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Report to the Chairman, Subcommittee on Regulatory Affairs and Federal Management, Committee on Homeland Security and Governmental Affairs, U.S. Senate

May 2019

RENEWABLE FUEL STANDARD

Information on Likely Program Effects on Gasoline Prices and Greenhouse Gas Emissions

GAO-19-47

GAO Highlights

Highlights of GAO-19-47, a report to the Chairman, Subcommittee on Regulatory Affairs and Federal Management, Committee on Homeland Security and Governmental Affairs, U.S. Senate

Why GAO Did This Study

Congress established the RFS in 2005 and expanded it 2 years later. The RFS generally mandates that transportation fuels—typically gasoline and diesel—sold in the United States contain increasing amounts of biofuels. In addition, the RFS is designed to reduce greenhouse gas emissions by replacing petroleum-based fuels with biofuels expected to have lower associated greenhouse gas emissions. The most common biofuel currently produced in the United States is corn-starch ethanol, distilled from the sugars in corn. EPA uses RINs associated with biofuels blended with petroleum-based fuels to regulate compliance with the program.

In 2014, GAO found that refiners' costs for complying with the RFS had increased, and in 2016, GAO found that greenhouse gas emissions are unlikely to be reduced to the extent anticipated because production of advanced biofuels—which reduce greenhouse gas emissions more than corn-starch ethanol—has not kept pace with the yearly increases or the target of 21 billion gallons by 2022 called for by the statute. GAO was asked to review additional issues related to the effects of the RFS.

This report examines what is known about (1) the effect the RFS has had to date on retail gasoline prices in the United States and (2) the RFS's effect on greenhouse gas emissions and whether the RFS will meet its goals for reducing those emissions. The report also provides information about RINs.

To address the likely effects of the RFS on gasoline prices, GAO reviewed studies and interviewed experts and industry stakeholders, and conducted a

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What GAO Found

Effect on prices. Evidence from studies, interviews with experts, and GAO's analysis suggest that the nationwide Renewable Fuel Standard (RFS) was likely associated with modest gasoline price increases outside of the Midwest and that these price increases may have diminished over time. Variations in these gasoline price effects likely depended, in part, on state-by-state variation in the costs to transport and store ethanol. For example, the Midwest was already producing and blending ethanol when the RFS came into effect, so that region had lower transportation costs and had already invested in necessary storage infrastructure. Other regions began blending ethanol later to meet the RFS's requirements, thereby incurring new transportation and storage infrastructure costs that resulted in gasoline prices that were several cents per gallon higher than they otherwise would have been.

In addition, experts told GAO that the RFS caused an initial increase in refining investment costs that, over the long term, reduced refining costs for gasoline. Specifically, once all locations had made the infrastructure investments and most gasoline blendstock produced was consistent with blending ethanol then there would be two continuing effects: (1) the transportation and blending costs of ethanol, which would tend to push retail prices higher and depend on the distance traveled and the modes of transport, and (2) the lower cost of producing lower octane blendstock. The former effect might dominate for locations far from the production source of ethanol and for which more costly modes of transport were used, while the lower blendstock costs might dominate for locations close to the production source of ethanol and/or those that have low transportation costs.

GAO's analysis of the effect that state ethanol mandates had on gasoline prices also showed gasoline price effects that differed in the Midwest and elsewhere. Specifically, during the period GAO studied, when the ethanol mandates in Minnesota and Missouri were in effect, all else remaining equal, retail gasoline prices were lower by about 8 and 5 cents per gallon in these states, respectively, than they would have been without the mandates. In contrast, when the ethanol mandates in Hawaii, Oregon, and Washington were in effect, GAO's model showed that retail gasoline prices were higher by about 8, 2, and 6 cents per gallon, respectively, than they would have been without the ethanol mandates. These results suggest that the RFS likely had gasoline price effects in other states that did not have state-wide ethanol mandates but that incrementally began blending ethanol as a result of increasing RFS requirements that by around 2010 had led to almost all gasoline sold in the United States being blended with 10 percent ethanol.

Effect on greenhouse gas emissions. Most of the experts GAO interviewed generally agreed that, to date, the RFS has likely had a limited effect, if any, on greenhouse gas emissions. According to the experts and GAO's prior work, the effect has likely been limited for reasons including: (1) the reliance of the RFS to date on conventional corn-starch ethanol, which has a smaller potential to reduce greenhouse gas emissions compared with advanced biofuels, and (2) that most corn-starch ethanol has been produced in plants exempt from emissions statistical analysis of state ethanol mandates that were similar to the mandates of the RFS. GAO selected the experts based on their published work and recognition in the professional community. GAO selected stakeholders representing a range of perspectives, including stakeholders from the renewable fuels, petroleum, and agricultural industries, as well as from environmental groups.

Because the RFS was implemented on a nationwide basis at the same time that other factors, such as the global price of crude oil and domestic demand for retail gasoline, were affecting retail gasoline prices across the nation, it is not possible to directly isolate and measure the effect the RFS had on gasoline prices nationwide given data available to GAO. Instead GAO developed and extensively tested an econometric model that estimated the effects on retail gasoline prices of state ethanol mandates. These state mandates are similar to the RFS but were put in place voluntarily by states before the RFS led to widespread ethanol blending in every state. This model estimated how ethanol mandates affected gasoline prices in these five states. These estimates suggest the RFS likely had effects in states that did not have state-wide mandates. These states incrementally blended ethanol because of the increasing volumes of ethanol required to be blended nationally by the RFS.

Regarding the RFS's effect on greenhouse gas emissions, GAO interviewed 13 experts in government and academia. GAO selected these experts based on their published work, prior GAO work, and recommendations from other experts.

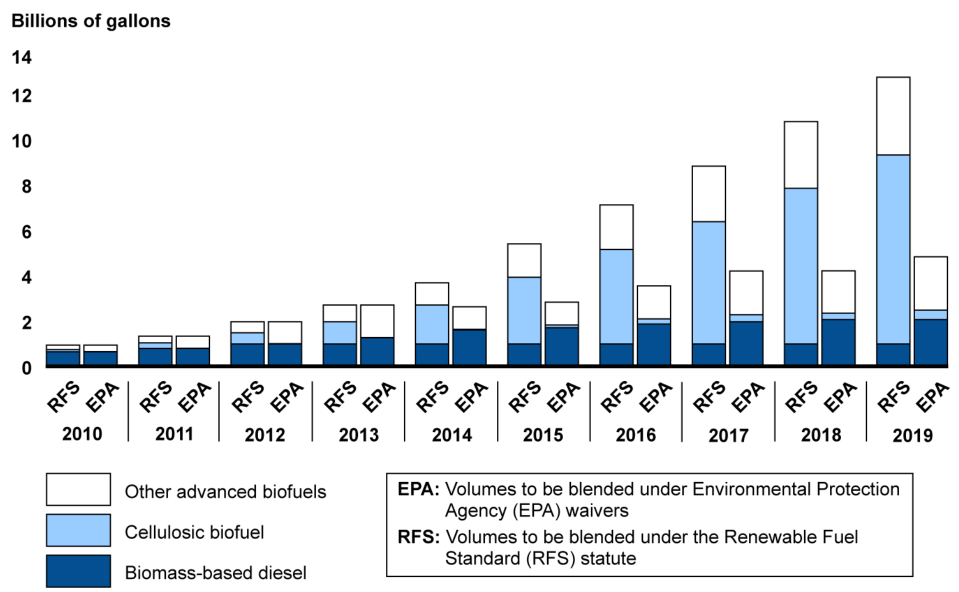
During the course of the work, GAO gathered information on the topic of RINs through interviews, a review of relevant literature, and prior GAO work.

GAO makes no recommendations in this report. In commenting on a draft of this report, USDA disagreed with GAO's finding that the RFS has had a limited effect on greenhouse gas emissions, citing research on the effects of ethanol on reducing emissions generally. GAO reported on the specific effects of the RFS on emissions. USDA also criticized GAO's methodology using experts' views. GAO employed that method to reach consensus among those with a range of perspectives. DOE and EPA did not comment on the draft report.

reduction requirements, likely limiting reductions early on when plants were less efficient than they are today.

Further, the RFS is unlikely to meet the greenhouse gas emissions reduction goals envisioned for the program through 2022. Specifically, GAO reported in November 2016 that advanced biofuels, which achieve greater greenhouse gas reductions than conventional corn-starch ethanol, have been uneconomical to produce at the volumes required by the RFS statute so the Environmental Protection Agency (EPA) has waived most of these requirements (see figure).

Volumes of Advanced Biofuels to Be Blended into Domestic Transportation Fuel, as Set by the Renewable Fuel Standard Statute and by EPA, 2010 through 2019



Source: GAO analysis of legal requirements and EPA data. | GAO-19-47

Renewable identification numbers. EPA uses renewable identification numbers (RINs) to regulate industry compliance with RFS requirements for blending biofuels into the nation's transportation fuel supply. In GAO's March 2014 report on petroleum refining, GAO noted that the RFS had increased compliance costs for the domestic petroleum refining industry or individual refiners. GAO reported that corn-based ethanol RIN prices had been low—from 1 to 5 cents per gallon from 2006 through much of 2012—but in 2013, RIN prices increased to over $1.40 per gallon in July before declining to about 20 cents per gallon as of mid-November 2013. Since the March 2014 report, corn-ethanol RIN prices have experienced more periods of volatility. Most experts and stakeholders GAO interviewed recently stated that RINs had either a small effect on prices or no effect on prices, though a few disagreed. Finally, GAO's past work, as well as EPA analysis, has identified several issues of concern with RINs, including possible fraud in the market and concerns about the effect on small refiners, price volatility, and the point of obligation.

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Abbreviations

EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
LCFS	low carbon fuel standard
MTBE	methyl tertiary butyl ether
PADD	Petroleum Administration for Defense District
R&D	research and development
RFS	Renewable Fuel Standard
RIN	renewable identification number
RVP	Reid vapor pressure
VEETC	Volumetric Ethanol Excise Tax Credit

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 3, 2019

The Honorable James Lankford
Chairman
Subcommittee on Regulatory Affairs and Federal Management
Committee on Homeland Security and Governmental Affairs
United States Senate

Dear Mr. Chairman:

As part of U.S. efforts to increase energy independence and security and increase the production of clean, renewable fuels, Congress enacted the Renewable Fuel Standard (RFS) as part of the Energy Policy Act of 2005 and 2 years later expanded it in the Energy Independence and Security Act of 2007 (EISA). The RFS generally mandates that transportation fuels—typically gasoline and diesel—sold in the United States contain annually increasing amounts of biofuels—fuels produced from renewable sources such as agriculture, rather than through geological processes, such as those involved in forming petroleum. The most common biofuel currently produced in the United States is corn-starch ethanol, which is distilled from the sugars in corn. The Environmental Protection Agency (EPA), which is responsible for implementing the RFS, defines the goals of the RFS as to (1) expand the nation's biofuel sector while reducing reliance on imported oil and (2) reduce greenhouse gas emissions.

The initial RFS required that a minimum of 4 billion gallons of biofuels be blended into gasoline in 2006, rising to 7.5 billion gallons by 2012. EISA expanded both the amounts of biofuels to be blended into gasoline and the length of time during which those amounts are to increase, establishing target volumes that rise from 9 billion gallons in 2008 to 36 billion gallons in 2022. In March 2014, we reported that domestic consumption of petroleum products had fallen from 2005 through 2012, resulting in a smaller domestic market for refined petroleum products and an increased cost of RFS compliance for some refiners.[1] In 2016, we reported that the reductions in greenhouse gas emissions envisioned for the program are unlikely to occur because production of advanced biofuels—which have a greater impact than corn-starch ethanol on

[1]GAO, *Petroleum Refining: Industry's Outlook Depends on Market Changes and Key Environmental Regulations,* GAO-14-249 (Washington, D.C.: Mar. 14, 2014).

greenhouse gas emissions—has not kept pace with statutory requirements.[2]

EPA regulates compliance with the RFS using a tradable credit system. Companies in the United States that refine or import transportation fuel must submit credits—called renewable identification numbers (RINs)—to EPA that equal the number of gallons of biofuel that the RFS requires them to blend with the petroleum-based fuel. RINs may be used by the company that generates them, may be sold to other companies, or retained for future use.

You asked us to review additional issues related to the effects of the RFS. This report examines what is known about (1) the effect that the RFS has had to date on retail gasoline prices in the United States and (2) the effect that the RFS has had on greenhouse gas emissions, including whether the RFS is expected to meet its goals for reducing those emissions. In addition, we are providing information about RINs.

To address our objectives, we reviewed relevant studies and conducted semistructured interviews with 18 experts we identified through snowball sampling based on expert referrals. Specifically, we identified experts through a review of selected studies, references within the studies to other relevant articles, prior GAO work that included discussions with a panel convened by the National Academy of Sciences, and recommendations from other experts identified through the studies. Because so little empirical work has been conducted on the relationship between prices and the RFS, especially work of a retrospective nature, we selected some experts specifically because of the relevance of their published work. We also selected experts who are recognized as experts in the professional community or among their peers. In addition, we selected individuals who have expertise or have published work relevant to lifecycle assessment of greenhouse gas emissions of various biofuels, or who have published work relevant to the effect of the RFS on greenhouse gas emissions or biofuel production and use. Finally, to obtain views from experts representing a range of perspectives, we selected experts who represented various disciplines, including economics, engineering, and physical sciences. Of the 18 experts we interviewed, 7 discussed the effect that the RFS has had on retail

[2]GAO, *Renewable Fuel Standard: Program Unlikely to Meet Its Targets for Reducing Greenhouse Gas Emissions,* GAO-17-94 (Washington, D.C.: Nov. 28, 2016).

gasoline prices and 13 discussed the effect that the RFS has had on greenhouse gas emissions, including 2 who also discussed the effect on retail gasoline prices. The specific areas of expertise varied among the experts we interviewed, so not all of the experts commented on all of our interview topics. Appendix I includes the list of experts we interviewed and identifies which experts we interviewed about which topics.[3]

We also interviewed representatives from various industry stakeholders who have been affected by the RFS to obtain their views about how the RFS has affected gasoline prices and greenhouse gas emissions. We reviewed much of the literature on this subject, and used the literature, along with referrals from other experts and recommendations from the National Academy of Sciences for prior GAO work to identify stakeholders to interview. We also employed snowball sampling by asking the officials we interviewed to recommend others who have knowledge about the effect of the RFS on gasoline prices and greenhouse gas emissions. Industry stakeholders were selected based on the relevance of their mission to biofuels and to the RFS. In considering industry stakeholders, we selected those that would allow us to obtain a wide range of perspectives on these issues. For example, we selected industry stakeholders that represent the renewable fuels industry as well as those that represent the petroleum industry. We also selected industry stakeholders that represent the farmers who grow the agricultural products frequently used for biofuels, and we selected those whose primary focus is on the environment. The views of these stakeholders are not generalizable to those we did not interview. A list of industry stakeholders whose representatives we interviewed can be found in appendix II.

Because the RFS was implemented on a nationwide basis at the same time that other factors, such as the global price of crude oil and domestic demand for retail gasoline, were affecting retail gasoline prices across the nation, it is not possible to directly isolate and measure the effect the RFS had on gasoline prices nationwide given data available to us. Instead we developed and extensively tested an econometric model that estimated the effects on retail gasoline prices of state ethanol mandates that are similar to the RFS but that states voluntarily put in place before the RFS targets led to widespread ethanol blending in every state. This model enabled us to estimate how ethanol mandates affected gasoline prices in

[3]One expert declined to be identified and is not listed in the appendix.

these five states, and these estimates allow us to infer the effects that the RFS had in other states that did not have state-wide mandates but that were incrementally forced to blend ethanol based on RFS requirements. Specifically, the state-level analysis allowed us to isolate the effect of ethanol mandates on retail gasoline prices in five states—Hawaii, Minnesota, Missouri, Oregon, and Washington—by using other states to control for other factors that influenced retail gasoline prices over time. These state mandates were put into effect by 2008, at which time the RFS was requiring relatively low levels of ethanol blending. In doing this analysis, we used all the states identified as having met the criteria of having state-wide ethanol blending mandates put into effect no later than 2008.[4] Therefore, these state mandates likely accelerated ethanol blending in those states during our study period. We conducted a regression analysis using monthly average after-tax retail gasoline prices from 49 states and the District of Columbia for 2001 through 2010.

Our model required data on retail gasoline prices and biofuel policies, as well as on other factors that might have affected gasoline prices, so that we could control for these factors and isolate the effects of the state ethanol mandates. We obtained the gasoline price data from the Oil Price Information Service, a leading provider of retail fuel prices. We also collected data from government agencies, including the Department of Energy's Energy Information Administration, the Department of Transportation's Federal Highway Administration, and the Nebraska Energy Office.

To assess the reliability of the data, we interviewed officials who maintain the data, reviewed related academic studies, and tested the data for missing or erroneous values. We found the data to be sufficiently reliable for the purposes of our reporting objectives. We focused our analysis on regular-grade gasoline, as it represented more than 80 percent of gasoline sales in 2017. Appendix III provides a technical discussion of our econometric model. We compared our results to expert views and related peer-reviewed studies examining the effects of ethanol blending on fuel prices. Also, to obtain additional information about the effect of the RFS on gasoline prices, we interviewed officials from the Department of Agriculture, the Department of Energy, and EPA; relevant experts as described above; and relevant industry stakeholders as described above.

[4]We identified states with relevant mandates by reviewing the Oil Price Information Service Regs and Specs Handbooks and then researched state specific statutory and regulatory requirements in the identified states.

To examine the effect of the RFS on greenhouse gas emissions, we interviewed officials from the Department of Agriculture, the Department of Energy, and EPA and asked them about the effect of the RFS on emissions. We also interviewed relevant experts and industry stakeholder representatives as described above about the effect of the RFS on greenhouse gas emissions. The expert pool included researchers who were well equipped to speak both to the impacts of RFS on corn prices and agricultural commodities as well as how this then impacts land use change and greenhouse gas emissions. This is because the RFS' effect on gasoline prices and the effect on greenhouse gas emissions are not distinct issues. In addition, during our interviews with experts, some referred us to specific studies to illustrate a point, and we reference some of these studies. We reviewed the methodology of those that we reference and found them to be sufficiently sound.

In the course of conducting our work to examine the effect that the RFS has had to date on retail gasoline prices in the United States and greenhouse gas emissions, we also collected information on the topic of RINs. We gathered this information through interviews and a review of relevant literature, and we supplemented it with information from our previous work. We summarized how RINs are used to show compliance with the RFS, historical RIN prices, how RINs affect retail fuel prices, and steps EPA has taken to improve the functioning of the RIN market.

We conducted this performance audit from January 2017 to May 2019 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

RFS Greenhouse Gas Emissions Goals and Requirements

EPA states that one goal of the RFS is to reduce greenhouse gas emissions.[5] Specifically, the RFS is designed to reduce these emissions by increasingly replacing petroleum-based fuels with biofuels that have lower associated greenhouse gas emissions released throughout their lifecycle. Some of these greenhouse gas emissions are directly released at each stage of a fuel's lifecycle, which, for biofuels, includes the emissions associated with growing the feedstock, transporting it, converting it to a biofuel, distributing the biofuel, and burning it in an engine. Other emissions are released indirectly through broad economic changes associated with increased biofuel use, such as changes in land use.

The lifecycle greenhouse gas emissions from biofuels cannot be directly measured, so they are estimated using mathematical models that account for greenhouse gas emissions at each stage of the lifecycle. These models—in particular, Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model—have been used by researchers for nearly 30 years. However, the complexity of estimating the lifecycle emissions associated with biofuels and the sensitivity of the models to assumptions limit the precision of the modeled results.

The RFS established statutory greenhouse gas reduction requirements for specific types of biofuels. These types can be grouped into two broad categories—conventional biofuels and advanced biofuels—defined by the amount of reduction they are required by statute to achieve in lifecycle

[5]Common greenhouse gases are carbon dioxide, methane, nitrous oxide, and fluorinated gases such as hydrofluorocarbons. Such gases trap heat in the atmosphere. Reducing greenhouse gas emissions is part of a strategy to limit the environmental impacts from climate change. Under the RFS, determining the amount of greenhouse gas emissions from biofuel production and use is the responsibility of EPA.

greenhouse gas emissions relative to the 2005 emissions baseline for gasoline or diesel.[6]

- **Conventional.** Conventional biofuels from new facilities must achieve greenhouse gas emissions at least 20 percent lower than traditional petroleum-based fuels, which include gasoline and diesel.[7] The dominant conventional biofuel produced to date is corn-starch ethanol.
- **Advanced.** Advanced biofuels must achieve lifecycle greenhouse gas emissions at least 50 percent lower than traditional petroleum-based fuels. Advanced biofuels may include a number of fuels, including fuels made from algae or sugar cane, but the category excludes ethanol derived from corn starch. This category includes the following subcategories:
  - **Biomass-based diesel:** biodiesel or renewable diesel that has lifecycle greenhouse gas emissions at least 50 percent lower than traditional petroleum-based diesel fuels.
  - **Cellulosic:** renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and has lifecycle greenhouse gas emissions at least 60 percent lower than traditional petroleum-based fuels.[8]

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[6]By statute, EPA uses lifecycle analysis to identify a fuel's greenhouse gas emissions relative to a baseline reflecting 2005 emissions from traditional petroleum-based fuels. The statute defines lifecycle greenhouse gas emissions as the aggregate quantity of greenhouse gas emissions (including direct emissions and indirect emissions such as significant emissions from changes in land use), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery to and use of the finished fuel by the final consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential. EPA told us that because of the relatively large initial release of sequestered carbon that accompanies changes in land use, multi-decade time horizons are generally necessary to assess biofuels' lifecycle greenhouse gas emissions.

[7]Biofuel facilities that were producing fuel prior to the enactment of EISA are grandfathered under the statute, meaning these facilities are not required to meet the greenhouse gas reductions. As a consequence, corn-starch ethanol plants in operation or under construction before December 19, 2007, generally are not subject to the requirement to reduce greenhouse gas emissions by at least 20 percent. According to EPA, these older plants accounted for about 89 percent of RFS blending volume in 2017.

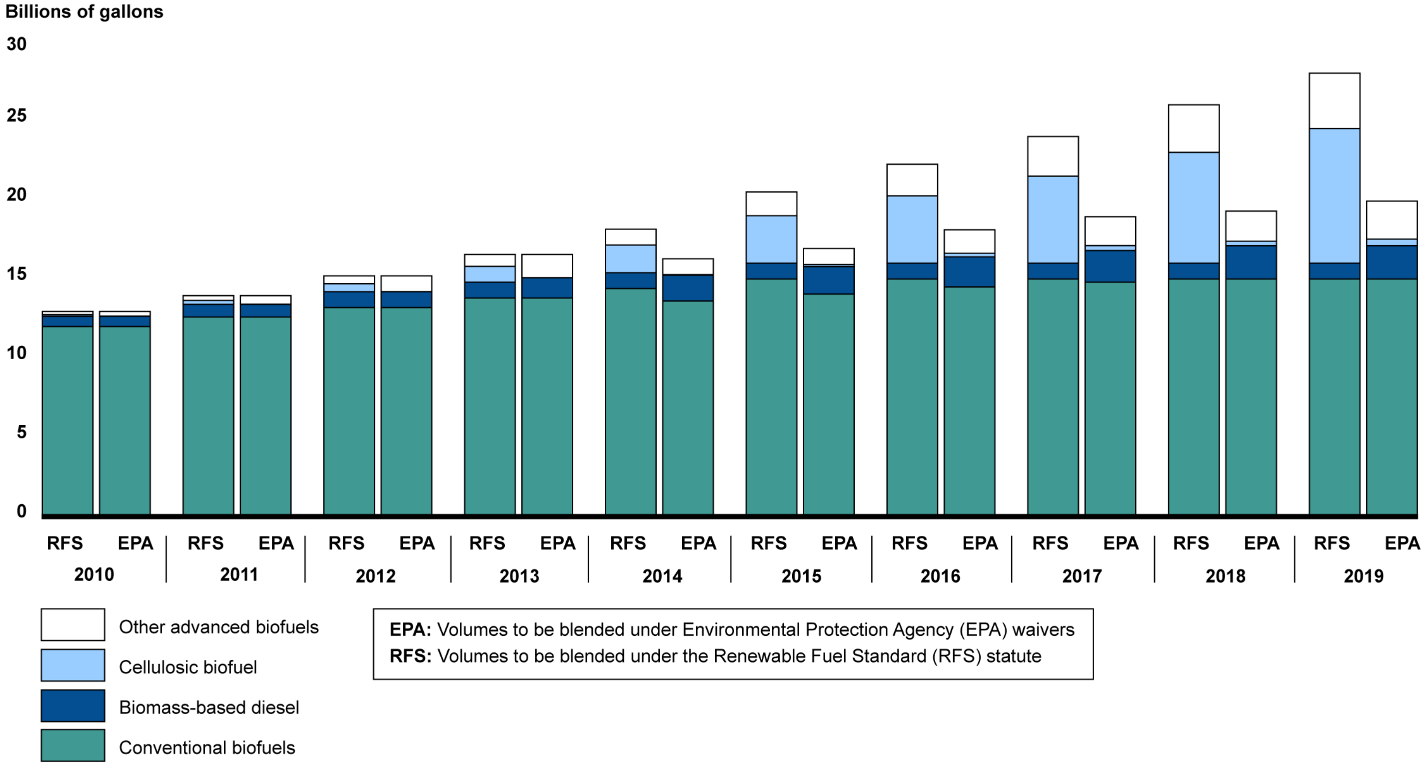
[8]Renewable biomass consists primarily of cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are made up of potentially fermentable sugars. Lignin provides the structural integrity of plants by enclosing the tightly linked cellulose and hemicellulose molecules, which makes these molecules harder to reach.

Types and Volumes of Biofuels to Be Blended under the RFS

The RFS established statutory requirements for the amount of biofuels that must be blended into gasoline. These amounts increase from 9 billion gallons in 2008 to 36 billion gallons in 2022. The RFS sets statutory volume requirements for each type of biofuel based on the categories described above, but EPA can waive those requirements and establish its own, if warranted. From 2010 through 2013, EPA used its waiver authority each year to reduce the volume requirement for cellulosic biofuel while keeping the total volume requirement for all biofuels at the statutory level. Starting in 2014, EPA set lower volume requirements for all advanced biofuels and lower total biofuel blending requirements. EPA cited, among other things, inadequate domestic supply as a reason for the waivers.[9] Since 2014, the gap between RFS requirements for advanced biofuels and EPA requirements after waivers were issued has increased. Figure 1 compares RFS statutory volumes for various types of biofuels with volumes that EPA established using the waiver authority.

[9]The law provides that for any calendar year for which the projected volume of cellulosic biofuel production is less than the statutory volume, the Administrator of EPA must reduce the applicable volume of cellulosic biofuel to the projected volume available during that calendar year. 42 U.S.C. § 7545(o)(7)(D)(i).

Figure 1: Volumes of All Biofuels to Be Blended into Domestic Transportation Fuel, as Set by the Renewable Fuel Standard Statute and by EPA, 2010 through 2019



Source: GAO analysis of legal requirements and EPA data. | GAO-19-47

Notes: The Renewable Fuel Standard is codified at 42 U.S.C. § 7545(o).

Biofuels can be grouped into two broad categories—conventional biofuels and advanced biofuels—defined by the amount of reduction they are required to achieve in lifecycle greenhouse gas emissions relative to the 2005 emissions baseline for gasoline or diesel. Conventional biofuels from new facilities must achieve greenhouse gas emissions at least 20 percent lower than traditional petroleum-based fuels, which include gasoline and diesel. The dominant conventional biofuel produced to date is corn-starch ethanol. Biomass-based diesel is biodiesel or renewable diesel that has lifecycle greenhouse gas emissions at least 50 percent lower than traditional petroleum-based diesel fuels. Cellulosic biofuel is renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and has lifecycle greenhouse gas emissions at least 60 percent lower than traditional petroleum-based fuels. Other advanced biofuels include those derived from sugar or waste material.

In 2018, the biofuel used most often to comply with the RFS has been conventional ethanol derived from corn starch. As we reported in 2016, production of cellulosic and other advanced biofuels has not progressed as initially expected under the RFS. Although, as we reported, advanced biofuels are technologically well understood, current production is far below the volume needed to meet the statutory targets for these fuels. For example, the cellulosic biofuel blended into transportation fuel in 2015 was less than 5 percent of the statutory target of 3 billion gallons. Given current production levels, most experts we interviewed told us that advanced biofuel production cannot achieve the statutory targets of 21 billion gallons by 2022.

The shortfall of advanced biofuels is the result of high production costs, despite years of federal and private research and development (R&D) efforts. The federal government has supported R&D related to advanced biofuels through direct research and grants in recent years, with the focus of this R&D shifting away from cellulosic ethanol, an advanced biofuel that is not fully compatible with current vehicle engines and fuel distribution infrastructure, and toward other biofuels that are compatible with this infrastructure.

Ethanol as a Fuel Additive

Even before the establishment of the RFS, ethanol was used as an additive in gasoline. It serves as an oxygenate, to prevent air pollution from carbon monoxide and ozone; as an octane booster, to prevent early ignition, or “engine knock;” and as an extender of gasoline stocks. In purer forms, it can also be used as an alternative to gasoline in automobiles specially designed for its use. Approximately 99 percent of blended gasoline consumed in the United States is “E10”—a blend of gasoline with up to 10 percent ethanol.

The use of ethanol as an oxygenate is linked to the demise of a petroleum derivative known as methyl tertiary butyl ether, or MTBE. MTBE had been used as an octane booster since the late 1970s, and was used in later years to fulfill the oxygenate requirements set by Congress in the 1990 Clean Air Act amendments. According to a report by the Congressional Research Service, MTBE contaminated drinking water, and about half of the states passed legislation to ban or restrict its use.[10] Although MTBE was not restricted by federal law, gasoline refiners sought a substitute because of concerns over potential liability. To replace MTBE, refiners switched to ethanol.

[9] Congressional Research Service, *MTBE in Gasoline: Clean Air and Drinking Water Issues* (updated Apr. 14, 2006).

State Ethanol Mandates

Five states passed and put into effect ethanol mandates similar to the RFS—Hawaii, Minnesota, Missouri, Oregon, and Washington.[11] In Minnesota, Missouri, and Oregon these mandates required 10 percent of blended gasoline to be ethanol, while Washington required 2 percent ethanol in gasoline and Hawaii required that 85 percent of fuel sold in the state must contain 10 percent ethanol. Minnesota was the first to put an ethanol mandate into effect—in May 2003. Hawaii followed with an effective date of April 2006. The Missouri, Oregon, and Washington mandates were put into effect in 2008. Louisiana, Montana, and Pennsylvania also passed laws requiring ethanol blending mandates, but these mandates have not gone into effect because in-state ethanol production volumes have not reached levels required to trigger them.

Tax Credits

The federal government has supported the development of a domestic biofuels industry not only through the RFS but also through tax credits. The Energy Tax Act of 1978, among other things, provided tax incentives designed to stimulate the production of ethanol for blending with gasoline. These blending incentives were restructured as part of the Volumetric Ethanol Excise Tax Credit (VEETC) in 2004.[12] In 2009, we found that the VEETC and the RFS may have been duplicative with respect to their effects on ethanol consumption.[13] We and others found that the VEETC was no longer stimulating additional ethanol consumption. The blending incentives in the VEETC expired in December 2011.

There are also federal tax incentives to promote the production and use of advanced biofuels. These include the Biodiesel Income Tax Credit, which provides a $1 per-gallon tax credit for producers of certain forms of

[11] Florida also enacted an ethanol mandate; however, this mandate did not become effective until December 31, 2010, at which point the nationwide RFS was already requiring ethanol to be blended at high levels, and the Florida mandate was repealed in 2013.

[12] The tax credit was available to those producing alcohol fuel mixtures for sale or use in a trade or business, including the crude oil refiners or gasoline wholesalers that blend the ethanol with gasoline.

[13] GAO, *Biofuels: Potential Effects and Challenges of Required Increases in Production and Use,* GAO-09-446 (Washington, D.C.: Aug. 25, 2009).

biodiesel or renewable diesel.[14] Separately, the Second Generation Biofuel Producer Tax Credit provided advanced biofuel producers a tax credit of up to $1.01 per gallon of advanced biofuel produced and used domestically.[15]

Available Evidence and Analysis Indicate That the RFS Was Likely Associated with Modest Gasoline Price Increases outside the Midwest and Modest Decreases within the Midwest

Evidence from studies, interviews with experts, and our analysis suggest that the nationwide RFS was likely associated with modest price increases outside of the Midwest. Likely variations in these gasoline price effects depended, in part, on state-by-state variation in the costs to transport and store ethanol. For example, the Midwest was already producing and blending ethanol, so it had lower transportation costs and had already built necessary storage infrastructure. Other regions began blending ethanol later as rising volumes of ethanol required under the RFS forced more ethanol into the system and as states began blending ethanol. These states incurred new transportation and storage infrastructure costs, which likely resulted in higher gasoline prices compared to those in the Midwest states or states that had not yet begun to blend ethanol. Overall, it is likely that as the expanded blending requirements of the RFS caused non-Midwestern states and localities to begin blending ethanol, these states and localities experienced increased gasoline prices of a few cents per gallon compared to what they otherwise would have been.

[14]26 U.S.C. § 40A. The biodiesel credit of any taxpayer for any taxable year is $1 for each gallon of biodiesel that is not in a mixture with diesel fuel and that during the taxable year (1) is used by the taxpayer as a fuel in a business, or (2) is sold by the taxpayer at retail to a person and placed in the fuel tank of such person’s vehicle. This credit currently applies only to sales or uses of biodiesel and renewable diesel on or before December 31, 2017.

[15]To qualify for the Second Generation Biofuel Producer Tax Credit, the taxpayer must produce a second generation biofuel and, during the taxable year, sell it to another person for use in producing a qualified second generation biofuel mixture in trade or business, for use as a fuel in trade or business, or to be sold at retail and placed in the fuel tank of the buyer. Such production must occur after December 31, 2008, and before January 1, 2018, to be eligible. Second generation biofuel is defined as liquid fuel produced from any lignocellulosic or hemicellulosic matter that is available on a renewable or recurring basis or any cultivated algae, cyanobacteria, or lemna.

Experts, Stakeholders, and Studies Indicate that the RFS Likely Caused Changes in Retail Gasoline Prices that Varied by Region

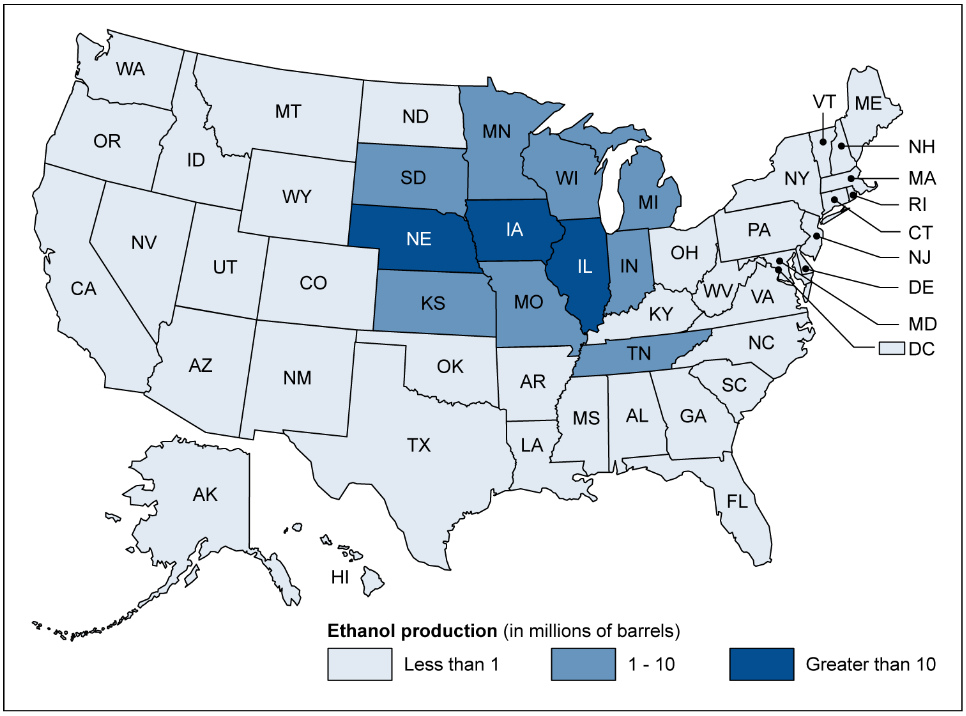
According to the experts we interviewed as well as the studies we reviewed, the RFS likely caused small changes in retail gasoline prices that varied by region. The experts, stakeholders, and studies identified two main ways in which the RFS may have affected prices. Specifically, the RFS may have (1) increased transportation and storage costs in regions outside the Midwest, and, (2) caused an initial increase in refining investment costs that over the long term reduced refining costs for gasoline.

Transportation and Storage Costs

The RFS may have affected retail gasoline prices by increasing transportation costs in certain regions. Retail gasoline consists of two components—ethanol and blendstock, which is the petroleum-based gasoline that ethanol is blended with to make retail gasoline. Currently, blendstock and ethanol are typically transported in different ways. Blendstock can be shipped via pipeline, which is the most cost-efficient method of transporting fuel. However, ethanol is more corrosive and cannot be shipped in pipelines currently used for blendstock; as a result, it must be transported using costlier methods, such as rail, barge, and tanker truck.

Ethanol is produced primarily in the Midwest, where most corn is produced. According to the studies we reviewed, this means that Midwest gasoline retailers, being closer to the supply of ethanol, may have been able to charge consumers lower prices for retail gasoline relative to non-Midwest gasoline retailers because of their lower transportation costs for ethanol. Similarly, higher transportation costs outside of the Midwest may have resulted in higher prices of retail gasoline in those regions. Figure 2 illustrates U.S. ethanol production in 2005, before the RFS became effective.

Figure 2: Ethanol Production by State, 2005



Sources: GAO analysis of Energy Information Administration data; Map Resources (map). | GAO-19-47

In addition, the RFS may also have affected retail gasoline prices by increasing storage costs in certain regions. Because ethanol is more corrosive than blendstock, it must be stored differently. According to one study we reviewed, ethanol was being blended into gasoline in many locations in the Midwest prior to the establishment of the RFS.[16] As a result, the Midwest already had the infrastructure needed to store ethanol. According to another study, in some places outside of the Midwest ethanol was typically not being blended into gasoline prior to the establishment of the RFS, and therefore costly infrastructure changes, such as installing different seals and gaskets in tanks, were needed so that retailers could store blended gasoline.[17] For example, the California

[16] Anderson and Elzinga, "A ban on one is a boon for the other: Strict gasoline content rules and implicit ethanol blending mandates," *Journal of Environmental Economics and Management*, vol. 67(2014), pp. 258-273.

[17] California Energy Commission. "Supply and cost of alternatives to MTBE in gasoline." Staff report. February 1999.

Energy Commission estimated the costs of such infrastructure changes to be approximately $60 million in California. Unlike transportation costs, the costs of infrastructure changes were incurred just once, according to industry stakeholders we interviewed; therefore the effect of such costs on retail prices would be expected to have diminished over time.[18]

Production Costs

The cost of producing retail gasoline depends in part on the costs of its two components. The RFS may have affected the costs of blendstock and ethanol in various ways, and according to the experts we interviewed, past GAO work, and the studies we reviewed, these costs may have contributed to changes in gasoline prices.

Blendstock. The RFS may have initially increased both refiners' costs to produce blendstock compatible with ethanol blending and the costs of shipping and storing such blendstock; however, these costs may have decreased over time. More specifically, the RFS may have initially increased refiners' costs because refiners had to change their configuration to produce a lower octane blendstock to accommodate ethanol blending. Many experts we interviewed stated that producing blendstock with a lower octane level required costly changes to refinery infrastructure and processes. However, according to these experts and stakeholders, since ethanol is relatively high in octane, blending ethanol into retail gasoline allows refiners to produce blendstock with a lower octane level. As a result, according to many of the experts we interviewed, after the initial investment by refineries to switch to the lower octane blendstock, refiners could produce that blendstock at lower cost. This would have led to higher initial costs but lower long-term costs once infrastructure costs had been capitalized.

The higher initial cost is consistent with our past work in which we noted that shipping more types of blendstocks—the result of a proliferation of blendstocks adopted by states and localities to meet Clean Air Act standards—increases the costs of shipping and storing

[18]These infrastructure changes accommodate gasoline with up to 10 percent ethanol. If the percentage of ethanol were to increase, then additional costly infrastructure changes would be needed in locations not already blending to these levels.

blendstocks at terminals for distribution to retail sellers.[19] As a result, according to one expert familiar with our past work, as ethanol blending spread further and further away from the production center in the Midwest states, there were more types of blendstocks in the pipeline and storage terminals, which would have increased costs. This expert said that over the longer run and once ethanol blending had expanded to encompass the majority of gasoline sold in the United States, this effect would have disappeared because virtually all the blendstock flowing through the pipeline and storage system would be compatible with blending ethanol.

Ethanol. It is unclear whether the RFS increased or decreased the cost of ethanol. One source we reviewed indicated that the RFS may have increased the cost of ethanol by increasing demand for corn, which would drive up the price of corn.[20] On the other hand, one expert we spoke to stated that the RFS may have decreased the cost of ethanol in the long term by providing incentives for producers to invest in more efficient ethanol production processes, which would lower production costs over time.[21]

However, it is unclear what the longer-term effects of ethanol blending on gasoline prices have been. We believe this is because once all locations had made the infrastructure investments and most gasoline blendstock produced was consistent with blending ethanol then there would be two continuing effects: (1) the transportation and blending costs of ethanol, which would tend to push retail prices higher and depend on the distance traveled and the modes of transport, and (2) the lower cost of producing lower octane blendstock. The former effect might dominate for locations far from the production source of ethanol and for which more costly modes of transport were used while the lower blendstock costs might dominate for locations close to the production source of ethanol, those

[19] See GAO, *Gasoline Markets: Special Gasoline Blends Reduce Emissions and Improve Air Quality, but Complicate Supply and Contribute to Higher Prices.* GAO-05-421 *(Washington, D.C.: June 17, 2005).* In this report, we found that “The proliferation of special gasoline blends has put stress on the gasoline supply system and raised costs, affecting operations at refineries, pipelines, and storage terminals. Once produced, different blends must be kept separate throughout shipping and delivery, reducing the capacity of pipelines and storage terminal facilities, which were originally designed to handle fewer products. This reduces efficiency and raises costs.”

[20] Robert Wisner. “Corn, Ethanol and Crude Oil Prices Relationships - Implications for the Biofuels Industry.” AgMRC Renewable Energy Newsletter, August 2009.

[21] Some argue that RINs also play a role in determining how the RFS affects input prices and therefore also retail gasoline prices. See below.

that have low transportation costs, or both. However, the data available to us do not allow us to test this long-term effect.

Our Analysis of State Ethanol Mandates Also Found Gasoline Price Decreases in the Midwest and Increases Elsewhere

We studied the effects of ethanol blending mandates in the five states that had such mandates prior to and including 2008; these mandates are similar to but preceded the RFS ethanol blending mandates on retail gasoline prices. We found that these state mandates were associated with gasoline price decreases in the two Midwestern states we evaluated and price increases in three non-Midwestern states.[22] Specifically, during the period we studied, when the ethanol mandates in Minnesota and Missouri were in effect, our model estimates that, all else remaining equal, retail gasoline prices were lower by approximately 8 and 5 cents per gallon in these states, respectively, than they would have been without the mandates. By contrast, when the ethanol mandates in Hawaii, Oregon, and Washington were in effect, our model estimates that, all else remaining equal, retail gasoline prices were higher by approximately 8, 2, and 6 cents per gallon in these states, respectively, than they would have been without the mandates.[23] These results are consistent with what other studies and experts found about the effects of blending ethanol with gasoline.

Our model provides an indicator of the types of effects that the RFS likely had on retail gasoline prices as the increasing ethanol blending targets of the RFS began to push ethanol into more gasoline markets. Specifically, we can infer from the model that the RFS was associated with a modest gasoline price decrease in Midwest states. According to one expert familiar with our analysis and with the blendstock pipeline and storage system, expanding the volumes of lower octane feedstocks to the Midwest states would have the effect of reducing refining production costs because refiners serving the Midwest could do larger runs of lower octane blendstock and therefore benefit from economies of scale in refining runs. In addition, this would also have the effect of reducing pipeline and storage costs for blendstocks because larger volumes of lower octane blendstock could be shipped northward from the refining center in the Gulf of Mexico states to the Midwest. Larger volumes of uniform

[22]We estimated these results using data on gasoline prices throughout the United States from 2001 through 2010.

[23]All state mandate coefficients are statistically significant at the 1 percent level, with the exception of Oregon, which is not different from zero at any relevant level of significance (p-value=0.15).

blendstock during pipeline shipping reduce costs compared to smaller shipments because different blendstocks intermix at the point they interface in a pipeline, and these mixed blendstocks either have to be downgraded and sold for less or pulled out entirely and re-refined to meet existing fuel standards.[24] Conversely, we can infer from the model that the RFS was associated with modest gasoline price increases in states further from the Midwest producers as increasing ethanol targets caused those states to begin blending ethanol for the first time and for which more refining capacity had to convert to produce lower octane feedstock and ship it to more locations, thereby initially raising refining, pipeline, and storage costs as discussed previously in this report.[25]

The results of our analysis are also generally consistent with other work that examined the effects of different state ethanol-blending requirements on gasoline prices. For example, some states and localities started blending ethanol before the RFS made it effectively mandatory when these states and localities banned MTBE, an additive that increased the oxygen content of the fuel. When MTBE was banned, ethanol was typically added in its place. The one peer-reviewed study we identified that estimated the effects of the MTBE ban on gasoline prices found that in locations required to blend ethanol because of state MTBE bans, retail gasoline prices increased by 3 to 6 cents per gallon in non-Midwestern states, with larger price increases during times of high ethanol prices relative to crude oil prices. This study also found that retail gasoline prices in the Midwest may not have changed.[26]

While our own analysis, other studies we reviewed, and experts we spoke to cannot estimate precise price effects of the RFS on retail gasoline, we believe that collectively the evidence points to likely effects that varied by geographic region and that as RFS blending requirements rose and more and more non-Midwestern states and localities adopted ethanol blending, it is likely they saw modest increases in retail gasoline prices on the order of several cents per gallon. Conversely, as more and more states and localities blended ethanol and more refiners began producing larger runs of lower octane blendstock, the costs of acquiring this blendstock likely

[24]See GAO-05-421.

[25]As stated previously in this report, the increase in refining investment eventually reduced refining costs for the blendstock used to blend with ethanol.

[26]Anderson and Elzinga, "A Ban on One Is a Boon for the Other," pp. 258-273.

fell, and because Midwestern states had very low transportation costs for ethanol, their gasoline prices likely fell.

The RFS Has Likely Had a Limited Effect on Greenhouse Gas Emissions to Date and Is Unlikely to Meet Its Future Greenhouse Gas Emissions Reduction Goals

Most of the experts we interviewed generally agreed that to date the RFS has likely had a limited effect, if any, on greenhouse gas emissions. Further, the RFS is unlikely to meet the greenhouse gas emissions reduction goals envisioned for the program through 2022. Regarding the RFS and greenhouse gas emissions to date, experts noted that the effect has been difficult to assess precisely and we found disagreement among some experts about whether the effect has been positive or negative. However, most experts agreed that the effect—whether an increase or decrease—has likely been limited. Regarding meeting RFS greenhouse gas emission reduction goals through 2022, as we reported previously, although advanced biofuels, such as cellulosic ethanol, achieve greater greenhouse gas reductions than conventional biofuels, such as corn-starch ethanol, the latter are likely to continue to account for most of the biofuel blended into domestic transportation fuels under the RFS because they are economical to produce while most advanced biofuels are not.

The Experts We Spoke with Generally Believe the Effect of the RFS on Greenhouse Gas Emissions Has Likely Been Limited to Date

Of the 13 experts we interviewed, 10 generally agreed that the RFS has likely had a limited effect, if any, on greenhouse gas emissions to date.[27] However, these experts said that the effect is difficult to assess precisely, and they disagreed on whether the limited effect has been positive or negative. Specifically, the experts commenting on the topic were roughly evenly split between increases or decreases in greenhouse gas emissions, with some saying there were negligible effects. Experts we interviewed said that the effect that the RFS has had on greenhouse gas emissions is difficult to assess precisely because it involves complex factors that are challenging to quantify, including the lifecycle emissions associated with biofuel use.

The RFS's reliance on corn-starch ethanol to fill biofuel mandates has limited the ability of the RFS to reduce greenhouse gas emissions. Specifically, as we reported in November 2016, most of the biofuel blended to date has been conventional corn-starch ethanol, which has a smaller potential to achieve greenhouse gas reductions compared with

[27]We interviewed 13 experts regarding this objective—the effect of the RFS on greenhouse gas emissions to date. The specific areas of expertise varied among the experts we interviewed, so not all of the experts commented on all of our interview topics.

advanced biofuels.[28] Because of this, several experts we interviewed for the November 2016 report raised concerns about the extent to which the RFS has achieved its design of reducing greenhouse gas emissions.

Furthermore, because the RFS has not been responsible for all of the ethanol used in the United States since the program took effect, not all greenhouse gas reductions associated with ethanol use have been the result of the RFS. More specifically, most experts agreed that ethanol use was historically driven, in part, by favorable market conditions and other policies, including state biofuel mandates, ethanol tax credits, and the phaseout of MTBE as an oxygenate for gasoline. Most experts we interviewed said they believed that the RFS had some effect on biofuel production by creating a guaranteed market for biofuels. Although experts' views differed on the amount of ethanol that would have been produced without the RFS, most of them said that ethanol production capacity would likely be lower today if the RFS had not helped to establish markets. For example, four experts and one industry stakeholder representative that we interviewed hypothesized that if the RFS were repealed, refiners would continue to blend ethanol into fuel, although two experts and one stakeholder representative acknowledged that less ethanol would probably be blended without the RFS. In contrast, one expert indicated that the RFS provides a safety net for the ethanol industry but that this safety net may not be needed anymore.

In addition, according to EPA officials, the vast majority of the corn-starch ethanol used to date has been produced by so-called grandfathered plants—plants in operation or under construction before a certain date—that have been exempt from RFS emissions reductions requirements.[29] The grandfathered plants have likely limited the ability of the RFS to achieve greenhouse gas emissions reductions, but this effect has likely changed over time. Early on, when a higher percentage of grandfathered ethanol plants used coal as an energy source and had older technologies, EPA estimates indicated that ethanol from such plants produced more

[28]GAO-17-94.

[29]Specifically, the RFS does not generally require corn-starch ethanol from plants that were in operation or under construction before December 19, 2007, to achieve any greenhouse gas emissions reductions relative to gasoline. EPA officials said that in 2011, 97 percent of corn-starch ethanol used to meet RFS requirements was produced in grandfathered plants. In 2017 that figure was 89 percent, according to the officials.

greenhouse gas emissions than petroleum-based gasoline.[30] However, most of the experts we interviewed told us that over time grandfathered plants have upgraded technology to remain economically competitive and have converted to natural gas as an energy source, resulting in industry-wide efficiency improvements that reduce greenhouse gas emissions. These experts indicated that such upgraded plants do not likely have significantly different emissions than the newer plants subject to RFS emissions reductions requirements.[31] Little quantitative information is available to compare the difference between greenhouse gas emissions associated with grandfathered plants and those associated newer plants.

Finally, experts we interviewed disagreed on whether ethanol produced today generally complies with the RFS statutory requirement to reduce lifecycle greenhouse gas emissions by 20 percent relative to those of petroleum-based gasoline, which affects the extent to which the RFS has influenced greenhouse gas emissions. Of the 11 experts commenting on the topic, approximately half said that ethanol produced today likely met the 20 percent RFS greenhouse gas reduction requirement. Most of these experts pointed to recent lifecycle analysis studies. Recent studies have found that, relative to petroleum-based gasoline, corn-starch ethanol could reduce lifecycle emissions by 19 to 48 percent.[32] While there are limitations and uncertainty associated with all lifecycle analyses, most experts we interviewed said that the models used for lifecycle analyses have improved over time and can provide reasonably accurate estimates of certain components of direct lifecycle greenhouse gas emissions, such as emissions associated with the energy used for farming and for producing the biofuel in a plant.

[30]See Environmental Protection Agency, "Lifecycle Greenhouse Gas Emissions for Select Pathways," July 2016, accessed January 14, 2019. https://www.epa.gov/fuels-registration-reporting-and-compliance-help/summary-table-lifecycle-greenhouse-gas-emissions.

[31]According to the Renewable Fuel Association, a small percentage of ethanol plants today still use coal as an energy source. Ethanol plants powered by coal produce greater greenhouse gas emissions than those powered by natural gas.

[32]For example, experts referenced studies including Michael Wang, Jeongwoo Han, Jennifer B Dunn, Hao Cai and Amgad Elgowainy. "Well-To-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for U.S. Use," Environmental Research Letters, vol. 7 (2012), and ICF International Inc., A Life-Cycle Analysis of the Greenhouse Gas Emission of Corn-Based Ethanol, a report prepared for the U. S. Department of Agriculture, January 12, 2017.

Of the roughly half of experts who said that corn-starch ethanol likely does not meet the RFS greenhouse gas reduction requirements, almost all pointed to the potential for indirect emissions associated with biofuel production and use. Indirect emissions are complex to estimate and a source of uncertainty in lifecycle estimates, but including them could offset emissions reductions. These indirect emissions can be produced as the result of broad economic changes associated with increased biofuel use, including the following:

- **Indirect land use change.** Indirect land use change occurs when using agricultural land to grow biofuel feedstocks causes the conversion of previously nonagricultural lands in the United States and elsewhere in the world to maintain world agricultural production of food, feed, and fiber.[33]
- **Fuel market effects.** Though difficult to quantify, expanded biofuel use may lead to an unintended increase in the global use of transportation fuel and more greenhouse gas emissions, according to most of the experts saying that corn-starch ethanol does not meet greenhouse gas reduction requirements. For example, increasing biofuel use in one part of the world could increase the relative supply of petroleum in other parts of the world, thereby lowering petroleum prices and increasing use of petroleum products there.

We Previously Reported That Limited Production of Advanced Biofuels Makes the RFS Unlikely to Meet Its Greenhouse Gas Reduction Goals

In November 2016 we reported that, with the exception of biomass-based diesel, production of advanced biofuels was far below the volume needed to meet the statutory targets for these fuels (see fig. 3).[34] For example, we reported that the cellulosic biofuel blended into transportation fuel in 2015 was less than 5 percent of the statutory target of 3 billion gallons. We found in another November 2016 report that the shortfall was the result of high production costs, despite years of federal and private R&D efforts.[35] With regard to future advanced biofuel production, most experts we interviewed for the November 2016 report told us that such production cannot achieve the statutory targets of 21 billion gallons by 2022 because the investments and development required to make these fuels more

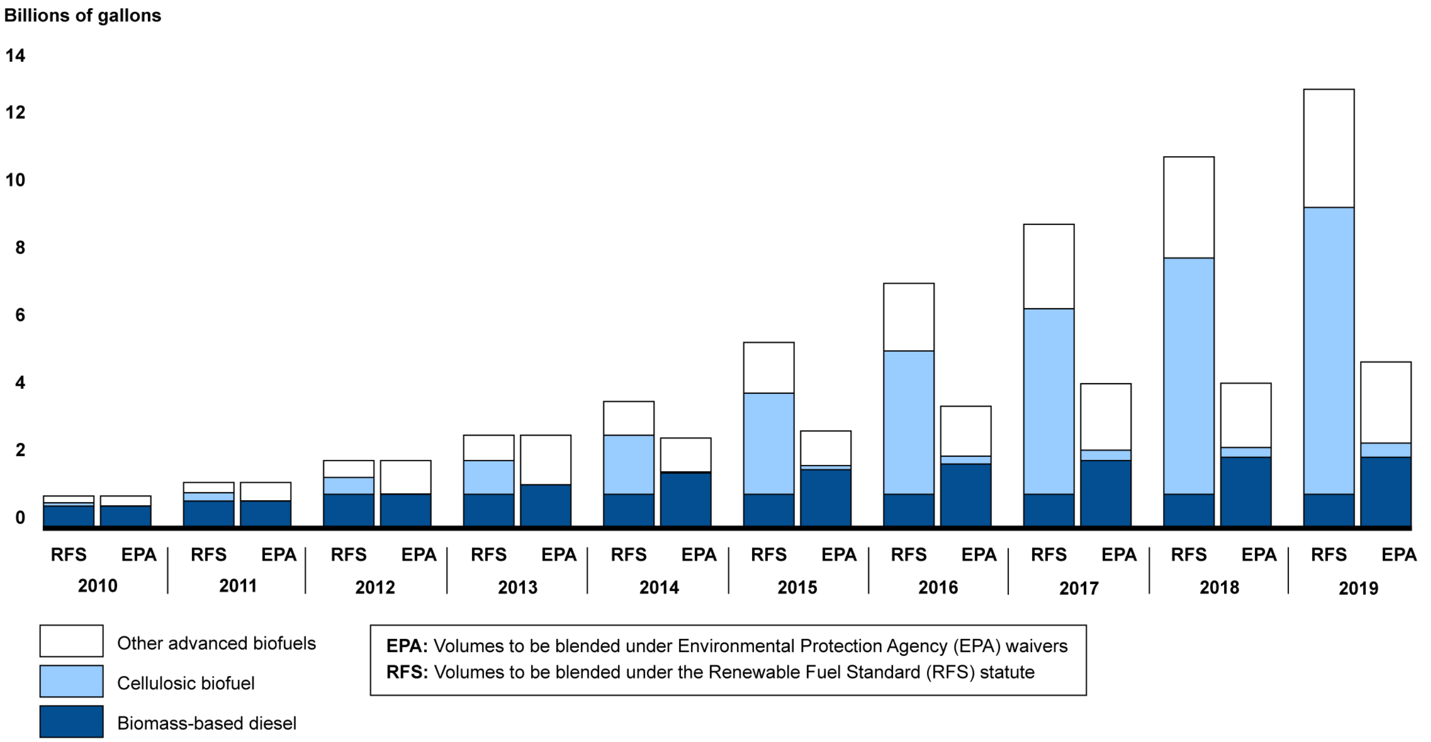
[33]The RFS requires consideration of land use change in estimating a biofuel's lifecycle emissions. The two studies referenced above by Wang et. al. (2012) and ICF (2017) include analyses of indirect land use change.

[34]GAO-17-108.

[35]GAO-17-94.

cost-effective, even in the longer run, were unlikely in the investment climate at the time.[36] Factors affecting this included the magnitude of investment and the expected long time frames required to make advanced biofuels cost competitive with petroleum-based fuels.[37] Because the bulk of greenhouse gas emissions reductions were to come from such advanced biofuels, the expected emissions reductions have also not occurred.

Figure 3: Volumes of Advanced Biofuels to Be Blended into Domestic Transportation Fuel, as Set by the Renewable Fuel Standard Statute and by EPA, 2010 through 2019



Source: GAO analysis of legal requirements and EPA data. | GAO-19-47

[36]GAO-17-94. For this report, we contracted with the National Academy of Sciences for a list of experts on issues related to the RFS. The National Academy of Sciences identified 24 experts with whom we conducted semistructured interviews. For the list of experts we interviewed, see app. II of GAO-17-94.

[37]According to USDA, several large lending institutions have expressed a lack of interest in certain advanced biofuel projects because of the long due diligence process and the fact that the different projects are for now not easily replicated.

Historical Prices of RINs, Concerns regarding Their Effects on Fuel Prices, and EPA's Actions to Mitigate These Concerns

As mentioned previously, EPA uses RINs to regulate compliance with the RFS. Refiners or importers of transportation fuel in the United States are known as "obligated parties" and must submit RINs to EPA. The number of RINs that an obligated party must submit to EPA is proportional to the volume of gasoline and diesel fuel that it produces or imports and depends on the volumes of biofuel that must be blended with transportation fuels during the following calendar year as set by EPA. In accordance with EPA guidelines, a biofuel producer or importer assigns a unique RIN to a gallon of biofuel at the point of production or importation. When biofuels change ownership (e.g., are sold by a producer to a blender), the RINs generally transfer with the fuels.

When a gallon of biofuel is blended or supplied for retail sale, the RIN is separated from the fuel and may be used by the obligated party to demonstrate compliance with the RFS or may be traded, sold, or held for use in the following year. Some vertically integrated refiners own blending operations, so they generate RINs that they can use to demonstrate compliance because they also blend their own fuel. Other refiners do not blend their own fuel and must purchase RINs to demonstrate compliance. The latter are called merchant refiners. Since biofuels supply and demand can vary over time and across regions, a market has developed for trading RINs. If a supplier has already met its required share and has supplied surplus biofuels for a particular biofuel category, it can sell the extra RINs to another entity or it can hold on to the RINs for future use. An obligated party that faces a RIN deficit can purchase RINs to meet its obligation.[38]

Historical RIN Prices

In our March 2014 report on petroleum refining, we noted that the RFS had increased compliance costs for the domestic petroleum refining industry or individual refiners.[39] We reported that, according to the U.S. Energy Information Administration, corn-based ethanol RIN prices were low—from 1 to 5 cents per gallon from 2006 through much of 2012—because it was generally economical to blend up to or above the level that the RFS required. However, in 2013, prices for these RINs increased

[38]RINs may be used for RFS compliance in the year they were generated or the following calendar year. No more than 20 percent of the current-year obligation may be met with the previous year's RINs. The EPA Moderated Transaction System is used to register RIN transactions.

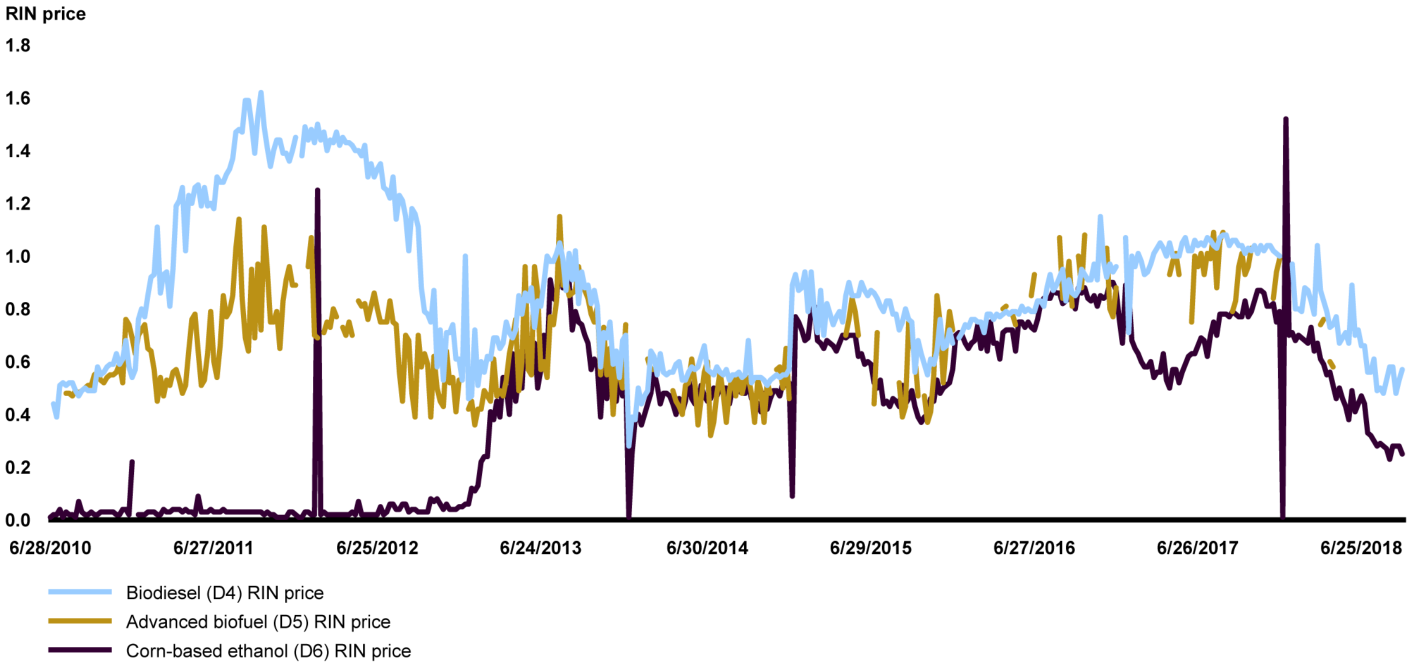
[39]GAO-14-249.

to over $1.40 per gallon in July before declining to about 20 cents per gallon as of mid-November.

Several stakeholders told us at the time that this increase in RIN prices was primarily due to RFS requirements exceeding the capability of the transportation fuel infrastructure to distribute and the fleet of vehicles to use biofuels, a situation referred to as the blend wall. EPA officials told us at the time that high corn prices, which made ethanol more expensive relative to gasoline, also contributed to higher RIN prices during this period. A refiner we spoke with at the time attributed the decline in RIN prices in the second half of 2013 to EPA's statements expressing its desire to address the blend wall. In our report, we noted that while the RFS applies to all refiners in the same way, the effect of the rise in RIN prices may depend on each refiner's situation. Figure 4 shows historical RIN prices for conventional, advanced, and biodiesel RINs.[40]

[40]The figure shows current-year RIN prices using vintage prices for the current compliance year. For example, 2010 conventional RIN prices are for 2010 vintage RINs and 2011 prices are for 2011 vintage RINs. EPA officials told us that the spikes in corn-based ethanol RIN prices that appear in the graph do not follow the trend but may be valid values. EPA officials did not speculate as to why these price spikes occurred; however, we think it is possible that the spikes are the result of a relatively small number of current-year RIN trades as older RINs were used up before expiration at the start of a new calendar year.

Figure 4: Historical Renewable Identification Number (RIN) Prices



Source: GAO analysis of Environmental Protection Agency data. | GAO-19-47

Since our March 2014 report, corn-starch ethanol RIN prices have experienced periods of volatility. One expert stated that this is because ethanol prices have become tied with biodiesel prices since the RFS has required levels above the 10 percent blend wall. EPA officials agreed that once the 10 percent blend wall was reached, ethanol RIN prices have often risen to the price of biodiesel RIN prices. More specifically, biodiesel RIN prices are strongly affected by expectations about whether the biodiesel tax credit will be allowed to expire, which has often happened. In fact, EPA has at times explicitly taken the existence of the biodiesel tax credit into account when making rulings related to the RFS.[41] As a result, both biodiesel RIN prices and ethanol RIN prices experience volatility. In general, ethanol RIN prices have closely tracked biodiesel RIN prices for the last 5 years.

As we noted in our March 2014 report on petroleum refining, prices for RINs reflect several factors, including the cost of renewable fuels

[41] 78 Fed. Reg. 49813 (Aug. 15, 2013).

compared with the petroleum fuels they displace and the stringency of annual blending requirements.[42] One expert we spoke with during the course of the audit work for this report stated that uncertainty about the future of the RFS has also affected RIN prices.

Effect of RINs on Retail Fuel Prices

Three experts and three industry stakeholders we interviewed spoke directly about the effect of RINs on retail fuel prices. All three experts stated that if RINs have any effect on prices it is small, while two of those experts also asserted that it was possible that RINs had no effect on prices at all. These experts argued that in a perfectly competitive fuel market, the blendstock refiners increase the price of blendstock because they know that they will need to pay for the RINs. At the same time, the retail gasoline blenders are able to save costs related to ethanol because of the value they receive for selling the RINs. In practice, according to experts, the market may not be perfectly competitive, so it is possible that RINs add from 1 to 10 cents to the retail price of gasoline in some parts of the country. One industry stakeholder also expressed the opinion that RINs would have little to no effect on retail gasoline prices, citing the same argument.

Two industry stakeholders indicated that RINs would increase retail gasoline prices, although they did not specify by how much. These stakeholders argued that RINs represent the cost of producing retail gasoline; because ethanol has historically had a higher cost per mile than gasoline (though not per gallon), the RINs would represent this increased cost and would be reflected in retail gasoline prices. An EPA analysis found that RIN prices did not have a significant impact on retail fuel prices and concluded that any expected impact would be very small.[43] For retail gasoline, EPA made the same argument as experts and stakeholders cited above.

[42]GAO-14-249.

[43]Environmental Protection Agency, Office of Transportation and Air Quality, *A Preliminary Assessment of RIN Market Dynamics, RIN Prices, and Their Effects* (Washington, D.C.: May 14, 2015).

Problems Identified with the RIN Market and Steps Taken by EPA to Address These Problems

Although oil refineries and importers are the entities that are obligated to demonstrate compliance with the RFS, not all of them produce blended fuels. Thus, these entities cannot earn RINs themselves and need to purchase them on the RIN market. Our past work, as well as EPA analysis, has identified several issues of concern with RINs, including possible fraud in the market and concerns about the effect on small refiners, price volatility, and the point of obligation.

- **Fraudulent RINs.** As we reported in our November 2016 report on the RFS, some experts we spoke with at the time identified reducing RIN fraud and price volatility as a federal action that could incrementally encourage investment in advanced biofuels.[44] Specifically, these experts said that a lack of transparency in the RIN trading market has led to an increased risk of fraud and increased volatility of RIN prices. Because RINs are essentially numbers in a computerized account, there have been opportunities for fraud, such as double counting RINs or generating RINs for biofuels that do not exist.[45] For example, in our March 2014 report on petroleum refining we reported that EPA had issued several notices of violation alleging that five companies generated invalid RINs without producing qualifying renewable fuels.[46] EPA officials told us that, since that time, EPA has made additional notices of violation, although many pertain to actions taken prior to March 2014.

  Since the start of the RFS, EPA has alleged that approximately 382,524,480 RINs are invalid. Furthermore, obligated parties that inadvertently purchase fraudulent RINs lose the money spent to purchase them, must purchase additional RINs to meet their obligations, and face additional costs. This has a disproportionate effect on small refiners, according to our November 2016 report.[47] Whereas large obligated parties—in particular, vertically integrated refiners that typically own blending operations—can generate RINs by blending fuel, small refiners do not blend fuel, must purchase their

[44]GAO-17-94.

[45]Congressional Research Service, Analysis of Renewable Identification Numbers (RINs) in the Renewable Fuel Standard (RFS), R42824 (Washington, D.C.: July 22, 2013).

[46]GAO-14-249.

[47]GAO-17-94.

RINs on the market to meet their obligations, and are therefore more likely to be adversely affected by fraudulent RINs.

To address concerns over these issues, EPA established an in-house trading system called the EPA Moderated Transaction System (EMTS). EPA officials believe that this system provides significant capabilities over prior reporting tools used to implement the RFS, allowing enforcement to more quickly identify potential RFS violations versus entry errors that were common with pre-EMTS RFS reporting. EPA officials also informed us of a voluntary quality assurance program intended to provide obligated parties a program to ensure that RINs entering commerce are valid. However, EPA has maintained that verifying the authenticity of RINs is the duty of obligated parties.

- **Distribution of compliance costs.** In our March 2014 report on petroleum refining, we reported that, according to EPA, refiners experience the same compliance costs regardless of whether they are vertically integrated refiners or merchant refiners that purchase RINs for compliance.[48] However, we also reported that the views of several stakeholders differed from EPA's. In that regard, in a 2011 study, the Department of Energy reported that the degree to which a small refiner can actively blend refinery production with biofuels could contribute greatly to the economic hardship incurred from complying with the RFS.[49] We noted that, while the RFS applies to all refiners in the same way, effects of rising or falling RIN prices may vary depending on each refiner's situation. According to several stakeholders we interviewed at the time, RFS compliance had been most difficult for merchant refiners, because they did not blend their own fuel and had to purchase RINs from others, increasing their costs of compliance.
- **Price volatility.** Similarly, according to the experts we interviewed for our November 2016 report on the RFS,[50] price volatility in RIN markets had adversely affected small refiners in particular and led to uncertainty among investors. While most RINs are bought and sold through private contracts registered with the EMTS, as we mentioned

[48]GAO-14-249.

[49]Department of Energy, Office of Policy and International Affairs, *Small Refinery Exemption Study: An Investigation into Disproportionate Economic Hardship* (March, 2011).

[50]GAO-17-94.

previously, RINs are also traded in markets. Some experts that we interviewed for the November 2016 report told us that price volatility may have been due, in part, to nonobligated parties speculating in these markets. Such price fluctuations introduced uncertainty for small refiners about the costs of compliance with the RFS because they had to purchase their RINs on the market.

- **Placement of the point of obligation.** In our November 2016 report on the RFS,[51] we reported that according to some experts, blenders should be the obligated parties instead of importers and refiners. According to some of these experts, when EPA designed the RFS, it placed the obligation for compliance on the relatively small number of refiners and importers rather than on the relatively large number of downstream blenders in order to minimize the number of obligated parties to be regulated and make the program easier to administer.

  However, these experts told us that obligating refiners and importers has not worked to incentivize investors to expand infrastructure to accommodate higher ethanol blends. One expert we spoke with stated that because blenders are either retailers or sell to retailers, blenders would be better situated to pass RIN savings along to consumers. This in turn might encourage demand for higher ethanol blends and incentivize infrastructure expansion. Some experts told us at the time that EPA should make RIN market trading more open and transparent like other commodity markets, which could reduce the potential for fraudulent RIN activities and reduce RIN price volatility.

EPA has taken some actions to address these issues. Specifically, EPA officials we interviewed for this report told us that EPA publishes a variety of aggregated information on its website each month to promote market transparency, including RIN generation and use, available RINs, RIN prices and trade volumes, RIN holdings, and small refinery exemption information. According to these officials, EPA also requires all RIN trades to be entered into EMTS from both the buy and sell sides, and only finalizes a transaction in the system if the buy and sell sides match. EPA officials said that transparency of aggregated RIN data helps the market function more efficiently and minimizes price volatility; however, they acknowledged that many factors contribute to RIN prices and RIN price changes, and it is impossible to attribute such changes to any single factor. Furthermore, according to EPA officials, the memorandum of understanding on RIN market manipulation that EPA has entered into with the Commodity Futures Trading Commission will also help make RIN

[51] GAO-17-94.

markets more open and transparent. Finally, EPA officials stated that in response to a recent White House direction, EPA is currently drafting a regulatory proposal to implement market reforms and additional transparency measures to prevent price manipulation in the RIN market.

According to EPA officials we interviewed for this report, EPA received several petitions requesting that it consider changing the point of obligation from refiners and fuel importers to fuel blenders. In November 2017, EPA denied the petitioners' request. In the denial, EPA said that it does not expect a benefit of increased use of biofuels as a result of changing the point of obligation. Furthermore, it is EPA's position that changing the point of obligation could increase the complexity of the RFS program and would likely disrupt both the RFS program and the fuels market.

By law, small refineries were exempted from the RFS through compliance year 2010, and 24 small refineries were granted an exemption for compliance years 2011 and 2012.[52] Beginning with the 2013 compliance year, small refineries have been able to petition EPA annually for an exemption from their RFS obligations. EPA states on its website that EPA may grant the extension of the exemption if EPA determines that the small refinery has demonstrated disproportionate economic hardship. According to EPA officials, the statute directs EPA to consult with the Department of Energy, and to consider the department's Small Refinery Study and "other economic factors" in evaluating small refinery exemption petitions. EPA conducts its review of small refinery petitions on a case-by-case basis and applies these statutory criteria to its evaluations.

According to EPA's website, EPA's decision to grant an exemption has the effect of exempting the gasoline and diesel produced at a refinery from the percentage standards, and the exempted refinery is not subject to the requirements of an obligated party for fuel produced during the compliance year for which the exemption has been granted. For the first few years, EPA data show that EPA granted roughly half of petitions; however, starting in compliance year 2016, the number of exemptions granted increased significantly. In compliance year 2016, EPA received

[52]The RFS regulations define a small refinery as one with an average crude oil throughput no greater than 75,000 barrels per day (bpd) crude in 2006. Additionally, the small refinery may not have an average aggregate daily crude oil throughput greater than 75,000 bpd in the most recent full calendar year prior to submitting a petition, and cannot be projected to exceed the 75,000 bpd threshold in the year or years for which it is seeking an exemption.

20 petitions and granted 19, with the final petition still pending. In compliance year 2017, EPA received 37 petitions and granted 29, with 1 declared ineligible or withdrawn and the remaining 7 still pending.[53] The data show that this increase in granted exemptions correlates to an increase in estimated exempted volumes of gasoline and diesel, with the exempted amounts increasing from 3.07 billion gallons in compliance year 2015 (equivalent to an estimated 290 million RINs) to 13.62 billion gallons in compliance year 2017 (equivalent to an estimated 1,460 million RINs). To put these volumes into context, EPA data show that the total renewable volume obligation for compliance year 2015 was 17.53 billion gallons and for compliance year 2017 it was 18.91 billion gallons.

Agency Comments and Our Evaluation

We provided a draft of this report to the Departments of Agriculture and Energy, and to the Environmental Protection Agency, for review and comment. USDA, DOE, and EPA provided technical comments, which we incorporated where appropriate. USDA also provided written comments, which are reproduced in appendix IV. In summary, USDA expressed concerns in three areas.

First, USDA disagreed with GAO's conclusion that the RFS has had a limited effect, if any, on reducing greenhouse gas emissions. USDA asserts that scientific research shows significant effects on greenhouse gas emissions from blending ethanol into the nation's fuel supply, based on the greenhouse gas benefits of ethanol produced using current technologies relative to gasoline. The objective of our work was to address the effect to date on greenhouse gas emissions that has been specifically attributable to the RFS, not whether blending ethanol into the nation's fuel supply has effects on greenhouse gas emissions. We report that the RFS is not the only reason that ethanol is used in the fuel supply, and that ethanol would have been produced and used in the United States, even without the RFS. For example, as we noted in the report, ethanol blended into gasoline provides benefits as an oxygenate, to prevent air pollution from carbon monoxide and ozone; as an octane booster, to prevent early ignition, or "engine knock;" and as an extender of gasoline stocks. As a result, not all greenhouse gas reductions associated with ethanol use have been the result of the RFS. Drawing conclusions about the broader impact of ethanol on emissions generally

[53]EPA has received 22 petitions during compliance year 2018, all of which currently remain pending.

was not our objective and is not appropriate for a report examining the impact of the RFS.

Second, USDA criticized our methodology, which reported experts' views on the effect of the RFS on greenhouse gas emissions. USDA stated that this methodology, by design, could not arrive at a consensus and did not synthesize the latest research. We chose our methodology, which relied on expert views supplemented by relevant reported research, because of its ability to yield more extensive, informative, and supportable answers to our objective than a narrower literature review, as suggested by USDA. More specifically, we reviewed much of the literature on this subject, and used the literature, along with referrals from other experts and recommendations from the National Academy of Sciences for prior GAO work, to assist in selecting experts whose expertise included knowledge of the relevant and most recent research on the issue. We selected respected experts representing all perspectives to span the disciplines required to answer our objective and to guard against drawing biased conclusions. Those experts were aware of all research, even that with conclusions contrary to their own. The studies that USDA cites do not represent a wide range of perspectives; they represent the views of a few studies focused specifically on the lifecycle emissions of ethanol. In addition, as we indicate, the perspectives we obtained from industry stakeholders were not used to support our findings on the effects of the RFS on greenhouse gas emissions, as USDA implies. Rather, stakeholders' views were used to inform some of our examples and corroborate some aspects of the experts' views—we attribute information to the stakeholders in these instances. The consensus we found among experts representing diverse perspectives was that the RFS has likely had a limited effect on greenhouse gas emissions to date and that the program is unlikely to meet its future greenhouse gas emissions reduction goals.

Third, USDA commented that our conclusion that the RFS likely had modest impacts on gasoline prices should be augmented by a discussion of the volatility of gasoline prices. USDA's comments appear to imply that the changes in prices we found are even smaller or less impactful on consumers because overall gasoline prices are themselves volatile. This is not an accurate interpretation of what we found. For example, increased prices in non-Midwest states represent additional expenditures on gasoline and consequent reductions in other household spending. Because a discussion of historic gasoline price volatility does not have bearing on the effect of the RFS on prices, we are not including it.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the appropriate congressional committees; the Secretaries of Agriculture and Energy; the Administrator of the Environmental Protection Agency; and other interested parties. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

Sincerely yours,

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Lists of Experts GAO Interviewed

To determine what is known about the effect that the Renewable Fuel Standard (RFS) has had to date on 1) retail gasoline prices in the United States and 2) greenhouse gas emissions, we conducted semistructured interviews with 18 experts with expertise on these topics. Of the 18 experts we interviewed, 7 discussed the effect that the RFS has had on retail gasoline prices. Thirteen discussed the effect that the RFS has had on greenhouse gas emissions, though one expert declined to be identified. Two of the experts commented on the effect of the RFS on both prices and emissions. The specific areas of expertise varied among the experts we interviewed, so not all of the experts commented on all of our interview topics. The experts we interviewed for each topic are listed below.

Experts Interviewed about the Effect of the RFS on Retail Gasoline Prices

Dr. Soren Anderson, Michigan State University

Dr. Bruce Babcock, University of California, Riverside

Dr. Antonio Bento, University of Southern California

Dr. Scott Irwin, University of Illinois

Dr. David Just, Cornell University

Dr. GianCarlo Moschini, Iowa State University

Dr. Sebastien Pouliot, Iowa State University

Experts Interviewed about the Effect of the RFS on Greenhouse Gas Emissions

Dr. Antonio Bento, University of Southern California

Dr. John M. DeCicco, University of Michigan

Dr. Jason Hill, University of Minnesota

Dr. Stephen Kaffka, University of California, Davis

Dr. Madhu Khanna, University of Illinois

Dr. Lee Lynd, Dartmouth College

Dr. Steve McGovern, PetroTech Consultants, LLC

Dr. John Miranowski, Iowa State University

Dr. GianCarlo Moschini, Iowa State University

Dr. Richard Plevin, University of California, Berkeley

Dr. Wallace E. Tyner, Purdue University

Dr. Michael Wang, Argonne National Laboratory

One expert we interviewed declined to be identified.

Appendix II: List of Industry Stakeholders Whose Representatives GAO Interviewed

Advanced Biofuels Association

American Petroleum Institute

American Soybean Association

Andeavor

Growth Energy

Natural Resources Defense Council

National Corn Growers Association

National Wildlife Federation

POET

Renewable Fuels Association

Union of Concerned Scientists

Appendix III: Technical Discussion of Econometric Model Estimating Effects of Ethanol Mandates on Retail Gasoline Prices

This appendix describes the econometric model we developed to estimate the effect of the state ethanol mandates on retail gasoline prices, provides the results, and discusses limitations.

Econometric Model

In order to develop evidence of the likely effects of the Renewable Fuel Standard (RFS) on the incremental adoption of ethanol blending by states as RFS targets grew, we developed an econometric model to analyze the effect state ethanol mandates on retail gasoline prices. Specifically, we analyzed how state policies mandating certain levels of ethanol blending in retail gasoline affected retail gasoline prices in those states.

We obtained retail gasoline price data from the Oil Price Information Service.[1] The data identified the simple average price across each state for each grade of fuel—regular grade gasoline, midgrade gasoline, premium gasoline, and diesel. There also exist local fuel specifications, on top of state policies. Price data are only available at the state level, and we are not able to identify directly the effect of local fuel policies on prices. We therefore included controls that represent the percentage of retail stations in the state that are affected by the local specifications.

To reduce distortion from dissimilar regulations and outliers, we did not include prices (1) from the state of California[2] and (2) for products other

[1]The Oil Price Information Service is a leading provider of retail fuel prices.

[2]Reid vapor pressure (RVP) is a common measure of and generic term for gasoline volatility. California regulates fuel RVP at the “air basin” level rather than at the county level, so we could not accurately code in the RVP variables. More important, California’s Low Carbon Fuel Standard (LCFS) may complicate analysis. The LCFS is a policy that is somewhat similar to the RFS but that has important differences. Like the RFS, it incentivizes use of fuels other than gasoline through a requirement that a certain number of credits be submitted to show compliance, similar to the Renewable Identification Number system. However, rather than requiring specific fuel volumes or percentage blends of ethanol and biodiesel, the LCFS and its credits are based on calculated carbon intensity values for different types of fuel. Therefore, the LCFS would create incentives that would be different from those created under volume standards such as the ones included in the RFS. As a result, we excluded data from this state from the model.

than regular-grade gasoline.[3] Therefore, the data we used for our analysis comprised prices collected from 49 states and the District of Columbia for the period of 2001 through 2010, for a total of 6,000 observations.

Over the period 2001 through 2010, retail gasoline prices are highly correlated across states over time. Specifically, to illustrate, we ran a simple regression model of retail gasoline prices on year-month (fixed-effect) controls. The results show that over 90 percent of the variation in retail gasoline prices over time across states is explained by these simple year-month controls. This suggests nationwide factors explain much of the variation in retail gasoline prices across states over time. The available data are not sufficiently rich to allow us to reliably disentangle the separate effects on retail gasoline prices of various nationwide factors, such as, perhaps, changes in crude oil prices, demand for gasoline, and the roll-out of the RFS. Hence, below, we examine instead the (incremental) effect on state-level retail gasoline prices of state ethanol mandates that are effective at a time when the RFS was requiring relatively low levels of ethanol blending nationwide.

Dependent Variable

Our dependent variable in the model was the monthly average after-tax retail price in dollars per gallon of regular-grade gasoline.

Explanatory Variables

Our model included a variety of explanatory variables, including state ethanol mandates, other state and local ethanol policies and fuel specifications, and the Petroleum Administration for Defense District

[3]The Oil Price Information Service defined the grades of gasoline in the data. These grades are not the same across the country. We decided for methodological reasons to focus on the effect of ethanol mandates on regular-grade gasoline prices. For example, according to the information in the Oil Price Information Service Fuel Regs & Specs Handbooks, fewer states had effective biodiesel mandates and effective biodiesel mandates largely required very low blends of biodiesel, which may reduce statistical power to quantify an effect. Some states exempted premium gasoline from the ethanol mandates, creating the same problem, and many states had fewer gasoline stations that sold midgrade and premium gasoline, also reducing the statistical power. Because our report is retrospective and ethanol makes up a much larger proportion of required fuel blending than biodiesel, this scoping decision largely reflects the influence of the RFS on fuel prices to date.

(PADD)-level gasoline inventory-sales ratios and refinery capacity utilization rates.[4]

- **State ethanol mandates.** The variables of interest in the model were indicators for state ethanol mandates; the state ethanol mandate indicator variables take the value of one for any month in which that state has an effective ethanol mandate and take a value of zero otherwise.[5] The mandates ranged in the percentage of ethanol they required to be blended into gasoline, from approximately 10 percent in Minnesota, Missouri, and Oregon to 2 percent in Washington, with Hawaii having a unique requirement that 85 percent of fuel sold in the state must contain 10 percent ethanol.
- **Other state ethanol policies.** We used as controls indicators for several other state ethanol policies to shed light on how these policies may have affected retail gasoline prices. Specifically, we controlled for state fleet requirements to use ethanol; direct ethanol incentives that reduce the cost of ethanol per gallon of fuel, such as tax credits or rebates; ethanol production incentives; and ethanol consumption incentives. Production incentives included financial incentives to produce ethanol, such as grants or payments to build or operate an ethanol plant or to grow ethanol feedstock. Consumption incentives included financial incentives to sell or use ethanol, such as grants or tax incentives to upgrade fueling infrastructure to sell ethanol or a tax credit to stations selling ethanol. We also controlled for state methyl tertiary butyl ether (MTBE) bans, as ethanol was the primary substitute that could be used in place of MTBE.
- **Local-level fuel specification requirements.** We controlled for local-level fuel specification requirements, such as the gasoline type, RVP levels, and oxygenated fuel requirements.[6]

[4]PADDs are geographic aggregations of the 50 states and the District of Columbia into five districts: PADD 1 is the East Coast, PADD 2 is the Midwest, PADD 3 is the Gulf Coast, PADD 4 is the Rocky Mountain Region, and PADD 5 is the West Coast.

[5]A few states adopted ethanol mandates that would not take effect until certain production levels of ethanol were met in the state. We do not change the value of the ethanol mandate indicator to one until these qualifications are met and the mandate becomes active. For some policies, this never occurs, and those state ethanol mandates have a value of zero in our data set.

[6]For more information on the importance of controlling for different fuel specifications when modelling gasoline prices, see W. David Walls and Frank W. Rusco, “Price Effects of Boutique Motor Fuels: Federal Environmental Standards, Regional Fuel Choices, and Local Gasoline Prices,” The Energy Journal, vol. 28, no. 3 (2007), pp. 145-163.

- **Volume of inventory of gasoline relative to the volume of sales of gasoline.** We used as a control the ratio of finished motor gasoline stocks to the sales of motor gasoline. This variable indicates when supply is high relative to demand and vice versa.
- **Refinery capacity utilization rate.** We controlled for refinery operable utilization rate, which represents the utilization of crude oil distillation units. This variable represents the balance between supply volume and costs of production. Both this variable and the inventory-sales ratio have been found to be endogenous in past work.[7]
- **State gas taxes.** We control for the level of state gas taxes using data from the Department of Transportation's Federal Highway Administration.
- **Fixed effects.** We used a set of indicator variables to account for fixed effects associated with time and individual states. Specifically, we used a set of state fixed effects to account for persistent differences between states, such as transportation costs of fuels to that state. Each model also included year-month fixed effects—one for each month in the data—to control for nationwide events, as well as state-calendar month fixed effects to allow seasonality to vary by state.

The Model

Our model can be written as follows:

$$y_{smt} = \beta_0\, RACity\ errors\ + (STATE_s \times ethanolmatdate_{smt})'\beta_1 + (FRAC_{st} \times FUELREGS_{smt})'\beta_2 + X'_{smt}\beta_3 + \alpha_{sm} + \gamma_{tm} + \varepsilon_{smt}$$

- y_{smt} is the dependent variable in our model; namely, the average after-tax price per gallon of regular grade gasoline at state s in month m and year t.
- $STATE_s \times ethanolmandate_{smt}$ is a vector of interaction terms, where $STATE_s$ is a vector of dummies for each state with a mandate—Hawaii, Minnesota, Missouri, Oregon, or Washington—and $ethanolmandate_{smt}$ an indicator that is equal to 1 for all months that an ethanol mandate is effective for that state, and zero otherwise.

[7]For more information on the endogeneity of these variables and the choice of instruments, see Michael Kendix and W. D. Walls, "Oil industry consolidation and refined product prices: Evidence from US wholesale gasoline terminals," Energy Policy, vol. 38 (2010), pp. 3498-3507.

- $FRAC_{st} \times FUELREGS_{smt}$ is a vector of interaction terms where $FRAC_{st}$ is a measure of the proportion of gas stations in a state likely affected by various fuel regulations in a given year, and $FUELREGS_{smt}$ is a vector of indicator variables equal to one in those months that a state is subject to fuel regulations related to RVP levels, boutique fuels, reformulated gasoline, and oxygenated fuel.
- X_{smt} is a vector of remaining control variables, including state gasoline tax in cents per gallon, inventory sales-ratio, refinery utilization rate, and indicator variables for other state ethanol policies, including effective MTBE bans, fleet requirements, direct incentives, production incentives, and consumption incentives.[8]
- α_{sm} is a set of state-calendar month fixed effects to account for permanent differences in a state's average gasoline prices across months.
- γ_{tm} is a set of month-year fixed effects to account for time-varying factors affecting average gasoline prices for all states, such as fluctuations in crude oil prices.
- ε_{smt} is an error term that is clustered by state.

Our model assumes that after controlling for time-variant factors, the timing of state ethanol mandates going into effect is not correlated with unobserved time-variant factors that affect gasoline prices. When this assumption is satisfied, then our model may estimate the effect of state mandates on gasoline prices. Since ethanol mandates go into effect at different times—in 2003 (Minnesota), 2006 (Hawaii), and 2008 (Missouri, Oregon, Washington)—our quasi-experiment introduces variation in ethanol mandates across time and across states. We are able to address many concerns about omitted variable bias by including detailed state-calendar month fixed effects and month-year fixed effects.

Results

We estimate that all else remaining equal, when the ethanol mandates in the Midwestern states of Minnesota and Missouri were in effect, retail gasoline prices in those states were lower by approximately 8 and 5 cents, respectively, than they would have been without the mandates. We also estimate that all else remaining equal, when the ethanol mandates in Hawaii, Oregon, and Washington were in effect, retail gasoline prices in

[8]Monthly data by state were unavailable for some controls. Specifically, we use annual state gasoline tax data from the Federal Highway Administration and refinery utilization rate and inventory sales-ratio based on monthly PADD-level data that the U.S. Energy Information Administration published.

those states were higher by approximately 8, 2, and 6, cents, respectively, than they would have been without the mandates.[9]

The variables used in the model to control for effects other than ethanol mandates had the expected directional effect on price or else were not significant (using a 5 percent significance level). Our controls for the boutique fuel blends and the state gasoline taxes were significant and positive, suggesting that states with more stringent fuel specifications and higher gasoline taxes have a higher after-tax gasoline price. The estimated effect for refinery utilization rate is negative and statistically significant, suggesting that fuel prices decrease with refinery utilization rates because higher supply decreases prices. Although we might expect that fuel prices would decrease with the inventory/sales ratio because this indicates that supply is high relative to demand, it is also possible that when inventories are below a critical threshold, prices will rise regardless of how high inventories are relative to sales, as has been seen in prior work, so the positive coefficient in our model has precedent.[10] Table 1 shows the results of the econometric model.

Table 1: Estimation Results for Retail Gasoline Prices Model, Using Two-Way Fixed Effects Estimation

Variable	Estimated coefficient
Hawaii ethanol mandate	0.076***
	(0.0084)
Minnesota ethanol mandate	-0.082***
	(0.018)
Missouri ethanol mandate	-0.049***
	(0.011)
Oregon ethanol mandate	0.018
	(0.013)
Washington ethanol mandate	0.059***
	(0.018)
State gasoline tax	0.0074***
	(0.0020)

[9]All state mandate coefficients are statistically significant at the 1 percent level, with the exception of Oregon, which is not different from zero at any relevant level of significance (p-value=0.15).

[10]See Kendix and Walls, "Oil industry consolidation and refined product prices: Evidence from US wholesale gasoline terminals" Energy Policy, vol. 38 (2010), pp. 3498-3507.

Variable	Estimated coefficient
State fleet requirement	-0.0071 (0.011)
Direct incentive	-0.0027 (0.015)
Production incentive	-0.0034 (0.012)
Use incentive	0.0072 (0.015)
Effective methyl tertiary butyl ether ban	-0.0080 (0.0085)
Percentage of gasoline stations in the state selling fuel with less than 9 lbs. Reid vapor pressure (RVP)	0.070 (0.11)
Percentage of gasoline stations in the state selling fuel with at least 9 lbs. RVP	-0.047 (0.040)
Percentage of gasoline stations in the state selling boutique fuel	0.14*** (0.037)
Percentage of gasoline stations in the state selling reformulated gasoline	0.37 (0.45)
Percentage of gasoline stations in the state selling oxygenated fuel	0.0029 (0.018)
Inventory-sales ratio	0.0028 (0.092)
Refinery utilization rate	-0.0024*** (0.00050)
Constant	1.87*** (0.11)
Observations	6000

Legend:
* = parameter estimate significance less than 10 percent;
** = parameter estimate significance less than 5 percent;
*** = parameter estimate significance less than 1 percent.

Source: GAO Analysis | GAO-19-47

Notes: If an estimate in this table has no asterisks, this means that the estimate is not significant at any of these levels. In this case, our estimates were either significant at the less than 1 percent level or were not significant at any of these levels. The table lists parameter estimates with standard error in parentheses. Heteorskedastic robust standard errors (we used xtreg in Stata with the robust option) were estimated using clustering at the state level. We do not report the fixed effect parameters for year-month or state-month, but they were included in the model.

We tested alternate specifications, such as the following:

- Including different subsets of the explanatory control variables in the model.
- Treating the inventory/sales ratio and the refinery utilization rate as endogenous.
- Using pre-tax prices by subtracting state gasoline taxes from after-tax prices rather than including taxes as a control variable.

Our results, including the magnitude and directional impact of the various state ethanol mandates, were not meaningfully affected across such specification tests.

Limitations

Our analysis had a number of limitations as listed below.

- **We did not directly estimate the effect of the RFS on prices.** The policy was nationwide and there are no reliable state-level data with which to measure state-level ethanol gasoline blend rates as the RFS was implemented over time. However, there is no reason to believe that other states that incrementally adopted the blending of ethanol as a result of increasing RFS targets would have experienced different effects.
- **There may be some endogeneity in the timing of the adoption of the ethanol mandates.** These policies are likely easier to pass through state legislatures when corn or ethanol prices are lower than oil or gasoline prices or when gasoline prices are high, but given that the effective dates are usually several years after the laws are enacted, this actual effective timing should be exogenous.
- **We believe the state-level ethanol regulation data are comprehensive, but some regulations may not appear in the data.** In our analysis, we include controls for ethanol mandates as well as several other types of ethanol incentives and fuel specification requirements. These variables control for the effects of related ethanol policies as well as variations in the cost of producing retail gasoline. We are certain that all state ethanol mandates were included in the model. However, our model may not perfectly control for all other regulations that could affect retail gasoline prices.
- **Some control variables were not available at the state or monthly level.** For example, some controls, such as the refinery capacity utilization rate, were available at the regional level only, so we had to parse out the regionally aggregated observations accordingly.

- **As in any model, there is the possibility of misspecification or bias.** Inappropriate assumptions about the functional form of the model, failure to deal with endogenous variables, or exclusion of relevant variables could also cause our estimated effects to deviate from the true effects. Some amount of this bias is present in almost all regression results, although the amount may not be very large.[11]

[11] For more information on specification error, see A.H. Studenmund, *Using econometrics: a practical guide.* Sixth edition, Pearson Education, Harlow, 2014.

Appendix IV: Comments from the U.S. Department of Agriculture

USDA

United States Department of Agriculture
Office of the Chief Economist
Room 112-A J.L. Whitten Building
1400 Independence Avenue, SW
Washington, D.C. 20250-3810

APR 9 2019

Mr. Frank Rusco
Director, Natural Resources and Environment
U.S. Government Accountability Office
Natural Resources and Environment
441 G Street, NW
Washington, DC 20548

Dear Mr. Rusco:

Thank you for the opportunity to provide comments and a response to the U.S. Government Accountability Office (GAO) report "Renewable Fuel Standard: Information on Likely Program Effects of Gasoline Prices and Greenhouse Gas Emissions". The Department of Agriculture (USDA) does not agree with the conclusions drawn by GAO that "the Renewable Fuel Standard (RFS) has likely has a limited effect, if any, on greenhouse gas (GHG) emissions." Our scientific research and recent research by others show significant and growing greenhouse gas benefits of corn-based ethanol and other biofuels.

We have concerns with the methodology used in the GAO assessment because it reflects the views of a group of individuals rather than a synthesis of the latest research. Instead of assessing recent relevant literature regarding the greenhouse gas profile of corn ethanol and the GHG impacts of the RFS, GAO chose to survey individuals it identified as subject experts and/or key industry stakeholders. The list of 13 experts (Appendix 1) and the list of 11 industry stakeholders (Appendix 2) was selected to have strong and divergent views and/or professional interests concerning corn ethanol – particularly its GHG profile. GAO states that it selected these experts and stakeholders to ensure that the report reflected the diversity of relevant views, interests, and professional expertise. This approach, however, also assures that: 1) no definitive consensus statements about the GHG impacts of the RFS and/or corn ethanol - will be possible; and 2) any summary statement concerning the group's views on a given impact will be that the net effect is limited and/or inconclusive. That is, for virtually any definitive statement about either, some experts will agree, some will disagree; and one or two will have a different opinion.

Where GAO does draw on the literature, it draws on dated analysis and results. For example, GAO's value for the GHG benefits of corn ethanol appears to be (i.e., it is never stated explicitly) the value developed by EPA in the 2010 Regulatory Impact Analysis (RIA) of the revised Renewable Fuel Standard – this value being 21% lower than an energy equivalent quantity of gasoline (EPA, 2010).

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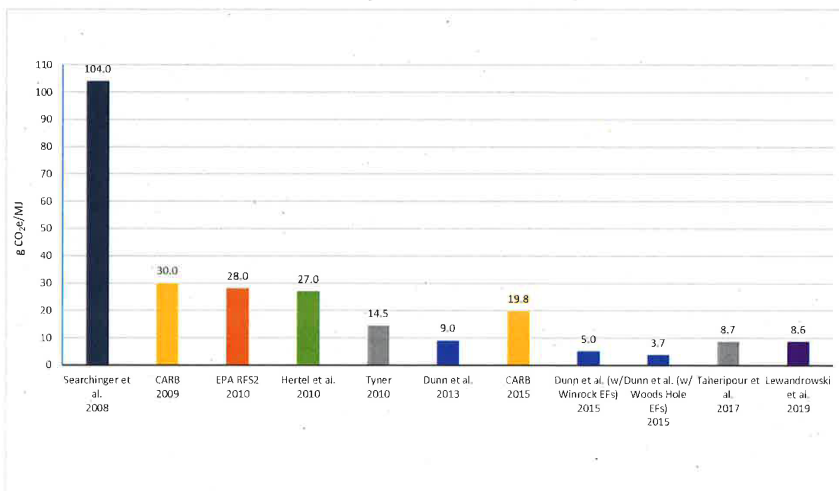
GAO's conclusions do not reflect the ethanol industry today. A large, and growing, body of research has been published since 2010. Productivity and process improvements have resulted in GHG benefits that were not accounted for in the RFS RIA. The most recent studies, assess the GHG benefits of corn ethanol at 39% to 47% lower than gasoline on an energy equivalent basis (Lewandrowski, 2019; Qin, 2018). While GAO correctly points out that the planned emissions reductions from advanced biofuels have not materialized, the reductions from conventional ethanol are significantly higher than previously thought. We believe that this should have been a key finding of the GAO.

Data, studies, technical reports, and other information developed since 2010 have collectively shown the emissions pathway corn-ethanol has followed. One particularly important set of studies analyze emissions related to international land-use change (iLUC). In the 2010 RIA, iLUC is the largest emissions source category in corn ethanol's GHG profile –accounting for 40% of all corn ethanol related emissions. As shown in figure 1, however, iLUC studies published since 2010 find both the quantity of land use change and the associated iLUC emissions related to U.S. ethanol expansion has been much lower than projected the 2010 RIA.

Figure 1: Estimated international land use change emissions related to U.S. corn ethanol production (selected studies).



The international land-use change (iLUC) source category is critical to understanding the magnitude and the uncertainty with respect to the GHG impacts of biofuels in general - and of corn ethanol in particular. EPA's 2010 Regulatory Impact Analysis (RIA) projected that by 2022 the lifecycle GHG emissions of corn ethanol produced in a new natural gas powered refinery would be 79,441 grams CO2 equivalent per million Btu (gCO_2e/MMBtu). Of this 31,790 gCO_2e/MMBtu are attributed to iLUC, making iLUC the largest source category of the 11 considered by EPA (EPA, 2010). Since 2010, a significant quantity of research has been

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published showing both the quantity of land use change and the associated iLUC emissions related to U.S. ethanol expansion has in fact been much lower than projected by EPA in 2010. This means more recent assessments of the GHG profile of corn ethanol find that ethanol has significantly higher GHG benefits than was developed in the RIA.

The impression conveyed by GAO is that the large majority of ethanol produced in today was produced in old refineries using 2007 (or older) technologies. This is not the case. For example, in 2007 many refineries used coal as a process fuel. Today the large majority use natural gas (a much less GHG intensive fuel). There have been numerous other GHG reducing innovations in ethanol refineries and across the ethanol supply chain since 2007. These changes have significantly improved the GHG profile of corn ethanol (relative to 2010 in particular) – even without explicit incentives to do so.

A peer-reviewed study recently published by a USDA researcher and collaborators in the journal *Biofuels* (Lewandrowski, 2019) found that the GHG emissions from corn ethanol are about 39 percent lower than gasoline on energy equivalent basis. The study, titled "*The greenhouse gas benefits of corn ethanol—assessing recent evidence*," also found that when ethanol is produced at natural gas-powered refineries, the GHG emissions are even lower—around 43 percent below gasoline.

The last decade was a time of great innovation and productivity improvement in both corn production and ethanol refinery technologies. The story of how farmers and ethanol producers responded to the requirements of the RFS is one worth understanding.

Earlier estimates of ethanol's GHG emissions assumed the increased price of corn (caused by increased demand for corn ethanol) would result in farmers bringing new land into production (otherwise known as land-use change). Projections warned of an increase in GHG emissions from tilling native grassland, and converting wetlands and forests for corn production. More recent research shows that, while there has been some conversion and reallocation of land, things did not end up playing out the way these earlier projections anticipated.

A 2015 peer-reviewed study published in the *Annual Review of Resource Economics* (Babcock, 2015) showed that although higher corn prices gave an incentive to farmers to grow more corn, farmers responded with increases in double-cropping and planting in fields that were fallow, and reducing temporary pasture to increase corn production—and far less land use change than originally predicted. In other words, although farmers produced more corn, they relied on improved technology and intensive cropping on existing fields rather than converting new lands into production.

Another peer-reviewed study published last year in the *American Journal of Agricultural Economics* (Li, 2018) found that between 2003 and 2014, increases in ethanol demand alone led to a 3 percent increase in corn acreage, and less than one percent increase in total crop acreage in the United States by 2012 compared to 2008. This was a far smaller impact than previously projected.

These studies demonstrate that although there *were* additional acres brought into corn production as a result of ethanol demand, the land use change impacts weren't nearly as drastic as we once thought.

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But it isn't just land use change that influences the GHG balance of ethanol. How corn is produced on farms and how refineries operate can also have a large impact on greenhouse gases, from the changes in soil carbon and the emissions associated with growing crops, to the GHG emissions from producing the fuel.

Independent of the USDA study, another recent peer-reviewed analysis titled, "*Land management change greatly impacts biofuels' greenhouse gas emissions,*" and published in the journal *Bioenergy* (Qin, 2018) found that when corn farmers adopt practices that increase soil organic carbon, such as using manure and cover crops, the lifecycle GHG emissions for ethanol are about 40 percent lower than gasoline.

USDA has fewer concerns with GAO conclusion that the RFS likely had modest impacts on gasoline prices that varied regionally – small decreases in the Midwest and small increases in other regions. It attributes the price changes to the existence, or lack thereof, of infrastructure needed to blend and store ethanol as the RFS ethanol mandates increased. Additionally, GAO states that infrastructure related increases in gasoline prices probably diminished over time as the one-time fixed costs of the infrastructure investments were incurred. This is all logical and any other conclusion would be suspect. While GAO did develop an empirical model of State-level gasoline prices to obtain the range of per gallon price impacts, GAO simply states the price impacts are modest. GAO could strengthen this finding with a paragraph on the volatility of gasoline prices over the analysis period. Whatever GAO's period of analysis is, gasoline prices have varied far more than $0.08 per gallon – $0.08 per gallon is probably common in month to month price variations. Year to year price variations are often a $1.00 or more per gallon. In this context, per gallon price variations of up to plus or minus $0.08 are relatively small.

We appreciate the opportunity to voice our strong concern with the GAO report, in order to set the record straight. Having a full and thorough understanding of the environmental benefits of corn ethanol is critical. In 2017 the United States was the world's leading ethanol producer, accounting for 58 percent of world production and exporting 1.4 billion gallons of ethanol. Consumption and production of ethanol have grown since 2010, with 16 billion gallons of ethanol produced, and 14.4 billion gallons consumed in 2017. The number of ethanol plants in the United States has increased and there are 209 plants in 2017, accounting for over 350,000 American jobs according to the Renewable Fuel Association. This industry is generating jobs and economic benefits in rural communities and is providing solutions to the environmental challenges we face. And contrary to the conclusion in GAO's report, the up to date and more recent peer-reviewed studies have all found that ethanol offers substantial aid increasing greenhouse gas benefits.

Sincerely,

Robert Johansson
Chief Economist

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Appendix V: GAO Contact and Staff Acknowledgments

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Staff Acknowledgments

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