75 metric tons of CO_2e per year, per the EPA's estimates. See https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references.

[26] *More funding won't solve Iowa's water quality problems.* (2016). *The Gazette*. Retrieved 25 April 2016, from http://www.thegazette.com/subject/opinion/guest-columnists/more-funding-wont-solve-iowas-water-quality-problems-20160424

[27] *Ibid.*

[28] For example, see Donner, S. & Kucharik, C. (2008). Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. *Proceedings Of The National Academy Of Sciences*, 105(11), 4513-4518. doi:10.1073/pnas.0708300105.

[29] 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

[30] 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

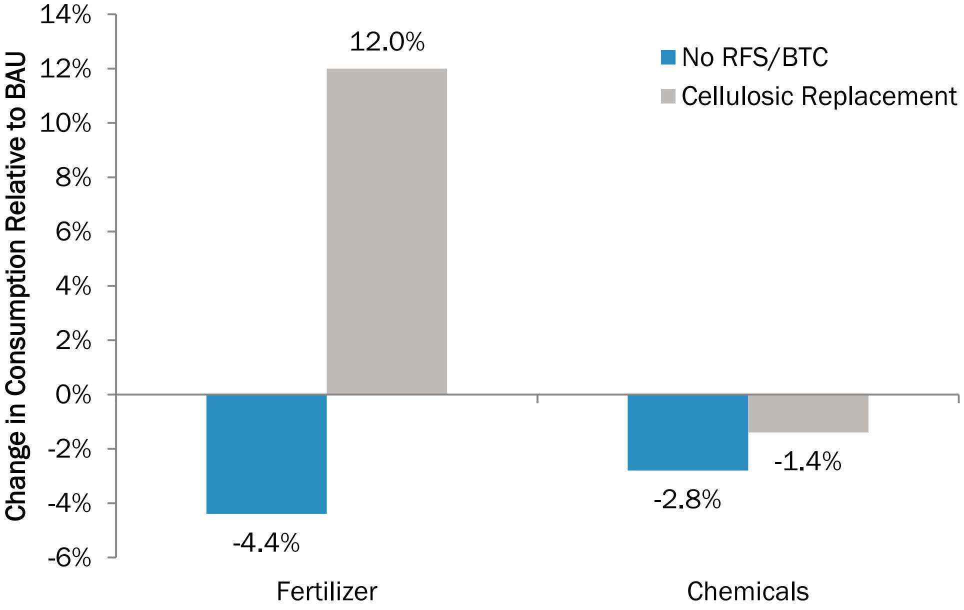
Table 2: U.S. Annual Soil Erosion by Scenario (million tons)

Scenario	2008	2016	Absolute Change	% Change
BAU	807	816	9	1.1
No RFS/BTC	807	713	-94	-13.2
Cellulosic Replacement	807	603	-204	-33.7

In both of these scenarios, I see a reduction in annual soil erosion due to a switch of corn crops over to less erosion-prone crops.

For fertilizer and chemical consumption, the scenario modeling shows decreases in the No RFS/BTC scenario relative to the BAU. As corn is replaced by other crops, such as soybeans and wheat, less fertilizer and chemical application is needed. As such, I see a decrease of 4.4 percent and 2.8 percent in fertilizer and chemical consumption, respectively.

Figure 4: Average Change in U.S. Agricultural Fertilizer and Chemical Consumption by Scenario, 2008-2016[31]



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. 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

Cropland Use and Crop Price Changes

As discussed in my original report, the RFS has had a major impact on cropland use and crop prices. In fact, in the Cellulosic Replacement scenario, the biggest economic driver is the change in cropland use (as shown in the figure below).

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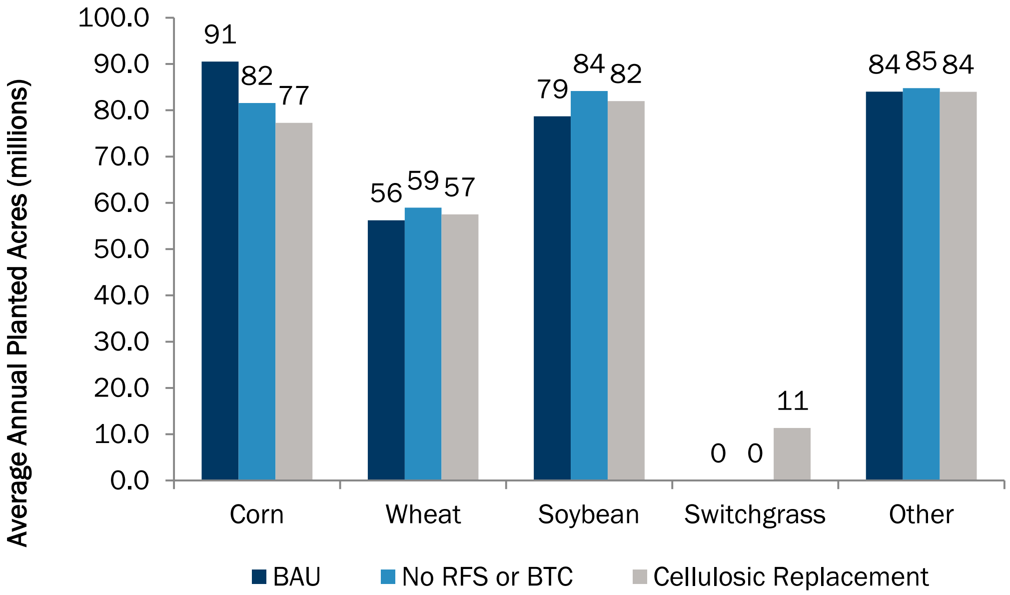
[31] The results here differ slightly from my original report due to two reasons: 1) updated volumes for 2014 and 2) I include agricultural lime in the fertilizer and chemicals figures, whereas it was excluded previously.

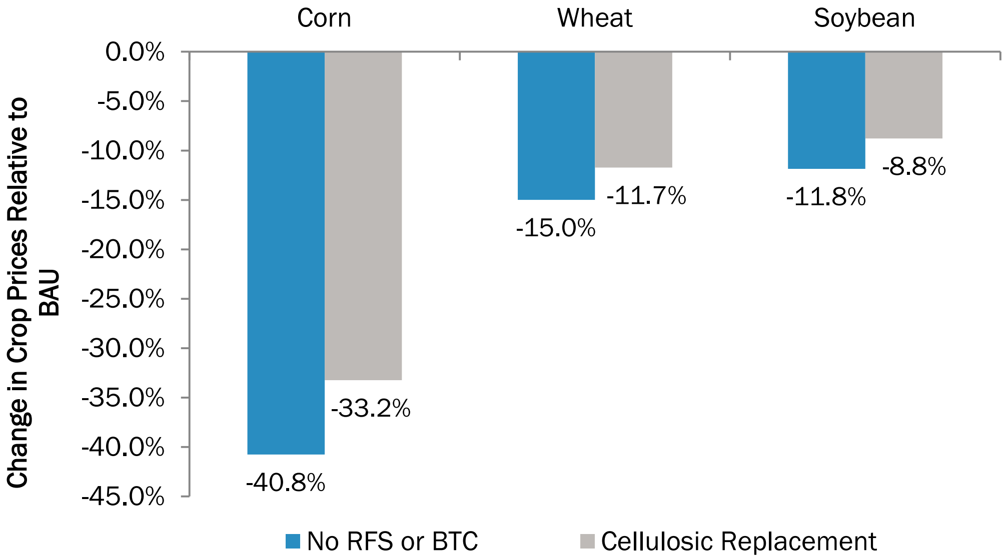
Due to a lower demand of corn ethanol, the No RFS/BTC and Cellulosic Replacement scenarios result in a reduction in total acreage planted to corn, falling from 91 million acres in the BAU to 82 (or a 10 percent decrease) and 77 (or a 15 percent decrease) million acres in the No RFS/BTC and Cellulosic Replacement scenarios, respectively. Because the artificial demand for corn in both scenarios, I see decreases in overall acres planted and an increase in other crop acreage.

Figure 5: Average Annual Acres Planted by Scenario, 2008-2016



Furthermore, the decrease in corn demand creates significantly lower corn prices (between 33 percent and 41 percent relative to the BAU for the Cellulosic Replacement and No RFS/BTC scenarios, respectively). With less corn plantings, there is a supply side increase in wheat and soybean acreage (as shown above), which reduces the prices for these commodities (as shown in the figure below).

Figure 6: Change in Annual Average Crop Prices by Scenario, 2008-2016



As I discuss in the next section, this decrease in price has important macroeconomic implications.

Changes in National Economic Indicators

The crop price reductions shown above translate into substantial savings that are passed to value chain participants (e.g., farmers) in terms of higher margins and to end-consumers in terms of lower food costs. We note though, that low crop prices also translate to lower incomes for farmers. And described in Section 4, the POLYSYS model provides two indicators of macroeconomic impacts under each scenario, namely: Net Realized Farm Income and Wholesale Crop Expenditure Savings.

In the BAU, NRFI averaged $84.9 billion between 2008 and 2016. This figure drops to $66.7 billion and $69.4 billion in the No RFS/BTC and Cellulosic Replacement scenarios, respectively. These impacts, along with the U.S. wholesale expenditure savings from lower crop prices, are shown in the table below.

Table 3: Annual Average Direct Economic Impacts Relative to BAU by Scenario, 2008-2016[32] (Billions of 2016$)

Scenario	U.S. Consumer Wholesale Expenditure Savings	Net Realized Farm Income Loss	NRFI % Reduction from the BAU
No RFS/BTC	$12.9	-$18.2	21%
Cellulosic Replacement	$10.0	-$12.1	14%

The Net Realized Farm Income Loss in both scenarios shows that the RFS has played a significant role as a farm support instrument. While there are merits in providing support to the farm sector, there are more efficient means of doing so than through the RFS, which would have better economic and environmental results.[33]

Using these two macroeconomic outputs from the POLYSYS model along with other estimations, I was able to approximate the overall net U.S. benefits under both scenarios for 2016 using the IMPLAN model. As described above, the net economic benefits under each scenario are calculated as the benefits less the opportunity costs. As shown in the table below, the net economic benefit of the No RFS/BTC scenario is $29.2 billion,[34] while the Cellulosic Replacement scenario shows a net economic benefit of $42.4 billion.[35]

Table 4: 2016 Net Economic Benefits by Scenario (Billions of 2016$)

Scenario	Net Benefit
No RFS/BTC	$29.2
Cellulosic Replacement	$42.4

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. The two figures below illustrate the changes in net returns (a proxy for Realized Net Farm Income at the regional level) for the agricultural sector[36]. The first figure

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[32] U.S. Consumer Wholesale Expenditure 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.

[33] Ray, Daryll, Daniel De La Torre Ugarte, and Kelly Tiller. (2003). "Rethinking US Agricultural Policy: Changing Course to Secure Farmer Livelihoods Worldwide," Knoxville, Tennessee: University of Tennessee, Agricultural Policy Analysis Center. http://www.agpolicy.org/blueprint.html

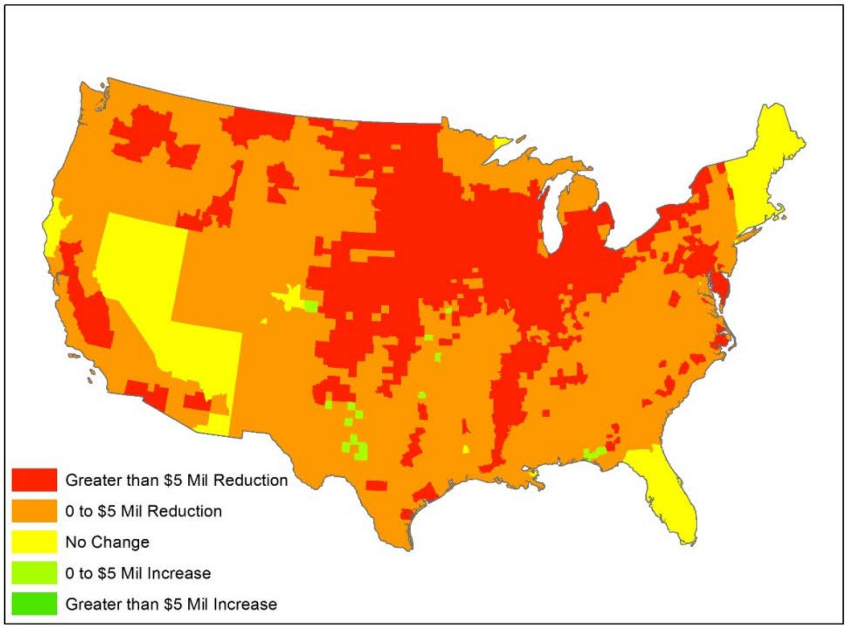
[34] The net economic benefit in this scenario is calculated as economic benefits of $87.5 billion *less* opportunity costs of $58.3 billion.

[35] The net economic benefit in this scenario is calculated as economic benefits of $91.2 billion *less* opportunity costs of $48.9 billion.

[36] The net return figures do not include livestock activities.

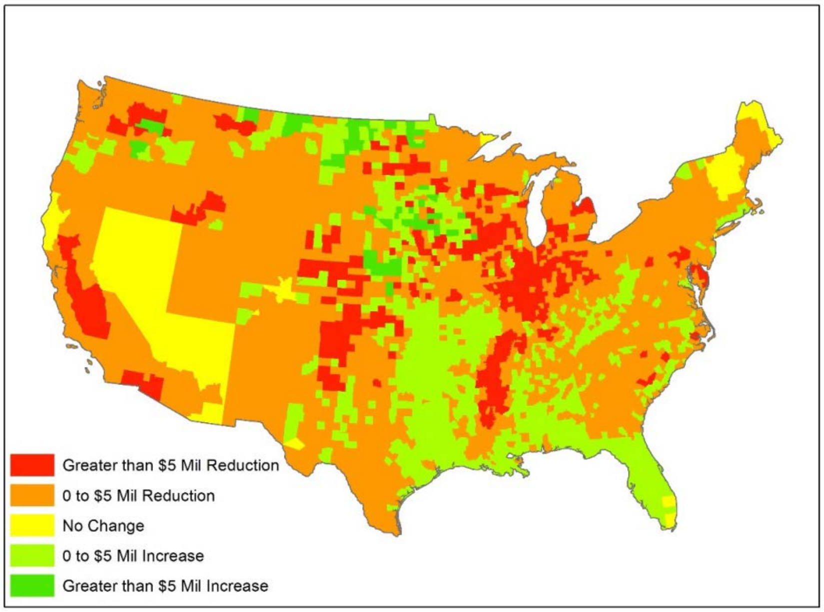
indicates that under the No RFS /BTC scenario there will be a reduction in net returns in the agricultural sector across the nation.

Figure 7: A Spatial Estimation of Changes in Net Returns to Agriculture: From BAU to No RFS/BTC Scenario, 2016, (Millions of 2016$)



On the other hand, the next figure shows that the impacts are significantly different in the case of the Cellulosic Replacement scenario. First, there is an increase in net returns in a large portion of the Southeast and Central Plains. Second, the decrease in net returns in the Northern Plains and the Corn Belt is smaller than under the No RFS/BTC scenario. These findings are a key indicator of the regional differences between the corn ethanol-based and cellulosic ethanol-based RFS strategies.

Figure 8: A Spatial Estimation of Changes in Net Returns to Agriculture: From BAU to Cellulosic Replacement Scenario, 2016, (Millions of 2016$)



While the analysis shows 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 select rural communities due to higher crop prices and volumes, ethanol refinery investment, and ethanol refinery production.

6. Conclusions

Since my first report in October 2015, political, economic, and environmental issues surrounding the RFS have continued to rapidly evolve. Shortly after the release of my initial report, the EPA's Office of Inspector General (OIG) opened a case against the agency's conduct in setting the new standard and is currently investigating several aspects of its ruling.

While it is uncertain what the outcome of this investigation will be, it is clear that the OIG wants to ensure that the EPA's ruling is complying with all requirements and is up to date on any new science that has been released in recent years. This is especially important as many recent studies question the validity of the EPA's lifecycle emissions analysis and whether the RFS has been meeting its intended policy objectives.[37]

Additionally, after the EPA set its final volume obligations for 2014-2016, a number of lawsuits were filed against the EPA from both RFS opponents and proponents. Some call for a complete repeal of the ruling, while others find fault with certain specifics within the rule. Nevertheless, it's clear the RFS has become the source of a much more pressing and contentious policy debate.

In this report, I set out to update my prior analysis of the economic and environmental impacts of the RFS. With updated production and consumption data for 2014-2016, I was able to run the POLYSYS and IMPLAN models to better understand what the impact of the rule has been (and is projected to be) through 2016. We ran two scenarios, the No RFS/Blender's Tax Credit scenario and the Cellulosic Replacement scenario (both described in Section 4), and compared the results with a Business as Usual (BAU) scenario.

The analytical results include the following findings:

1) Corn ethanol demand would have been 4.56 billion gallons in 2016 (or 30 percent of projected production) in the No RFS/BTC scenario. Cellulosic ethanol demand would have been 10.43 billion gallons in 2016 (or 70 percent of projected ethanol production) in the Cellulosic Replacement scenario;
2) The area planted to corn acres would have been reduced significantly, between 10-15 percent under the two alternative scenarios when compared to the BAU; consequently, this results in a 33-41 percent reduction in corn prices. The reduced corn plantings are replaced mostly with wheat and soybeans, which increases supply and generates a 12-13 percent decrease in wheat prices and a 9-12 percent drop in soybean prices;
3) Crop price reductions would have translated to approximately $12.9 billion and $10.0 billion of annual consumer wholesale expenditure savings but a loss of $18.2 billion and $12.1 billion in net realized farm income in the No RFS/BTC and Cellulosic Replacement scenarios, respectively;
4) The overall net economic benefits of the No RFS/BTC and Cellulosic Replacement scenarios in 2016 would have been $29.2 billion and $42.4 billion, respectively;
5) In 2016, carbon emissions from agricultural production and input use would have been 3.4 million metric tons lower in the No RFS/BTC scenario and 6.2 million metric tons lower in the Cellulosic Replacement scenario as compared with the BAU;
6) Soil erosion under both scenarios improves greatly compared with the BAU. Annual soil erosion between 2008 and 2016 would have decreased in the No RFS/BTC and the Cellulosic Replacement scenarios by94 and 204 million metric tons of soil, respectively; and

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[37] For example, see: Clean Air Task Force (CATF). 2013. Corn Ethanol GHG Emissions Under Various RFS Implementation Scenarios, April 2013; 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; and 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.

7) Fertilizer and chemical consumption decreases relative to the BAU in the No RFS/BTC scenario by 4.4 percent and 2.8 percent, respectively. The Cellulosic Replacement scenario shows a 12 percent increase in fertilizer and a 1.4 percent decrease in chemical consumption compared with the BAU.

Given the serious environmental and economic impacts of the RFS, highlighted in my research findings as well as many others, I continue to believe now is the time to create more modernized and efficient policy aimed at promoting advanced biofuels. With a policy objective that is focused on lowering GHG emissions, advanced biofuels can play an important role in meeting this objective.[38] Yet, it is clear that the focus of the RFS thus far – for more than a decade – has been on corn ethanol. Moreover, the RFS cannot be a substitute for sensible agricultural policies that support farmers and environmental performance.

And while cellulosic ethanol production in 2016 has already been making strides against the 2015 production pace up to this point,[39] policies aimed at promoting even higher growth are critical in terms of near- and long-term environmental and fuel diversity progress. One reason for this is the capital intensive nature of advanced biofuels (which is one reason why they have struggled to become more commercially viable over the past 10 years). 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. Thus, for advanced biofuels to sustainably enter the market, an investment-based mechanism may be necessary to overcome their capital intensity and technology risk.

As I argued in my prior analysis, an investment-based mechanism has two distinct advantages over other market designs that have been employed in the biofuels sector (such as RINs). Because the amount will be clear to an investor, the first advantage is the certainty that arises from an investment-based design. The second is related to the 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.

Additionally, an investment-based mechanism can be 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.

Ultimately, it is clear that the RFS continues to fall short of meeting its policy objectives – a struggle that has existed for more than ten years. Given my analysis in this report, I continue to believe 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 over the next 10 years aimed at achieving meaningful environmental and greater fuel diversity benefits.

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[38] Advanced biofuels include any biofuel that meets a GHG reduction target of 50 percent or greater. Biomass-based diesel and cellulosic biofuels (for the most part) fall under the definition of advanced biofuels.

[39] *A Cellulosic Ethanol Milestone.* Forbes. (2016). Available at: http://www.forbes.com/sites/rrapier/2016/04/26/a-cellulosic-ethanol-milestone/#169bcba867c0