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THE RENEWABLE FUEL STANDARD: A PATH FORWARD

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by James H. Stock*

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***James H. Stock** is the Harold Hitchings Burbank Professor of Political Economy, Faculty of Arts and Sciences and member of the faculty at Harvard Kennedy School, and a non-resident Fellow at the Center on Global Energy Policy at Columbia University. He previously served as Chair of the Harvard Economics Department from 2006-2009, as Co-Editor of *Econometrica* from 2009-2012, and as Member of the President's Council of Economic Advisers from 2013-2014.

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

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EXECUTIVE SUMMARY

America's renewable fuels policy is at a crossroads. The Renewable Fuel Standard (RFS) is derided by some as an inefficient program that is driving up costs for fuel suppliers and a threat to motorists at the pumps, while others insist it is a valuable tool to reduce US dependence on foreign oil that will also pay future dividends in the fight against climate change. Developed initially in 2005 and expanded in the Energy Independence and Security Act (EISA) of 2007, the RFS seeks to reduce both greenhouse gas emissions and US dependence on oil imports by establishing increasing quantities of renewable fuels that must be blended into transportation fuels. In part because of the RFS, the volume of renewable fuels in the US surface transportation fuel supply more than doubled from 2007 to 2013. But even though the twin climate and energy security goals of the RFS remain as valid as when the EISA was enacted, today the RFS is facing multiple challenges. The current first-generation biofuels mainly use food crops as feedstock and are either expensive or have modest GHG improvements over petroleum fuels. The development and commercialization of low greenhouse gas second-generation biofuels—critical to the ultimate success of the program—has fallen far short of the very ambitious goals laid out in the EISA. Moreover, many cars are limited to gasoline with at most 10% ethanol (the dominant biofuel)—the so-called E10 blend wall—and in 2013 the amount of ethanol in the US fuel supply reached the E10 plateau. As a result, the RFS, and US biofuels policy more generally, has reached a critical point at which some energy industry leaders and policy makers have called for it to be reformed or even overturned. Yet the challenge of transitioning to a low-carbon transportation sector remains, and if anything is made both more difficult and more pressing because of low gasoline prices and the likely associated increase in consumption. Because the first-best option of a carbon tax combined with substantial early-stage research and development funding remains politically unlikely, it is important to keep options open by supporting research and investment in a wide range of low-carbon technologies.

This paper examines the economics of the RFS in order to understand the challenges it has faced since 2013 and takes a critical look at the choices currently facing the RFS and US biofuels policy. In brief, the RFS serves as a tax on petroleum fuels and a corrective subsidy to renewable fuels. As a matter of economics, such a system is justified when one of the fuels generates more costs not borne by its users (i.e. externalities) than does the other fuel. That is the case here: renewable fuels both reduce dependence on foreign oil and generate less greenhouse gas emissions than do petroleum fuels. Under the RFS, the subsidy to renewable fuels operates through the market for RFS compliance permits, which are called Renewable Identification Numbers (RINs). The fundamental driver of RIN prices is the difference in the price at which a renewable fuel can be produced and the price at which it can be sold, at a given mandated volume of the renewable fuel. Because RINs can be banked, the RIN price depends not only on this fundamental subsidy value in the current year, but on expectations of future fundamental subsidy values. These current and future subsidy values in turn depend on economic factors, such as the price of oil and the cost of producing biofuels, as well as on current and future RFS policy about the volume (or fraction) of renewable fuels in the fuel supply.

In summary, the paper finds:

- The current combination of RFS policy uncertainty, the E10 blend wall, high RIN prices, and low investment means that the RFS currently is imposing costs while failing to provide the future benefits associated with domestic, low-greenhouse gas, second-generation advanced biofuels. In theory, RIN prices provide support for and promote the use of renewable fuels. In practice, during 2013 and 2014, uncertainty surrounding RFS policy combined with the E10 blend wall has resulted in high RIN prices without seeing significant advances either in the amount of ethanol in the fuel supply or in accelerating investment in domestic, low-greenhouse gas, second-generation advanced liquid fuels. The result has been postponed investment, both in the development and production of advanced biofuels and in dispensing infrastructure for higher blends. At the same time, volatile RIN prices expose some refiners and importers to RIN price uncertainty while doing little to promote renewables.

- The RFS broadly faces three paths forward. One path is to maintain the status quo, but the status quo is both costly and ineffective. A second path is for EPA to reduce RIN prices by keeping mandated volumes away from the blend wall, using the legal tools provided under the EISA. While this path, if successful and credible, would reduce compliance costs, it would fail to promote the development of second-generation biofuels, which hold the promise of large greenhouse gas reductions. Indeed, current low oil prices will increase the demand for petroleum fuels and make the task of reducing carbon emissions in the transportation sector even more challenging and pressing. Just as natural gas is a transitional fuel in reducing carbon emissions in the electricity generation sector, second-generation biofuels might play a key transitional role in the transportation sector, but those fuels, technologies, and dispensing infrastructure must first be developed.

- The third path is for EPA to expand the renewable content of the fuel supply, consistent with the policy goals of the EISA. The challenge for this third path is how it can be achieved while controlling its costs. Because the two main drivers of those costs are policy uncertainty and the blend wall, implementation of this path requires combining policy clarity and commitment with a credible set of steps to expand the ethanol content of the fuel supply.

- All three of these possible paths present risks, but only the final path holds out the possibility of providing economically efficient support to second-generation biofuels. Nobody knows whether second-generation biofuels will play a large role in reducing the carbon footprint of the transportation sector and in reducing US dependence on foreign oil, but by maintaining economically efficient support for those fuels, policy decisions today can maintain the option that those technologies will develop and one day play such a role.

- Intrinsic limitations of the RFS suggest that this third path is most likely to succeed if it is coupled both with reforms to the RFS and with additional steps outside the RFS. The goals of these reforms are to increase policy certainty, to promote the sales of higher blends, to reduce RIN price volatility, and to increase the economic efficiency of the RFS. Some of the reforms to the RFS could be implemented administratively, while others are likely to require legislation. These potential reforms are discussed in the final section of the paper.

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INTRODUCTION

The US Renewable Fuels Standard (RFS) has come under attack from many sides over the past eighteen months. The RFS has been variously accused of driving up fuel costs for US motorists and creating uncertainty about compliance costs for some petroleum refiners and importers.[1] Developed initially in 2005 and expanded in the Energy Independence and Security Act (EISA) of 2007, the RFS seeks to reduce both greenhouse gas emissions and US dependence on oil imports by establishing increasing quantities of renewable fuels that must be blended into transportation fuels.[2] Supporters of the program point out that the United States now consumes approximately one million barrels per day of biofuels, thereby displacing imported oil, that they have lower life-cycle greenhouse gas emissions than petroleum gasoline, and that second-generation advanced biofuels from nonfood sources hold the promise of large greenhouse gas reductions in the future.

Many of the current concerns about the RFS stem from the fact that in 2013 the United States reached the point at which ethanol comprised 10% of the US gasoline supply. The dominant US gasoline blend, E10, contains at most 10% ethanol, the maximum that many cars can accept under the manufacturer's warrantee. As discussed below, the challenges posed by this so-called E10 blend wall underlie the sharp increases in the cost of complying with the RFS, relative to 2012 and earlier. In addition, the unwieldy structure of the RFS generates policy uncertainty by requiring EPA to make annual rulemakings that set out the fraction of renewable fuels in the US fuel supply.[3] The 2013 final rule appeared in August 2013, more than eight months into the compliance period, and in November 2014 EPA announced that the 2014 final rule will appear in 2015.[4] The increased costs arising from the blend wall and policy uncertainty have generated extensive debate about the direction of future policy both for the RFS and for biofuels policy more generally. Combined, these factors have led to calls from some policy makers and analysts, along with many in the fuel supply business, to revise or even repeal the RFS requirements.

Despite these concerns and the many changes in the US economy and fuels markets since 2007, the twin policy goals of the EISA—reducing GHG emissions and reducing oil imports—remain as valid today as they did in 2007. Recent experience and additional scientific knowledge reinforce the imperative of moving toward a low-carbon economy, and one of the most challenging parts of that transition is reducing the carbon emissions in the transportation sector. Moreover, even though net oil imports are half what they were in 2005,[5] further reducing net petroleum imports reduces the economy's exposure to oil supply shocks of foreign origin: reducing oil imports through domestically produced biofuels enhances macroeconomic energy security.[6]

The RFS—and with it, US biofuels policy more generally—has thus reached a crossroads. While the first-best policy would be to replace the RFS with a carbon tax combined with significantly higher government R&D support for low-carbon transportation fuels, this option is not politically viable at present. Further, although there have been calls for repeal of the RFS, repeal alone would leave the United States with very limited ways to provide ongoing support for the development and use of domestic low-carbon fuels.

Broadly speaking, therefore, RFS policy could follow three paths. The first path is to continue the flexible, short-run focus in the annual rulemakings, so that annual renewable fuel requirements can be adjusted as policy goals evolve. The second path is to commit to a conservative approach that stays within the E10 blend wall while attempting to support low-carbon domestic advanced biofuels (such an approach was laid out in EPA's proposed 2014 RFS rule). The third path is to commit instead to an ambitious plan for expanding both conventional and advanced biofuels.

This paper has three goals. The first is to provide an accessible discussion of the economics of the RFS. The second is to draw on this economic discussion and recent experience with the RFS to analyze these three policy paths. The third is to lay out potential reforms to the RFS, both administrative within current law and reforms that would require legislative action, and to discuss additional biofuels policy steps that would complement the reforms to the RFS and would support the goals of biofuels policy in an economically efficient way.

In brief, among these three policy paths, the first provides maximum flexibility. Recent experience suggests, however, that the resulting policy uncertainty would likely lead both to high compliance costs and to low investment in advanced fuels and in the infrastructure that would support greater volumes of renewable fuels (especially ethanol) in the marketplace. Thus this first path is likely to be both costly and ineffective. The second path—commit to a conservative approach to the E10 blend wall—could, in theory, result in low compliance costs. However, the annual nature of the rulemakings combined with legal risk suggests that credible commitment to a conservative path could prove very difficult. In practice this path, like the first, would likely lead to policy uncertainty and high compliance costs without investment. Moreover, this path does not promote the development of additional ethanol infrastructure that would facilitate the long-term ability of new low-GHG sources of ethanol to enter the market. The third path would entail a conscious decision to expand ethanol consumption beyond the E10 blend wall through higher ethanol blends, in particular E85.[7] But because this path would entail a substantial increase in volumes of renewable fuels, by itself it runs the risk of high and economically inefficient compliance costs.

The analysis in this paper suggests that the third expansive path is the most likely to achieve the twin goals of promoting low-carbon domestic advanced fuels and enhancing macroeconomic energy security. Because there currently is no clear best low-carbon technology for the transportation sector, it is important to keep options open by supporting research and investment in a wide range of low-carbon technologies—including second-generation biofuels. The recent decline in oil prices underscores the importance of supporting this research and investment because of the currently high costs of many alternatives to petroleum in the transportation sector, and because low gasoline prices (if they persist) are likely to increase US gasoline consumption. But this likely expansion of gasoline consumption also provides a window in which the E10 blend wall is less pressing.

Given the unlikely prospect of broadly expanding federal research support for low-carbon transportation technologies (or for other first-best climate policy solutions such as a carbon tax), the RFS is the main tool available for supporting development and commercialization of advanced biofuels. But to be successful in promoting advanced biofuels and for it to be viable in the long run, RFS policy must be economically efficient. Perhaps paradoxically, I argue that this third path has the potential to achieve low long-run compliance costs and, of the three, to be the most economically efficient in the long run because it is the most likely to bring forth the investments that will relieve the underlying source of pressure on compliance costs produced by the E10 blend wall.

Because of the structural limitations of the RFS, this third path is most likely to be effective and economically efficient if coupled with a program of initiatives and reforms to biofuels policy both within and outside of the RFS. The paper therefore concludes with a list of such reforms: administrative reforms within the existing legal framework, legislative reforms to the RFS, and various non-RFS policy steps, including actions that can be taken by the biofuels industry, that would advance biofuels policy goals while promoting economic efficiency.

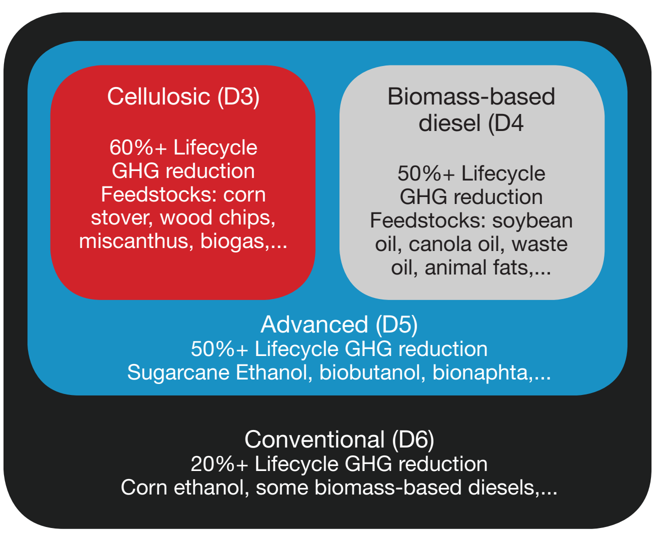
The remainder of this paper develops these arguments. The paper begins by reviewing how the RFS works and the history of biofuels production under the RFS, followed by a discussion of the economics of the RFS. The paper then turns to an analysis of the three paths and concludes with a discussion of potential reforms to the RFS program and additional policy options.

MECHANICS OF THE RFS

The EISA specifies volumetric requirements, or Renewable Volume Obligations (RVOs), for renewable fuels to be blended into US surface transportation vehicle fuels, which are subject to adjustment by the EPA under certain conditions, or waiver authorities (discussed later). The act requires EPA to set annual standards through annual rulemakings. Although the statutory requirements are volumetric, enforcing volumetric requirements is not practical. Instead, the EPA sets the standards as fractional obligations, computed as the volumetric requirement divided by the Energy Information Administration's projection of total petroleum gasoline plus diesel surface transportation fuel consumption (excluding Alaska and an exemption for small refineries). Compliance with the RFS is achieved using EPA's system of Renewable Identification Numbers (RINs).

RFS fuel categories. As shown in Figure 1, the RFS divides renewable fuels into four nested categories: total renewable, advanced, biomass-based diesel (BBD), and cellulosic. Under the EISA, each of these four categories has its own volumetric requirements, which the EPA translates into four corresponding fractional requirements through annual rulemakings. These categories are defined in terms of their reductions in life-cycle emissions of greenhouse gasses (GHGs), relative to petroleum, in terms of their feedstock, and in of their fuel characteristics.

Figure 1: The RFS fuel nesting scheme



Source: EPA

Total renewable fuels comprise conventional biofuels and advanced biofuels. Conventional biofuels must achieve a 20% reduction in life-cycle greenhouse gas (GHG) emissions, relative to petroleum fuels, on an energy-equivalent basis. The dominant conventional fuel is ethanol made from corn starch, although recently some conventional biomass-based diesel has entered the fuel supply. To qualify as an advanced biofuel, the fuel must achieve at least a 50% life-cycle GHG reduction—60% in case of cellulosic fuels—relative to the gasoline or diesel fuel that it replaces. The advanced biofuels category has three subcategories: biomass-based diesel, cellulosic fuels, and a residual comprised of other biofuels with a 50% GHG reduction.

- The biomass-based diesel category consists of diesel biofuels that achieve the 50% reduction threshold. Biomass-based diesel feedstocks include soy and other vegetable oils, waste cooking oil, and animal fats. Biomass-based diesel comprises biodiesel and renewable diesel, which are produced using different chemical processes.[8] In this paper, the term "biomass-based diesel" refers to this subcategory of advanced fuels, and conventional biomass-based diesel refers to biomass-based diesel that achieves between a 20% and 50% GHG reduction and therefore qualifies as a conventional (but not advanced) biofuel.

- Cellulosic biofuels are required to have at least a 60% life-cycle GHG reduction relative to petroleum fuels. Cellulosic feedstocks include corn stover (the nonkernel waste left after harvesting corn), wood chips, energy plants such as miscanthus, and other woody nonfood sources. These fuels are in early research or pilot stages, and the first domestic commercial-scale cellulosic ethanol plants are now opening.[9] The EPA has also qualified natural gas produced by landfills, municipal wastewater treatment facilities, and agricultural digesters as a cellulosic fuel when used for transportation.[10]

- The remaining "other" category consists of nondiesel, noncellulosic biofuels that achieve a 50% GHG reduction. Historically, the main fuel in this category has been imported Brazilian sugarcane ethanol.[11]

Statutory volumes and annual EPA rulemakings. The EISA specifies in statute RVOs for total renewable, total advanced, and cellulosic biofuels, and provides EPA with authority to waive those statutory RVOs under certain conditions. The statute also sets a floor for the biomass-based diesel RVO but leaves setting that RVO to EPA discretion, subject to specific guidance.

- The cellulosic waiver authority authorizes EPA to reduce the cellulosic RVO by the amount of a projected shortfall of cellulosic production below the statutory cellulosic RVO and, optionally, to reduce the total advanced and total renewable RVOs by up to the amount of the cellulosic shortfall.[12]

- The general waiver authority allows EPA to waive any of the volumes if it finds either that failing to do so would cause severe economic harm or if there is inadequate domestic supply of the relevant fuel.[13]

- The EISA specifies that the biomass-based diesel RVO must be at least one billion wet gallons, but leaves it to the EPA to set the RVO by weighing six statutorily specified criteria: (i) impact on the environment, including both climate change and local environmental effects such as water quality; (ii) the impact of renewable fuels on energy security; (iii) the expected annual rate of future commercial production of biomass-based diesel; (iv) the impact of renewable fuels on infrastructure and the sufficiency of infrastructure to deliver renewable fuels; (v) the impact of the use of renewable fuels on the cost to consumers of transportation fuel and on the cost to transport goods; and (vi) other factors including job creation, price of agricultural commodities, rural economic development, and food prices.[14]

- EPA's annual determination of the cellulosic RVO is guided both by the statute and a 2013 ruling by the US Court of Appeals for the District of Columbia. The court found that EPA had set the 2012 standard in a way that would tend to overestimate actual volumes and that doing so was inconsistent with the statute, which the court interpreted as requiring EPA to set the cellulosic RVO using a "neutral methodology" aimed at providing a prediction of "what will actually happen" regarding cellulosic production in the compliance year.[15]

Table 1 lists the statutory RVOs and the RVOs set by EPA in its annual rulemakings. Because cellulosic production has fallen far short of the statutory volumes, EPA has exercised the cellulosic waiver authority every year since 2010 but has only used it to reduce the cellulosic obligation, not the total advanced or total renewable RVOs. The final column in both blocks of Table 1 shows the implied volume of the conventional biofuels pool, which is the difference between the total renewable obligation and the total advanced obligation. The EISA capped this volume at 15 billion gallons (Bgal), reflecting the role of corn ethanol as a transitional fuel – one that delivers energy security benefits but relatively limited GHG benefits – to lower-GHG second-generation advanced and cellulosic biofuels.[16]

Table 1: RFS volumes: statutory and annual EPA rulemakings

	Statutory Volumes (Billions of gallons)					As Set by EPA Rule-Making (Billions of gallons)				
Year	Cellulosic	Biomass-based Diesel	Total Advanced	Total Renewable	Implied Conventional Pool	Cellulosic	Biomass-based Diesel	Total Advanced	Total Renewable	Implied Conventional Pool
2009	n/a	0.5	0.6	11.1	10.5	n/a	0.5	0.6	11.1	10.5
2010	0.1	0.65	0.95	12.95	12	0.00065	0.65[e]	0.95	12.95	12
2011	0.25	0.8	1.35	13.95	12.6	0.006	0.8	1.35	13.95	12.6
2012	0.5	1	2	15.2	13.2	0.0105[c]	1	2	15.2	13.2
2013	1	≥1.0[a]	2.75	16.55	13.8	0.0008[d]	1.28	2.75	16.55	13.8
2014	1.75	≥1.0[a]	3.75	18.15	14.4					
2015	3	≥1.0[a]	5.5	20.5	15					
2016	4.25	≥1.0[a]	7.25	22.25	15					
2017	5.5	≥1.0[a]	9	24	15					
2018	7	≥1.0[a]	11	26	15					
2019	8.5	≥1.0[a]	13	28	15					
2020	10.5	≥1.0[a]	15	30	15					
2021	13.5	≥1.0[a]	18	33	15					
2022	16	≥1.0[a]	21	36	15					
2023	b	b	b	b	b					

Notes: Units are billions of RIN gallons for cellulosic, total advanced, and total renewable, and billions of wet gallons for BBD. The "Implied conventional pool" is the difference between the volumes in the total renewable and total advanced pools. [a] Statute sets floor of 1.0 Bgal, actual mandate to be determined by EPA through annual rulemaking. [b] To be determined by EPA through a future rulemaking. [c] The 2012 cellulosic volume was vacated by a Jan. 25, 2013 ruling of the US Court of Appeals for the District of Columbia, which stated that EPA did not but must apply a "neutral methodology" for determining the cellulosic RVO. See the 2013 rule preamble for a discussion, 78 FR 49800-49801. [d] Reduced to 0.8 mgal in May 2014, from 6 mgal in the 2013 final rule, in response to petitions from the American Petroleum Institute and American Fuel and Petrochemical Manufacturers (79 FR 25025). [e] The 2009 and 2010 biomass-based diesel standards were implemented together, for total BBD of 1.15 by the end of 2010 (75 FR 14670). Source: Congressional Research Service, Environmental Protection Agency.

Finally, if EPA waives a specific statutory volume by more than 20% for two consecutive years, or by more than 50% for one year, it must promulgate a modified table of prospective volumes for the affected category.[17] Accordingly, EPA will need to reestablish the table of cellulosic volumes starting in 2016. As discussed below, calculations suggest that EPA will need to reestablish the total advanced table of volumes in 2017 and the total renewable table of volumes in 2018.

Compliance through the RIN system. The compliance mechanism for the RFS is the Renewable Identification Number (RIN) system. By EPA regulation, refiners and importers, referred to as "obligated parties," are required to turn in (retire) RINs when they sell petroleum gasoline or petroleum diesel into the domestic surface transportation market. RINs are generated upon production or import of a qualifying renewable fuel and are typically separated from that fuel when it is blended or sold into the fuel supply. Detached RINs are tradable, so an obligated party can acquire RINs for compliance either by purchasing the renewable fuel with the RIN attached or by purchasing RINs on the secondary RIN market. Each of the four categories of fuels in Figure 1 generates its own RINs. For example, cellulosic ethanol generates a D3 RIN, biodiesel generates a D4 RIN, sugarcane ethanol (an advanced, noncellulosic, non-BBD fuel) generates a D5 RIN, and corn ethanol generates a D6 RIN. In 2013, for each gallon of nonrenewable fuel, the obligated party was required to hand 0.0812 D6 RINs, 0.0049 D5 RINs, 0.0113 D4 RINs, and 0.00004 D3 RINs (a total of 0.0974 RINs),[18] which will be referred to as the "RIN bundle" that must be turned in per gallon of petroleum fuel.

Excess D3 and D4 RINs can be used to satisfy the D5 and D6 requirements, and excess D5 RINs can be used to satisfy the D6 requirement. The number of RINs generated per gallon of renewable fuel is based on the energy equivalence value, relative to ethanol. Thus blending a gallon of ethanol generates one RIN; blending a gallon of biodiesel generates 1.5 RINs, and a gallon of nonester renewable diesel generates 1.7 RINs because those biodiesels have a higher energy density than ethanol. Thus there is a distinction, in RFS parlance, between the "wet" (actual physical) gallons of the fuel and the RIN-equivalent gallons. For example, a wet gallon of biodiesel generates 1.5 RIN gallons.

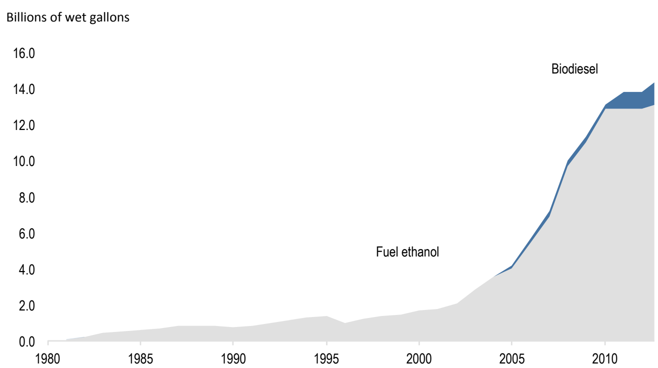
RINs are tradable and, subject to some restrictions, durable. For example, RINs generated in 2012 can be used to meet compliance obligations in 2011, 2012, or 2013 (although banked 2012 RINs cannot exceed 20% of the 2013 RVO). Because of this overlapping, tradable structure, a RIN can be thought of as having an indefinite lifetime, subject to the rollover cap.[19] Being able to bank RINs provides a buffer to fluctuations in supply and demand, such as a drought or an unexpected increase in the demand for gasoline.

Because of the small volumes of cellulosic fuels initially anticipated in the EISA, the statute instructs EPA to make available cellulosic waiver credits with which obligated parties can fulfill their cellulosic obligations. The only explicit restriction on RIN prices in the EISA concerns a statutory cap on the price of cellulosic waiver credits, which, when combined with a D5 RIN, can be used to satisfy the D3 RIN requirement. The cap on the price of the cellulosic waiver credit thus caps the spread between the D3 and D5 RINs. This cap is indexed to the price of gasoline and for 2013 was $0.42.[20]

BIOFUELS CONSUMPTION AND THE BLEND WALL

Over the past ten years, the biofuel content of the US fuel supply has risen from less than 2 billion gallons in 2000 to more than 14 billion gallons in 2013. As Figure 2 shows, most of that growth has been in ethanol (primarily corn ethanol and some cane ethanol). The sharp increase in ethanol consumption over the past decade is a result of several factors, including the phasing out of MTBE as an oxygenate and its replacement with ethanol as well as state and federal biofuels policy (including the ethanol blenders' tax credit and the RFS).

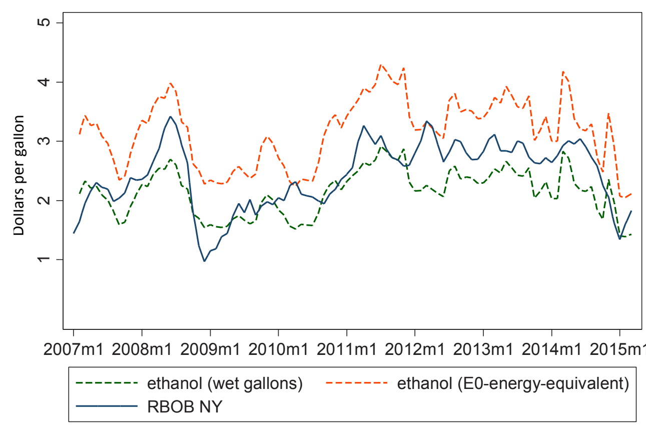
Figure 2: U.S. fuel ethanol and biodiesel consumption, 1981-2013



Source: EIA

US ethanol prices have historically moved with gasoline prices. As is shown in Figure 3, since 2007 the wholesale price of corn ethanol has typically been below the price of wholesale petroleum gasoline (RBOB)[21] on a volumetric basis, but above the petroleum gasoline price after adjusting for ethanol having only 68% the energy content of petroleum gasoline per gallon. Making precise inferences from these data either about the effect on retail gasoline prices of blending ethanol or on the underlying actual cost of production of ethanol faces two difficulties. First, because ethanol is used to boost octane and replaces petroleum octane boosters, it is competing both with gasoline on an energy basis and with the octane boosters, enhancing the value of ethanol. Second, the price of traded ethanol is influenced by a host of subsidies and policies, complicating the relationship between the production cost of ethanol and the wholesale traded price of ethanol. During the period after the expiration of the volumetric ethanol excise tax credit on December 31, 2012, and before high RIN prices in February 2013—when ethanol was approximately 10% of gasoline and was not receiving a direct subsidy from either the tax credit or the RFS—ethanol prices averaged approximately 20% less than wholesale gasoline on a volumetric basis, and approximately 15% more on an energy-adjusted basis. This episode happened to coincide with the drought of 2012, and during the first six months of 2012, before the severity of the drought became clear later in the summer, the price of ethanol was nearly 30% less than petroleum gasoline on a volumetric basis, and 5% above on an energy-adjusted basis. Using data through 2010, Knittel and Smith (2012) estimate that ethanol blending decreased US gasoline prices by up to $0.10 per gallon. Since the summer of 2014, ethanol prices have fallen with gasoline prices.

Figure 3: Price of wholesale gasoline and ethanol on an energy-equivalent basis

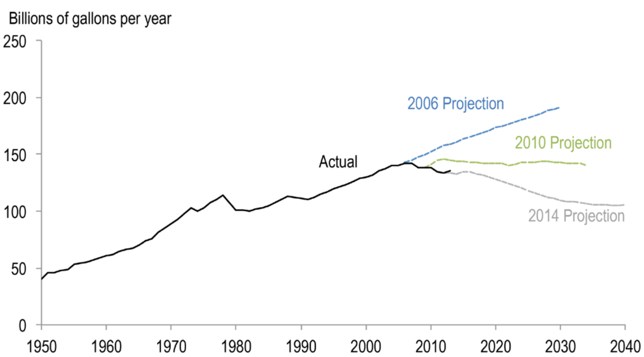


RBOB is wholesale reformulated petroleum gasoline price, New York harbor.
Source: Bloomberg and EIA

As can be seen in Figure 2, the composition of biofuel consumption has changed since 2010. These changes are largely a consequence of the E10 blend wall, the RFS, and various biofuels tax credits.

The EISA statutory volumes hit the E10 blend wall several years earlier than expected based on gasoline consumption projections at the time the EISA was developed and passed. As Figure 4 shows, the "reference scenario" in the EIA 2006 *Annual Energy Outlook* projected US gasoline consumption to grow into the indefinite future. But as a result of the Great Recession, new vehicle fuel economy standards, high gasoline prices, and possible changes in driving habits, total gasoline consumption has fallen, not increased, and the EIA's current estimate of 2014 gasoline consumption (including blended ethanol) is 137 billion gallons (Bgal), 15% below the 161 Bgal in the 2014 reference scenario projection in the EIA's 2006 *Annual Energy Outlook*. Based on the 2006 EIA projection, the 2014 E10 blend wall would be at approximately 16.1 Bgal of ethanol, whereas based on current estimates, it is at 13.7 Bgal, 2.4 Bgal less than based on the 2006 forecast.

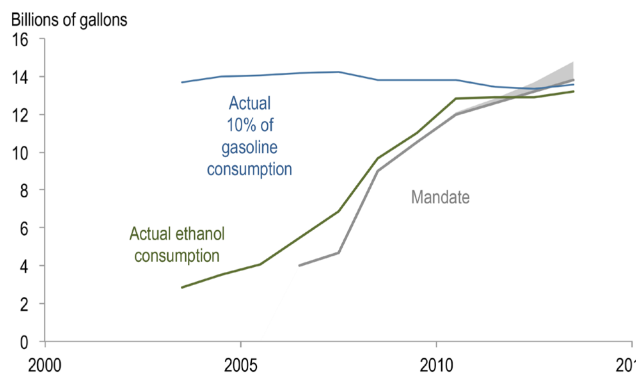
Figure 4: U.S. Consumption of Motor Gasoline, 1950-2040 (Actual and projected using EIA *Annual Energy Outlook* reference scenarios)



Source: AEO 2006, AEO 2010, AEO 2014, EIA.

If the conventional RVO exceeds 10% of gasoline consumption, then the conventional RVO cannot be filled by corn ethanol blended into E10 alone. This is the situation commonly referred to as the RFS mandate exceeding the E10 blend wall, although as discussed below this is more accurately not a "wall" but rather a situation in which additional ethanol must be provided through higher blends.[22] Through 2012, production and consumption of corn ethanol exceeded the RFS conventional mandate, that is, the conventional mandate did not bind. Figure 5 shows the relation between implied mandated ethanol consumption (shown as a range that adds statutory cellulosic volumes to the statutory conventional RVO), actual ethanol consumption, and 10% of actual gasoline consumption. In 2013, the conventional RVO of 13.8 billion gallons constituted 10.3% of gasoline consumption, exceeding the E10 blend wall. Because of very low penetration of higher blends, the resulting conventional biofuels shortfall was met through a combination of RINs banked from consumption in excess of the RVO in previous years, D4 and D5 RINs that were produced in excess of their respective RVOs, and D6 RINs generated by nonethanol conventional fuels.[23] In 2014 the statutory conventional RVO increases to 14.4 Bgal and, as shown in Table 1, it reaches its cap of 15 Bgal in 2015. That 15 Bgal cap is nearly 11% of currently projected gasoline consumption and exceeds the ethanol capacity of E10 by roughly 1.3 Bgal.

Figure 5: U.S. ethanol and gasoline consumption



Source: AEO 2006, Energy Independence and Security Act of 2007.
Note: The lower bound of the shaded region is the conventional mandate. The upper bound adds the statutory cellulosic mandate.

ECONOMICS OF THE RFS

The RFS provides a guarantee to biofuel producers that they will be able to sell up to the mandated volume for a given year. If the biofuel can be produced for less than the price of its petroleum alternative and if there are no non-price market failures or other impediments to the consumption of renewable fuels, then that fuel will enter the fuel supply for price reasons, not because it is required to by the RFS. If, however, the marginal cost of producing the biofuel exceeds what consumers are willing to pay, then a subsidy is needed to make sure the fuel is produced and consumed. Because RINs are separated by blending a biofuel into the fuel supply, and RINs must be turned in to the EPA when an obligated party (a refiner or importer) sells petroleum fuel into the fuel supply, the price of a RIN is the vehicle for transferring corrective production subsidies to ensure that biofuels are produced and consumed at the mandated level. By the same token, the price of RINs is a measure of the compliance cost of the program: the greater is the RIN price, the greater is the value of the RINs that the obligated party must turn in. For these reasons, understanding the theory and empirical behavior of RIN prices is central to understanding the economics of the RFS.

This section examines the theory and empirical evidence concerning RIN prices. It begins with a discussion of the fundamental determinants of RIN prices in both static and dynamic (bankable) settings. It then turns to the effect of RIN prices on final transportation fuels, both in theory and empirically. In theory, the cost of RINs should be passed through to consumers, increasing the price of fuels with low renewable content (like diesel, which on average contains roughly 3% renewables) and decreasing the price of fuels with high renewable content (like E85). Consistent with the theory, empirical evidence indicates that the price of diesel and petroleum gasoline (E0) rises with RIN prices, and the price of E10 does not vary with RIN prices. Theory also predicts that the price of E85 should fall when RIN prices rise, but the evidence suggests that there is incomplete pass-through of the RIN price subsidy to retail E85 prices, so that only part of the effective RIN subsidy for E85 is passed along to the consumer.

RIN PRICE DETERMINATION [24]

The price of RINs, like other assets, depends on underlying fundamentals. For RINs, the fundamental is the difference between the price necessary to produce and distribute the mandated quantity of the relevant biofuel and the price the consumer is willing to pay for it. Because of the nested fuel structure of the RFS, RIN prices can further depend not just on market conditions for the fuel generating the RIN, but on markets for other biofuels. In addition, because the RIN is bankable, the price of a RIN today depends on expected future fundamental values as well as the fundamental values today. Because the fundamental values depend on the RFS mandated volume, the price of the RIN today depends on current RFS policy and on expected future RFS policy.

RIN price fundamentals and annual subsidy values. The fundamental factor in determining the RIN price is the value of the subsidy needed in a given compliance year to produce and consume the relevant biofuel at the mandated level. For the moment, suppose that RINs must be used in the year they are generated, and ignore interactions between fuels induced by the RFS nesting. The basic idea of the RIN price fundamental is that a biofuel producer receives two payments when she blends a gallon of biofuel: one for the physical product that the consumer uses as fuel, the other for the RIN that is generated and sold when the biofuel is blended. In equilibrium, the price at which the producer is willing to sell the RIN will just cover the marginal cost of producing the required volume. Thus the annual subsidy value, or RIN price fundamental, is determined by the difference between the price producers require for the marginal gallon of biofuel and the price consumers are willing to pay for it.

This RIN price fundamental is illustrated for biodiesel in Figure 6a. The price that a producer requires to produce the mandated volume is the price on the biodiesel supply curve (the "supply price") at that volume. This supply curve is upward-sloping because as more biodiesel is produced, feedstock costs (and perhaps other marginal production costs) go up. Similarly, the price that consumers are willing to pay is the price on the demand curve (the "demand price") at that volume. In the figure, this demand curve is flat at the price of petroleum diesel, so that at current volumes, biodiesel is in effect interchangeable with petroleum diesel. In the figure, the supply curve lies above the demand curve because biodiesel is more expensive than petroleum diesel. The difference between these two prices is the amount that must be covered by selling the RIN. Thus, the RIN price fundamental is the difference between the supply price and demand price as shown in Figure 6a, that is, the annual subsidy value.[25] In the case illustrated in the figure, the subsidy value flows to the biodiesel producer because consumers are indifferent between using diesel and biodiesel, but producers cannot afford to produce volumes greater than the market equilibrium Q_0 without a subsidy.[26]

Figure 6: Biofuel supply and demand and subsidy values

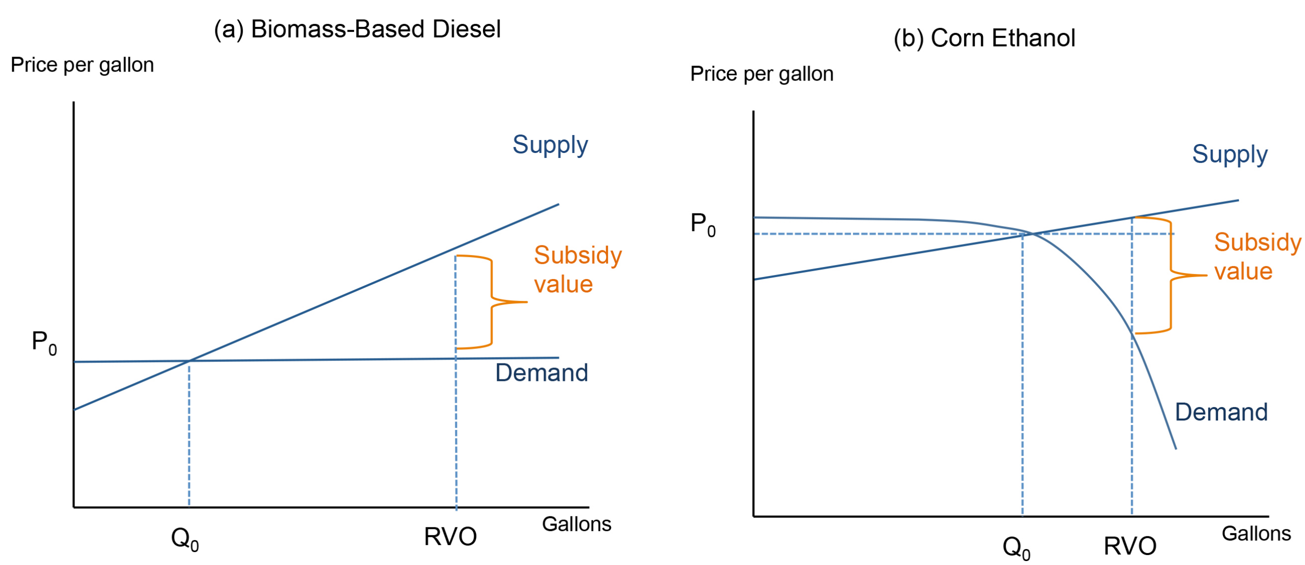


Figure 6b provides a qualitative illustration of the corn ethanol market, in which the nonlinear demand curve for ethanol is a stylized representation of the blend wall. Below the equilibrium level $Q_{0,}$ demand is insensitive to price as long as the price of ethanol is less than the price of petroleum gasoline. But for volumes exceeding Q_0, it becomes increasingly difficult to put additional ethanol into the market, so that a sharply growing consumer subsidy is needed. In this sense, the blend wall is not so much a "wall" but an inflection point after which sharply increasing subsidies are need to ensure consumption of incremental gallons of ethanol. In the case illustrated—in which the RVO is in the blend wall portion of the demand curve—most of this subsidy flows to the consumer in the form of lower ethanol prices, since not much of a supply price increase is needed to induce the small additional amount of ethanol production.[27]

RIN price implications of the RFS nesting structure. Under the nested fuel structure of the RFS shown in Figure 1, D4 RINs can be used to satisfy the biomass-based diesel requirement, the total advanced requirement, or the total renewable requirement; D5 RINs can be used to satisfy either the total advanced or total renewable requirement; and D6 RINs can only be used to satisfy the total renewable requirement. This nesting structure implies that a D4 RIN is at least as valuable as a D5 RIN, and a D5 RIN is at least as valuable as a D6 RIN. Moreover, as a result of this nesting structure there are different RIN price "regimes," depending on which of the different requirements are binding, that is, which fuels if any are produced in excess of their requirement to generate RINs to satisfy an obligation within which it is nested.

To make this concrete, consider the example of Figure

6 in which there are only two fuels, biodiesel and corn ethanol, and two RINs, D4 and D6. If the biodiesel subsidy value is less than the ethanol subsidy value, then biodiesel producers can produce in excess of the biodiesel requirement and sell the resulting D4 RINs for the purpose of satisfying the total renewable (conventional fuel) mandate. In this scenario, the amount of biodiesel produced will rise, and the amount of conventional ethanol will fall, to the point that the subsidy values in the two markets are equalized, so the D4 and D6 RINs have the same price. In contrast, if the subsidy value for biodiesel at the biodiesel requirement exceeds the subsidy value for conventional ethanol at its requirement, then biodiesel producers will have no incentive to produce excess biodiesel and the price of the D4 RIN will exceed the price of the D6 RIN.

More generally, the nesting structure implies the price inequalities, $P_{D4} \geq P_{D5} \geq P_{D6} \geq 0$ (where P_{D4} is the price of the D4 RIN, etc.). If the inequality is strict, then the mandate is binding, for example if $P_{D4} > P_{D5}$ then no biodiesel is being produced in excess of the biomass-based diesel mandate. In contrast, if $P_{D4} = P_{D5} = P_{D6}$, then both biodiesel and nondiesel, noncellulosic advanced fuels are being produced in excess of their mandates, and one or the other or both fuels are being used to generate RINs to satisfy the total renewable obligation.[28]

Bankability implies that current RIN prices incorporate future subsidy values and policy expectations. Suppose that the requirement is low this year but is expected to rise next year, so the subsidy value needed to meet the requirements will rise. Because RINs are bankable, their price will rise above this year's subsidy value in anticipation of next year's stiffer requirement, inducing production in excess of the requirement this year. The excess RINs are banked and used next year. In this example, bankability increases RIN prices this year and lowers them next year. Because RINs can, in effect, be rolled over indefinitely (subject to the 20% rollover cap), this logic further extends to future years. Thus RIN prices today reflect market participants' views about the stream of subsidy values extending for the life of the program.

RINs have features that are similar to financial options. First, they can be exercised (retired) for compliance this year or in the future. Second, they have a nonlinear payoff function: the fundamental value of the RINs is positive if the annual subsidy value is positive, otherwise it is zero (because RINs need never be retired, their price cannot be negative). This latter feature is analogous to a financial option having exercise value only if it is in the money.[29]

Like a financial option, the price of RINs today will increase if there is an increase in uncertainty about future fundamental (subsidy) values. This uncertainty arises from uncertainty both about future economic fundamentals (weather, driving demand, oil prices, geopolitical factors) and about future policy. For example, suppose a multiyear policy path is announced with low RVOs. Because legal uncertainty and the annual rulemaking process make it difficult to commit convincingly to such a path, there will remain a chance that policy might return to the more expansive path of the statutory RVOs, and as a result there is a chance that the annual subsidy value will be high in the future. This possibility of high future RIN prices in turn adds in a premium (which could variously be called a risk premium, or time value, or option value) arising solely from uncertainty. Thus RIN prices depend both on expectations of future policy and on the degree of certainty about future policy.

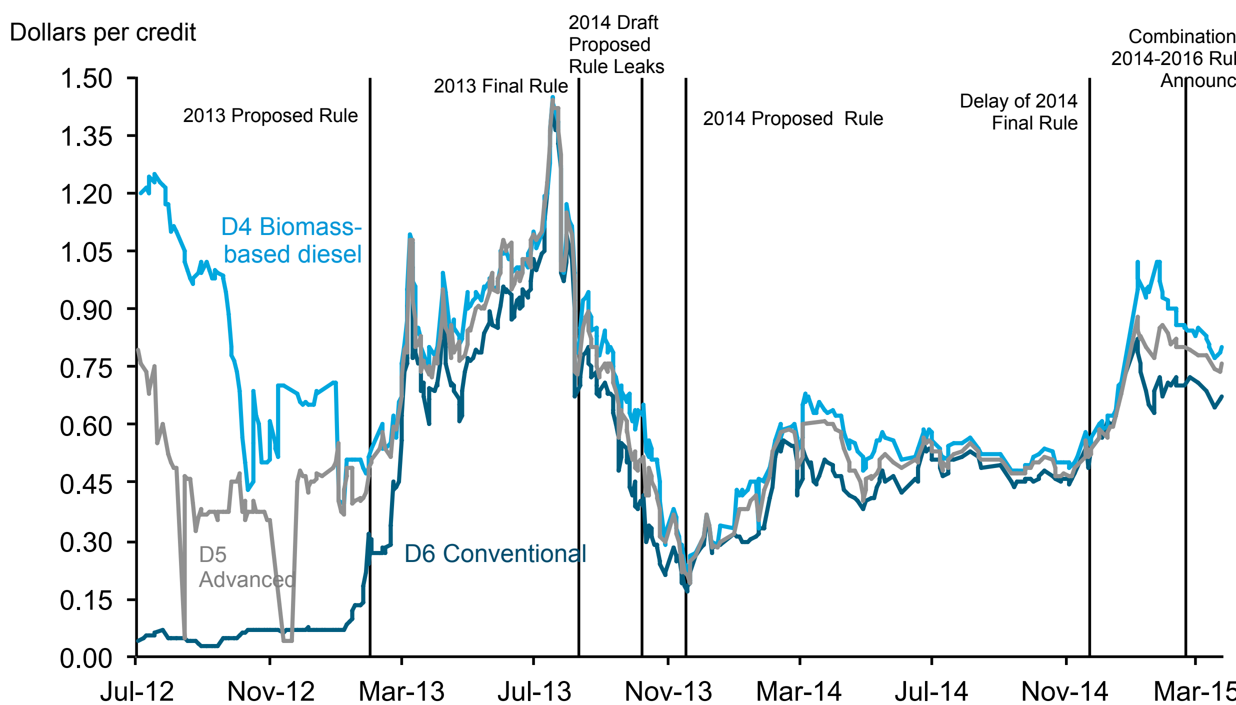
RIN PRICES SINCE 2012

Figure 7 shows the daily price of D4 (BBD), D5 (advanced), and D6 (conventional) RINs from July 2012 through March 24, 2015. Through the end of 2012, D6 RIN prices were low (less than $0.10) and the three RINs had distinct prices, indicating that the BBD, total advanced, and total renewable mandates were each binding. With increasing market awareness of the blend wall and with the release of the 2013 proposed rule, D6 RIN prices rose from mid-January through February 2013, and fluctuated around $0.75 from March through mid-May 2013. At this point, D6 RIN prices exceeded the 2012 D5 and D4 RIN prices, the BBD and Total Advanced RVOs became nonbinding—incentives were created to produce more advanced renewables—and excess D4 and D5 RINs were generated for compliance with the D6 mandate. Indeed, for most of the period since February 2013, the three RIN prices have moved in tandem, with the D4-D5 and D5-D6 spreads averaging $0.03 and $0.06, respectively, from March 2013 through November 30, 2014. These spreads arguably represent the greater option value associated with the lower RIN numbers: the option value for a D4 biomass-based diesel RIN will exceed that for a D5 RIN if there is some probability that the BBD RVO will be binding in the future (at which point the biomass-based diesel subsidy value will rise above the advanced fuel subsidy value). RIN prices separated again in early 2015 as petroleum prices fell.

Even though supply and demand conditions were relatively stable through 2013, with crop production recovering from the 2012 drought and the US and global economic growth relatively stable, 2013 saw large fluctuations in RIN prices. The initial run-up in RIN prices in early 2013 was due in part to the increasing awareness of the E10 blend wall, and some of the short-term volatility could have been due to the markets being thin.[30] The major source of the fluctuations, however, was arguably changing market expectations about the future course of policy.[31] RIN prices rose after the release of the 2013 proposed rule, which acknowledged the blend wall but indicated that there would be no adjustments to the total renewable or total advanced statutory RVOs, and that additional gaps between the RVO and the blend wall could be met by drawing down RIN stocks.

RIN prices fell substantially after the release of the 2013 Final Rule, which gave forward guidance indicating that, unlike the 2013 rule, the 2014 rule would be set bearing in mind the constraints of the blend wall. RIN prices fell further upon the leaking of a draft of the 2014 proposed rule, which proposed to use both the cellulosic and general waiver authorities to implement this guidance by backing the RVOs out of estimates of the total amount of ethanol that could be introduced into the fuel supply; the 2014 proposed rule implied 10.09% ethanol content, just over the E10 blend wall after taking into account a small amount of E85 sales. RIN prices rose subsequently based on evolving perceptions of the various pressures facing the EPA, including public statements that the RVOs could increase from the proposed to final 2014 rule and, most recently, the announcement that the 2014 RVOs would be finalized in 2015.[32]

Figure 7: Daily RIN prices, July 1, 2012 - March 24, 2015



Source: Bloomberg.

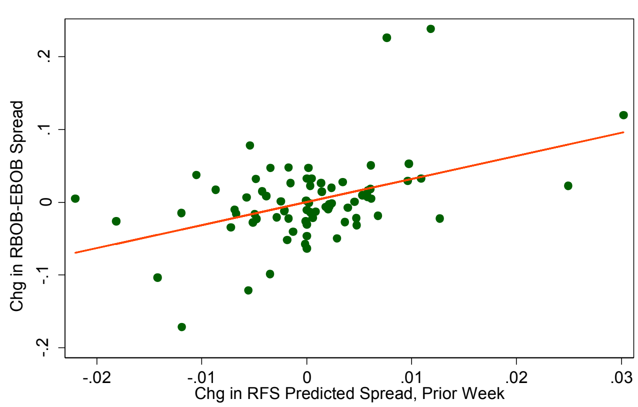
EFFECTS OF RIN PRICES ON FUEL PRICES

A central, highly charged question surrounding the RFS is the effect of RIN prices on pump prices.[33] In brief, RINs act as a tax on fuels with low renewable content and a subsidy to fuels with a high renewable content. As illustrated in Figure 6, in the long run (in equilibrium) the RIN price serves both to increase the supply of biofuels, relative to petroleum, and to increase consumption, and a RIN price increase is passed along in part to producers, who produce more, and in part to consumers. Because much of the debate has focused on the short-run link between RIN prices and fuel prices, the discussion here focuses on the short run, over which supply does not change and RIN prices change not because of current supply and demand considerations but for some other reason, such as changes in policy expectations.

To be concrete, consider RIN obligations in 2013, when the required RIN bundle consisted of a total of 0.0974 RINs (the sum of the required D3, D4, D5, and D6 RINs). Suppose all RIN prices increase by $1, so that the price of a RIN bundle increases by $0.0974. Because E10 is 90% petroleum, selling 0.9 gallons of petroleum would increase RIN costs to the obligated party by the cost of 0.9 RIN bundles, that is, by 0.9 x $0.0974 = $0.088. But blending 0.1 gallon of ethanol into E10 generates 0.1 D6 RIN, which the blender can sell for $0.10. In a competitive market, the petroleum producer passes on the $0.088 extra cost, the blender (who gets to sell the RIN) passes on the $0.10 savings, and the consumer comes out ahead by $0.012. Repeating the calculations above for diesel (which has a low renewable content) indicates that a $1 increase in the price of all RINs results in approximately a $0.05 increase in the price of diesel per gallon under perfect competition. Repeating the calculations again for E85 (which has on average 74% ethanol) results in a predicted decrease in the E85 price of $0.72 per gallon. Thus, with competitive markets and complete RIN price pass-through, if all RIN prices are $1, the net effect is a small subsidy to E10, a large subsidy to E85, and a tax on diesel, which has the lowest renewable content. The specific values of the tax and subsidy depend on RIN prices. For example, in mid-February 2015, D6, D5, and D4 RIN prices were approximately $0.70, $0.80, and $0.85, respectively; at those prices, with perfect pass-through their theoretical effect was to increase the pump diesel price by $0.03 per gallon, to decrease the E10 price by $0.01, and to decrease the E85 price by $0.50. Although specific tax and subsidy values depend on the RIN prices and the obligation percentages, the structure has the effect of taxing the lowest-renewable final fuel (diesel) and subsidizing the highest-renewable fuel (E85), with E10 receiving a slight subsidy because it has slightly more renewable content than the 2013 total renewable fractional obligation.

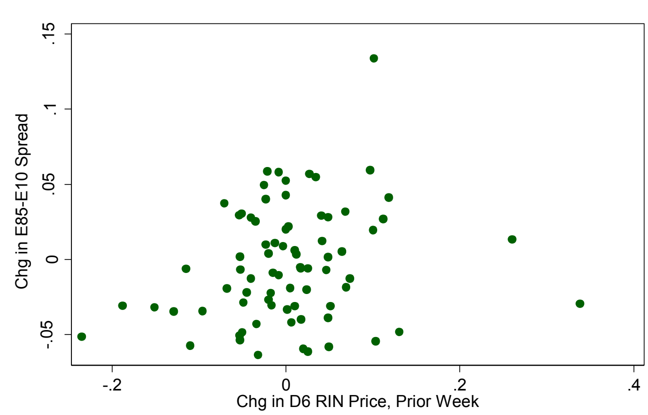
Figure 8 provides empirical evidence on two of these short-run pass-through predictions, for wholesale gasoline and for E10. On the margin, a refiner could choose to sell a gallon of gasoline into the US market, where the refiner

Figure 8a: RBOB-EBOB spread v. prior week RFS-predicted ***(Weekly Changes, 01 Mar 2013 to 14 Aug 2014)***



Source: Bloomberg; author's calculations

Figure 8b: E10 price v. prior week D6 RIN price



would incur the RIN bundle cost, or export it. As such, in equilibrium, the wholesale price of gasoline in the United States (RBOB) should equal the international price, plus the per-gallon price of the RIN bundle, differential transportation costs, and other tax and fee differentials. To the extent that transportation costs and other taxes and fees either do not change, or have changes that are unrelated to changes in RIN prices, exogenous changes in the price of the RIN bundle should translate one-for-one into changes in the spread between RBOB and international wholesale gasoline prices.

This pass-through prediction is examined in Figure 8a, which plots the weekly change in the spread between RBOB (f.o.b. New York) and EBOB (f.o.b. Rotterdam) versus the previous week's change in the price of the RIN price bundle. The scatterplot shows that, on average, changes in RIN prices in the previous week are positively associated with changes in the RBOB-EBOB spread. Once lags are taken into account, the empirically estimated pass-through is consistent statistically with complete pass-through, which is to say, US wholesale prices generally rise when RIN costs increase, and fall when they decline.

Figure 8b examines the relation between changes in the E10 pump price changes in the D6 RIN price in the previous week. Consistent with the theory outlined above, there is negligible estimated effect of RIN prices on pump E10 prices.[34]

Figure 8c: E85-E10 spread v. prior week RFS-predicted
(Weekly Changes, 01 Mar 2013 to 14 Aug 2014)

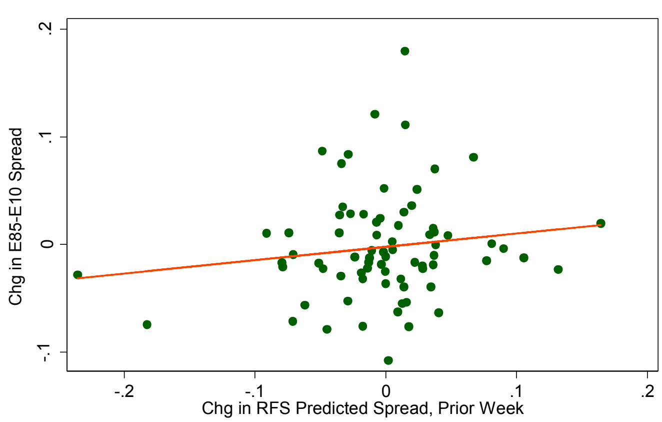


Figure 8c shows the relation between the change in the spread between E85 and E10 average retail prices and the predicted change in the spread based from previous-week changes in RIN prices. Consistent with theory, the relationship is positive (when the E85 price is predicted to drop, relative to E10, it does on average); however, the estimated pass-through is less than one-for-one. Regression analysis that includes lagged effects suggests that of a $1 increase in RIN prices, roughly one-third is passed through to consumers in the form of lower E85 pump prices. This finding of incomplete pass-through is consistent with the AJW Inc's (2013) finding of limited E85 price discounting, especially among major-brand stations, during the period of high RIN prices of 2013-2014.[35]

IMPLICATIONS FOR RFS POLICY

The overarching economic reason for the RFS and biofuels policy generally is to address four market failures, or externalities, in the market for biofuels. In this light, the role of the taxes and subsidies in the RIN system are to correct for existing market failures and to provide corrective subsidies to low-GHG domestic biofuels.

The first market failure is that carbon emissions impose a cost on future generations, but carbon is not priced in the market; in economic jargon, carbon emissions generate an externality, and the first-best policy would be to price carbon emissions to internalize that externality.

The second market failure is that fuel prices do not reflect externalities associated with energy security. This externality encompasses macroeconomic vulnerability to foreign oil supply price shocks and international policy costs borne by the United States as a result of its dependence on imported oil. In principle, if this externality could be monetized, then the first-best policy (putting aside legal considerations) would also be a tax to internalize this externality.

The third market failure is that the economic benefits of basic research and, to a lesser extent, learning by doing through early commercialization cannot be fully captured by private entities, so that the private sector will underinvest in basic research. This externality is relevant to biofuels because of its long lags between research and commercialization and the many biofuel pathways that are technically possible; first-best policy solutions provide cost-effective and reliable subsidies for early-stage research that incentivize ultimate wide-scale adoption of low-cost, low-GHG biofuels.

The fourth market failure is the presence of network externalities—that is, externalities that arise when the value to the user depends on the number of other users. In general network externalities can result in multiple equilibria that arise from "chicken and egg" problems, and these different equilibria can have values to society. These network externalities apply to biofuels that are not drop-ins, in particular to E85 sales of ethanol: if there are few E85 stations, the E85 market will not be competitive and each individual has little incentive to purchase (or utilize) a flex-fuel vehicle. Network externalities justify a government intervention when one of the equilibria produces greater social value than the other.[36]

These market failures and first-best policies, combined with the discussion of the previous section, highlight ten features of the RFS that are particularly salient for considering policy reforms.

1. The RFS cannot implement a first-best pricing policy because it is revenue neutral: it can adjust relative fuel prices based on their renewable content, but not overall fuel prices.

2. This said, in principle the RFS is capable of providing relative pricing incentives that capture the differential climate and energy security externality costs of the fuels in the various RFS fuel categories. The GHG externality value can be computed by using the US Government's Social Cost of Carbon, which is \$42 per ton of CO_2 in 2015 dollars[37] and by using ranges of GHG emissions consistent with various estimates of those in the different RFS fuel categories. The resulting range of externality values, on a RIN-gallon basis, is \$0.05–\$0.08 for D6, \$0.12–\$0.17 for D5, \$0.13–\$0.22 for D4, and \$0.15–\$0.21 for D3.[38] In the RFS Regulatory Impact Analysis, EPA estimated the energy security externality to be \$6.56 per barrel of renewable fuel (2007\$), with a range of \$0.94–\$12.23; this estimate translates into \$0.18 per ethanol-RIN gallon in 2015 dollars.[39] Combining the GHG externality with EPA's estimate of the energy security externality yields steady-state externality based RIN prices of roughly \$0.22–\$0.26, \$0.30–\$0.35, \$0.25–\$0.33, and \$0.33–\$0.39 for D6, D5, D4, and D3 RINs. There is considerable uncertainty around these ranges arising from, among other things, uncertainty about the life-cycle GHG reductions of the different fuels, the value of the social cost of carbon, and the energy security externality value,

so these externality-based RIN prices are a rough guide only.

3. The relevance of the R&D externality varies greatly by fuel. The corn ethanol and biodiesel industries are mature, so for those industries the externality is reasonably set to zero. In contrast, some advanced drop-ins and all cellulosic fuels (with the possible exception of biogas) are in the nascent stages that justify additional research and development. Qualitatively, these considerations would justify spreads of D3 over D5 RINs, and of D5 RINs over D6 RINs, larger than those based on the steady-state externality values computed above. For the D3-D5 spread to be positive, the cellulosic RVO must bind, and for the D5-D6 spread to be positive, the total advanced RVO must bind. In addition, for the D4-D5 spread to be (approximately) zero, the BBD RVO must not bind.

4. Using the RFS to internalize externalities by achieving price targets confronts the challenge of the E10 blend wall.[39] With current low E85 penetration and awareness, small changes in quantities at or just above the blend wall currently result in large changes in RIN price fundamentals (Figure 6b).

5. In addition, bankability means that RIN prices reflect expectations not just of future supply and demand fundamentals but also of future policy decisions. Because policy uncertainty raises the time value, and thus the price, of RINs, and because the welfare and compliance costs of the RFS are mediated through RINs, policy uncertainty directly increases the welfare cost of the RFS program.

6. The ability of high RIN prices to stimulate biofuels investment depends on whether investors can count on a RIN price subsidy to continue into the future. A robust finding of the economic theory of investment under uncertainty is that, all else equal, uncertainty reduces irreversible investment because firms prefer to wait until the uncertainty is resolved (e.g. Bernanke [1983], Majd and Pindyck [1987]). Thus policy uncertainty produces high RIN prices, but that uncertainty undercuts the ability of those high RIN prices to stimulate investment and the associated private R&D.

7. Because the total renewable pool is dominated by the conventional pool, the largest component of overall program compliance costs is the D6 RIN price, which in turn is driven by the blend wall and expectations (and uncertainty) about future policy concerning the blend wall.

8. Making commitments within the RFS is challenging because of the annual nature of the rulemaking under the EISA, combined with political pressures from stakeholders.

9. The RFS has so far been ineffective in stimulating sales of higher blends. There appears to be incomplete pass-through of RIN subsidies to E85 prices, and there has been slow national growth of E85 sales in 2013 and 2014 despite high RIN prices. A plausible working hypothesis is that slow growth of E85 sales stems from a combination of policy uncertainty (so that high RIN prices cannot be counted on over the period needed to pay off the fixed costs of blender pumps or tank upgrades), a lack of competition in the E85 market (because of the limited number of E85 service stations), and a group of consumers who are willing to pay a premium for E85. If so, as long as these conditions persist, the RFS will continue to be an inefficient and ineffective program for increasing sales of higher blends.

10. Two features of the RFS further impede its ability to provide support to cellulosic biofuels beyond that provided to advanced biofuels: the statutory cap on what EPA can charge for cellulosic waiver credits (set by EPA to be $0.42 in 2013), which in

turn caps the spread between the D3 and D5 RINs, and the 2013 court ruling requiring EPA to set the cellulosic RVO using a "neutral methodology" aimed at providing a prediction of "what will actually happen" regarding cellulosic production in the compliance year. If a neutral estimate is interpreted as meaning median-unbiased,[40] then half of the time the estimated cellulosic RVO would be less than actual production, that is, half the time the cellulosic RVO would not be binding. If so, the D3-D5 spread would be positive only because it might bind in a future compliance period. The first of these features caps the additional RIN price support that the RFS can provide to cellulosic production, and the second of these features pushes that additional support to zero, possibly strongly so. Because 2014 will be the first year with nonnegligible cellulosic production there is no historical experience yet on the impact of these twin restrictions on D3 RIN prices.

THREE POSSIBLE PATHS FOR BIOFUELS POLICY AND THE RFS

The introduction laid out three paths forward for the RFS and biofuels policy: a flexible, status quo path of making annual rulemakings as circumstances and policy goals evolve; a conservative path in which EPA commits to staying within the blend wall while supporting advanced biofuels; and an ambitious path for expanding both conventional and advanced biofuels. This section fleshes out and analyzes these three paths in light of the foregoing discussion of the economics of the RFS.

The context for this evaluation is the broader biofuels policy goal of promoting, in an economically efficient way, low-GHG domestic advanced biofuels and enhancing macroeconomic energy security. The transportation sector remains a particularly challenging area for achieving a transition to a low-carbon future. While there are advanced technologies for substantially reducing GHG emissions in transportation, such as hydrogen fuel cells and electric vehicles powered by renewables, they remain expensive and confront major technological and infrastructure hurdles. For these reasons, and because of their energy density and convenience, liquid fuels will plausibly continue to play an important role in the transportation sector in the foreseeable future. Although infrastructure changes or upgrades are needed for widespread use of advanced low-GHG biofuels in the transportation fleet, those changes are relatively modest compared with alternative low-GHG technologies. In this view, advanced biofuels act as a bridge to the zero-carbon technologies of the future.

The focus in this section is on these three paths for the RFS. The next section turns to specific reforms within the existing RFS, steps that can be taken outside the RFS, and possible legislative reforms to the RFS.

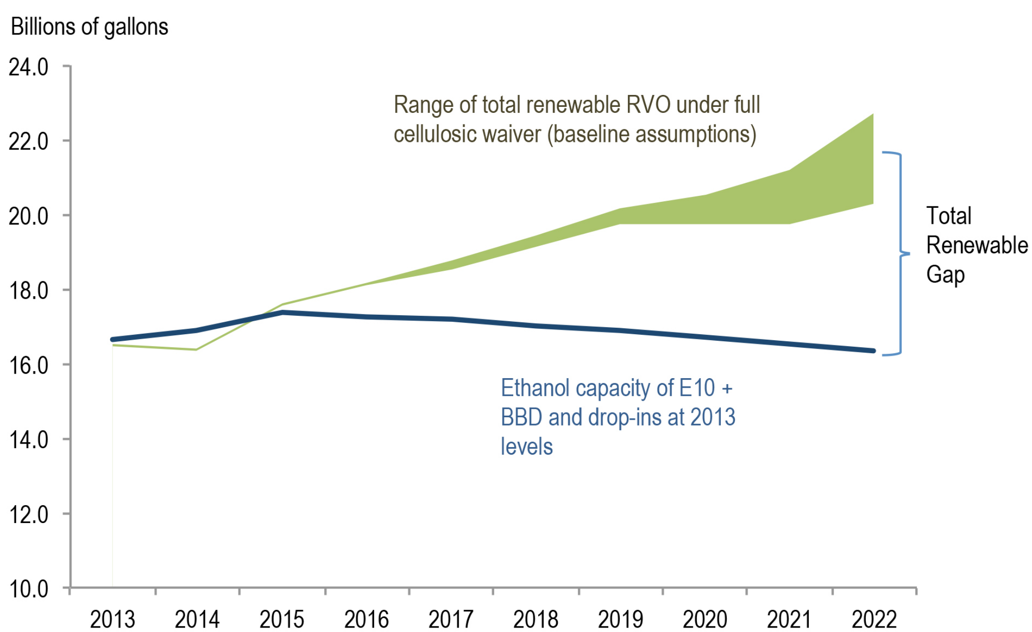
The first two paths each have advantages. The first path, which entails annual rulemaking with limited forward guidance, allows the EPA maximum flexibility as biofuels policy evolves. The second path, committing to a conservative approach to the blend wall, holds the promise of low D6 RIN prices and low compliance costs. But both paths have disadvantages. The first path, with its annual focus, invites a continuation of the policy uncertainty and RIN price volatility experienced since early 2013, resulting in the undesirable combination of high compliance costs and low investment both in nascent low-GHG technologies and in the E85 infrastructure investments that could relieve the pressure of the E10 blend wall. If credible multiyear commitment to a conservative path were possible, the second path would address the problem of uncertainty and high compliance costs, albeit not necessarily providing additional support to advanced biofuels.[42] But it is unclear whether EPA can make a credible multiyear commitment to a conservative path, and to the extent that there is a reasonable chance that the policy will be reversed in the future, the second plan, like the first, would entail policy uncertainty and the consequent combination of moderate to high compliance costs and low investment. Thus both these paths are unlikely to achieve the policy goal of economically efficient support for the development and potential widespread adoption of low-GHG domestic biofuels.

The third path—an ambitious expansion of both total renewable and advanced biofuels—could be implemented in various ways. For concreteness, the discussion here will focus on one specific implementation path, which relies on the cellulosic but not general waiver authority within the EISA. Specifically, this implementation would use the cellulosic waiver authority to reduce the total renewable RVOs by the amount of the cellulosic production shortfall, and to reduce the total advanced RVO by a lesser amount for a transitional period, after which the total advanced RVO would be reduced by the same amount as the total renewable RVO.[43] This combination of temporarily different reductions would result in a path for the growth of conventional biofuels that would ultimately hit the 15 Bgal statutory cap, but would do so later than the 2015 statutory date. Applying a smaller reduction to total advanced would recognize that the market is able to supply substantial quantities of advanced fuels, and would meet the policy objective of providing support for investment in new advanced and cellulosic technologies and production. The temporarily differential application of the cellulosic waiver authority would initially ease the pressure of the blend wall while committing to a policy path to expand consumption of conventional ethanol, which would in turn provide the multiyear support needed for investment in E85 infrastructure.

The challenge for this path is that the incremental volume of renewable fuels required is large. Moreover, even though the conventional fuel component is capped at 15 Bgal under the statute, the statute calls for increasing volumes of noncellulosic, non-BBD advanced biofuels; thus, even using the full cellulosic waiver authority, the total renewable RVO would increase. Because EIA projects flat then declining total gasoline consumption, under this path conventional biofuels would constitute an increasing share of fuel consumption, even as the capacity for ethanol sales through E10 is flat or declining. These dynamics thus create an increasing "total renewable gap" between the total renewable RVO and what can, or has been, supplied within the E10 blend wall.

Figure 9 illustrates a range of plausible magnitudes for the total renewable gap, which is the difference between the total renewable RVO under the full cellulosic waiver and the sum of the amount of ethanol in E10, the volume of nonethanol fuels supplied in 2014, and projected growth of cellulosic fuels. E10 capacity is projected based on EIA projections.[44] Said differently, Figure 9 shows the D6 RIN shortfall that would have occurred in 2014 (when nearly all ethanol was sold as E10), had the total renewable RVO been set at the level implied by the cellulosic waiver reduction in the various years plotted, adjusted for EIA's projected decline in total gasoline demand. The range of the shortfall shown in Figure 9 is illustrative and reflects two sources of uncertainty: uncertainty about future gasoline consumption and uncertainty about the growth of cellulosic biofuels.[45]

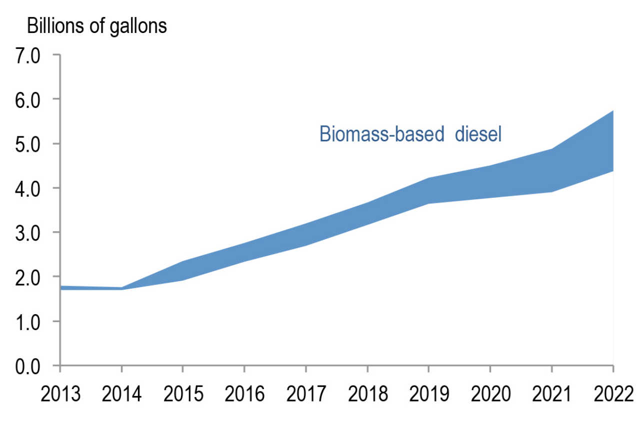
Figure 9: The total renewable gap under the cellulosic waiver



The shortfall illustrated in Figure 9 can be filled by any RIN-generating biofuel because all renewable fuels produced in excess of their RVO can be used to meet the total renewable RVO. In practice, the shortfall would most likely be filled by some combination of increased domestic biomass-based diesel produced in excess of the BBD RVO, increased conventional BBD imports, and increased sales of higher ethanol blends. These higher ethanol blends could be E15, E85 or, in theory, an intermediate blend. Some ethanol advocates promote E15 as an attractive high-octane fuel, however its penetration to date has been very low and there is controversy surrounding the E15 capability of many of vehicles on the road today. In contrast, E85 is a small but established fuel, and because of its high ethanol content far fewer gallons of E85 than E15 need to be sold to fill the total renewable gap. For these reasons, the discussion here about higher ethanol blends focuses on E85.[46]

Figure 10a shows the range of volumes of domestic BBD (in wet gallons) that would be needed were the total renewable gap to be filled entirely with D4 BBD. In 2013, 1.8 Bgal of domestic BBD was produced, and initial estimates based on 2014 D4 RIN generation point to a similar volume produced in 2014. Under the ranges in Figure 10a, these volumes increase to 1.9–2.4 Bgal in 2015 and to 2.7–3.2 Bgal in 2017, climbing by 2022 to 4.4–5.7 Bgal. Because the existing literature on the supply curve (both static and dynamic) for biodiesel is quite limited, it is difficult to estimate accurately what the economic effects of these increases would be, but the available evidence suggests that these represent very large increases in biodiesel over historical levels and even in the short run imply large to very large annual subsidy values.[47] In the long run, meeting these increases with domestic biodiesel would require doubling or even tripling domestic industry capacity and would have impacts on feedstock prices that are hard to predict but would very likely be substantial.[48] Although the United States currently imports some biodiesel, those imports would need to expand tremendously. The volumes in Figure 10a are so large after 2016 that it is unrealistic to think they will be filled entirely by domestic biodiesel, and instead that much or all of these increases need to come from E85, for which the increase in marginal cost of production associated with this expansion is much less than for BBD.

Figure 10: Filling the total renewable gap



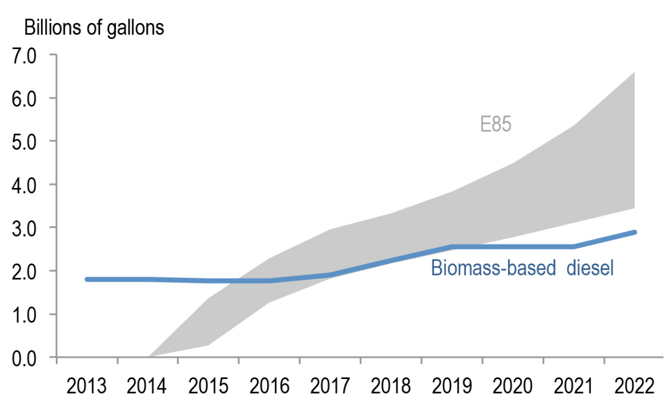


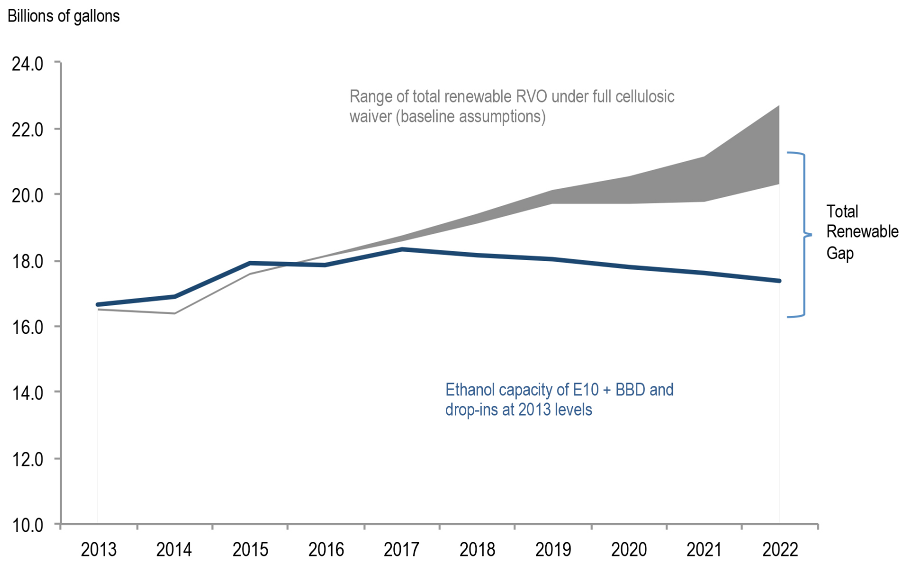
Figure 10b considers the alternative scenario in which E85 expands to fill the gap in conventional biofuels.[49] The total renewable gap is the sum of a total advanced shortfall and a shortfall in the conventional pool. In the cases considered in Figures 9 and 10, there is no significant shortfall in total advanced until 2018, after which the advanced shortfall rises to 1.7 Bgal (RIN gallons) in 2022. In Figure 10b, it is assumed that this advanced shortfall would be filled by BBD. Figure 10b also shows the volume of E85 needed to fill the remaining gap in the conventional pool. Under the cases in the figure, this volume is 1.3–2.3 Bgal in 2016, rising to 3.4–6.6 Bgal by 2022. Although there is technically the flex-fuel vehicle capacity to consume these quantities, doing so would require a vast increase in E85 sales. By 2022, the range in Figure 10b requires that the average ethanol content of US fuel supply be approximately 11.7–13.4%. To date, E85 has been lackluster, except perhaps in the few states that have had significant programs to promote E85 stations.[50]

The discussion of Figures 9 and 10 has so far omitted two factors that could postpone the opening of the large total renewable gap in Figure 9: increasing imports of nonethanol fuels, and increased gasoline consumption because of low oil prices.

Two recent developments suggest that imported biodiesel and renewable diesel could fill at least part of the total renewable gap. First, in 2013 conventional BBD generated approximately 250 million D6 RINs, and in 2014 this figure rose to approximately 340 million D6 RINs, up from less than 10 million D6 RINs in 2011 and 2012. This increase appears to be associated with conventional biodiesel imports. Although more needs to be known about the supply capacity for imported conventional biodiesel and renewable diesel, there is a possibility that these imports could expand further. Second, in January 2017 EPA approved a streamlined tracking program for Argentinian soy biodiesel, which the National Biodiesel Board estimates could potentially introduce 0.6 Bgal of BBD annually that would generate D4 RINs.[51] Although the net effect of these imports on RIN prices under the scenarios in Figures 9 and 10 is unclear, the potential for increasing volumes suggests that the total renewable gap in 2015 and possibly 2016 could be filled with imported biodiesel, and if so D4, D5, and D6 RIN prices would continue to be equal. Imported biofuels are consistent with the GHG reduction goals of the EISA (assuming their pathways are accurately assessed) but, from a macroeconomic energy security perspective, have similar effects to oil imports. In any event, a real possibility, at least in the short run, is that the total renewable gap would be met with nonethanol biofuel imports.[52]

The second factor is the sharp decline in oil prices since June 2014. Figures 9 and 10 use the February 2015 STEO projections for 2015–2016, with gasoline demand growth rates from the AEO 2014 thereafter. The February 2015 STEO forecast for 2015 is up 2.4% from the 2015 forecast made in May 2014 (9.00 million b/d, up from 8.79 million b/d). However, historical evidence on gasoline supply elasticities suggests that the cumulative increase in gasoline demand, relative to June 2014 levels, could be 8%, a much greater increase than EIA forecasts.[53] To illustrate the importance of this potential increase in gasoline demand, beyond the baseline used in Figures 9 and 10, Figure 11 shows the total renewable gap if gasoline consumption exceeds the February 2014 STEO by 4% (so the total increase is 6.4%, relative to June 2015 levels). Under this high gasoline demand scenario, the total renewable gap is substantially less through 2017, with a range of essentially no gap to 0.9 Bgal in 2017, a gap that could plausibly be filled by modest domestic expansion of E85 sales combined with increased biodiesel and renewable diesel imports as discussed above. The gap expands post-2017; however, under this scenario, higher gasoline demand combined with nonethanol imports provides a window to prepare for this expansion.

Figure 11: The total renewable gap under cellulosic waiver, high gasoline demand scenario



In the high gasoline demand scenario, gasoline consumption exceeds EIA projections by 4% to reflect potential additional growth in demand in response to low gasoline prices. See the notes to Figure 9. Source: Author's calculations

The discussion so far does not address the requirement in the EISA that EPA reset the volumes if it waives that volume by 20% for two consecutive years, or by 50% for one year, but no earlier than in 2016. Little has been written on this provision, but a straightforward reading of the EISA suggests that these reset triggers and requirements apply separately to the different RVOs. The cellulosic trigger has already been reached, so its volumes will need to be reset in 2016. Under all scenarios here, the total advanced trigger is hit in 2016, requiring a reset in 2017, and the total renewable trigger is hit in 2018, requiring a reset in 2019. These resets could reduce the RVOs, but under the cellulosic waiver path laid out in Figure 9, the total renewable gap would be 2.1–2.9 Bgal (RIN gal) in 2018, corresponding in Figure 10b to 2.1–3.3 Bgal of E85 sales. Even though the very large volumes of E85 after 2020 could be avoided by a conservative reset, the path to reach the 2018 reset considered here would require a breakthrough in E85 sales.

In summary, this discussion of Figures 9–11 yields four main conclusions. First, under the ambitious path using only the cellulosic waiver authority, very significant expansions would be necessary in biofuels. Second, although some of the gap could be filled by BBD, at least in the short run, it would be prohibitively expensive if not impossible to fill much or even most of the gap by BBD. Third, this expansion path provides considerable opportunities for BBD to be produced with high RIN prices, even if only to meet the total advanced RVO (as in Figure 10b), so there is no need for further supporting BBD through expanding the BBD RVO. Fourth, the alternative, expansion of ethanol consumption, would require massive increases in E85 sales. Based on fundamentals, increasing E85 sales could be cost effective—far more so than increasing BBD sales—but doing so requires moving the blend wall.

The challenge, then, is how to move the blend wall over the next few years to enable this expansion and to contain RFS compliance costs. If this ambitious path is in fact able to spur additional sales, then overall program economic costs can be kept down, including separating the D5 and D6 RIN prices as had been the case until early 2013. The history of the RFS and ethanol consumption suggests that the RFS alone is inadequate for spurring additional E85 sales; rather, the few states that have substantial sales have achieved those by complementary programs.[54] For this path to be viable and credible, a commitment to this path therefore needs to be coupled with a wide-ranging program to spur substantial additional ethanol sales.

BEYOND THE 2014 RULE

This section outlines several policy reforms that could provide more effective support for advanced, low-GHG, domestically produced biofuels. The section starts with modest but meaningful initiatives and reforms that can be undertaken within the existing RFS framework, then turns to reforms that would entail congressional action. This list is both incomplete and terse, and additional analysis of these and other proposals remains.

POTENTIAL REFORMS WITHIN THE RFS FRAMEWORK

Multiyear guidance and a multiyear plan. Even within the current annual rulemaking requirements of the RFS, EPA can reduce uncertainty by announcing a multiyear plan with transparent formulas. The previous section argues that, to be consistent with the goal of providing economically efficient support for the development and potential widespread adoption of low-GHG domestic biofuels, the announced path should be both ambitious and credible. Achieving credibility requires committing to a path in the future. EPA's announcement on February 19, 2015, that it would issue the 2014, 2015, and 2016 rules together is a meaningful step toward providing multiyear plans.

Forward guidance could be provided by EPA announcing a methodology (formulas) going forward along with a legal strategy to support that methodology. Were EPA to adopt the third path proposal laid out in the previous section, EPA could reduce uncertainty by announcing that it intends to use only the cellulosic waiver authority; it could find that it is consistent with the environmental policy intent of the statute that the cellulosic waiver authority be applied in full to reduce the total renewable obligation but to reduce the total advanced obligation by a lesser amount and use that differential authority from the outset; it could find that the demonstrated ability of BBD to compete with other advanced fuels in the advanced pool, and indeed in the conventional pool, combined with estimates of high marginal costs of supplying biodiesel, would justify no further expansion in the BBD RVO; and it could provide clarifying forward guidance on what market conditions would lead it to invoke the general waiver authority, both weakening its discretion and providing a clearly delineated safety net. Credibility would be further enhanced by providing precise, clearly articulated goals that both recognize the challenges ahead and outline complementary actions that will help to achieve that path in an economically efficient way.

Work to expand E85 consumption beyond simply relying on high D6 RIN prices. Examples of such initiatives include:

- *Work to Improve Transparency of E85 Pricing*. The ethanol content of E85 can range from 51–83% ethanol. This large range accommodates regional and seasonal variation including vapor pressure regulations and cold start conditions. But a consumer who does not know the precise ethanol (and thus energy) content of the fuel cannot comparison shop between E10 and E85, indeed she cannot even shop between different stations carrying E85. A conceptually straightforward fix to this problem would be to post E85 prices on an E10-equivalent basis. For example, E85 that contains 65% ethanol has 82% the energy content of E10; if that E85 were selling for \$2.00/gallon, its E10-equivalent price would be 2.00/.82 = \$2.44/gallon—which the consumer could then recognize as a bargain if E10 is \$2.80/gallon. This approach could be refined to account for ethanol octane boosting, but the point is to provide a simple, transparent way to encourage flex-fuel vehicle owners to comparison shop. The resulting transparency would also encourage price competition and RIN pass-through to E85.

- *Work to Improve E85 Penetration and Competition*. As discussed above, one plausible factor in the lack of pass-through of RIN prices into E85 pump prices is the lack of local competition in E85 stations. Increasing the density of E85 outlets would both increase availability and support price competition among E85 stations, just as there is price competition in E10. Although the federal government has limited ability to support blender pump installations,[55] there still is opportunity to work with industry and to promote industry efforts to expand blender pump (and especially E85) penetration.

Expedite the pathways approval process. There has been a chronically long lag in approving new pathways (the combination of feedstocks, their sources, and the technology by which they are transformed to fuel) under the RFS (McCubbins and Enders [2013]). This long approval queue runs against the program goal of incentivizing new low-GHG advanced fuels and technologies. In March 2014, EPA announced an initiative to expedite the pathways approval process.[56] The success of these reforms will be contingent on having EPA resources to implement them and to work through the backlog, which could benefit from additional targeted administration and interagency efforts.

Consider changing the obligated parties. RINs are separated at blending but the obligated parties are refiners and importers, not blenders. This creates two frictions. First, because blenders either are retailers or sell to retailers, blenders are better situated to pass the RIN subsidy for high-renewable content fuels along to the consumer than are the current obligated parties, who are further upstream. This raises the possibility that shifting the obligation to the blenders could improve RIN pass-through in E85 and other higher blends. Second, some obligated parties, such as merchant refiners, are currently left with net RIN deficits that need to be filled on the market by purchasing RINs from net RIN generators. As discussed previously, movements in RIN prices appear to be passed through to RBOB prices, suggesting that obligated parties with net RIN deficits can pass through their RIN costs on average.[57] Still, the current system leaves those obligated parties with net exposure to RIN price fluctuations, and their ability to recover RIN costs might be incomplete because of lags and variability in RIN prices. The purpose of the RIN system is to ensure compliance with the RFS, not to add price risk to the balance sheets of obligated parties that happen to have a generation/obligation mismatch.[58]

REFORMS THAT LIKELY REQUIRE CONGRESSIONAL ACTION

RIN price collar. A theme of this analysis has been that the RFS introduces uncertainty in compliance costs and in cross-subsidies because it is a quantity-based regulation in a situation in which price-based regulation is arguably more appropriate. A RIN price collar—a floor and ceiling on RIN prices, with different collars for different RIN categories—addresses this defect. The floor would ensure a continued base level of subsidy for renewable fuels while the ceiling would provide a cap to compliance costs. Providing both a ceiling and a floor would provide certainty to parties involved with the RFS. The floor and ceiling could be based on various considerations including the externality costs of nonrenewable fuels (environmental and energy security), nascent industry arguments (which would support additional higher D5 and D3 RIN prices), and the policy goal of supporting domestic, low-GHG, second-generation advanced fuels.

Change RIN generation from energy-equivalent values to GHG-reduction values. For example, under this proposal a biofuel with a 60% life-cycle GHG reduction (relative to petroleum on a Btu basis) would generate three times as many RINs as a biofuel with a 20% GHG reduction. This could be done within the current four fuel categories in Figure 1, using the statutory reductions for the qualifying fuels; this simply entails establishing a conversion rate for the different categories of RINs based on category threshold GHG reduction (for example, a single D3 RIN could be exchanged for three D6 RINs which in turn could be used to satisfy the total renewable obligation). Alternatively, each fuel pathway could have its own RIN generation multiplier. As a practical matter, administering fuel- and pathway-specific RIN conversions could be administratively challenging and GHG life-cycle analysis is a source of considerable uncertainty, so category-wide RIN conversion schedules might be sufficient. Mechanics aside, this change would provide subsidies to fuels in proportion to their GHG reductions and would provide additional incentives for the expansion of low-GHG fuels. At an extreme, the markets for different RINs and the distinct RVOs by category could be replaced by a single RIN, a single total RIN-equivalent volumetric target (specified in terms of conventional RIN gallons), and a single RIN fractional obligation (instead of currently retiring a bundle of RINs for each gallon petroleum fuel). All biofuels would thus compete to generate the RINs necessary to meet that target. This proposal could be combined with a floor and ceiling on the (single) RIN price to provide certainty to all market parties.

Lengthen the time between RFS rulemakings. Longer rulemakings—for example, quadrennial instead of annual—would address several fundamental problems. Most importantly, a multiyear obligation would provide investors with more guidance on which to make their decisions. Switching to a multiyear rulemaking would require additional technical changes given that the RFS is currently specified in volumetric mandates but is operationalized in fractional standards. Because of the blend wall, multiyear rulemakings would need to be combined with clear policy toward the blend wall. The technical challenges of multiyear quantity and fractional rulemakings are mitigated if there is a RIN price collar, which would stabilize RIN prices in the event of unexpected supply and demand developments.

Increase support for cellulosic fuels. Direct support for cellulosic fuels is currently limited by the statutory RIN price cap and the court-mandated requirement for a "neutral" estimate of cellulosic production. There are several mechanisms to provide greater support than is possible given this determination. The most direct and straightforward would be to implement the 10-year cellulosic production tax credit (with phase-out in final years) in the President's 2015 budget. An alternative would be support through an investment tax credit for cellulosic demonstration and production facilities. Another alternative would be to raise the cap on the cellulosic waiver in the RFS, which is currently set statutorily and is indexed to gasoline prices. However, although the cellulosic waiver price is currently used to price a synthetic D3 RIN, it is unclear whether the cap would be binding in a robust cellulosic market given the mandated "neutral" estimate of cellulosic production.

Support higher fractions of flex-fuel vehicles. Because the most cost-effective pathway toward a zero-carbon transportation sector is currently unclear, biofuels policy should aim to preserve the option for biofuels being an important part of that transition or possibly part of the long-term low-carbon solution. The view suggests developing the option that the fuel supply be capable of absorbing large volumes of advanced and cellulosic ethanol, which would require a vehicle fleet able to handle high ethanol blends. Because of slow fleet turnover, keeping open this possibility on the ten-to-fifteen-year time horizon means increasing the fraction of flex-fuel vehicles produced. One option to consider would be adopting a flex-fuel (E85-capable) vehicle standard, while options short of such a standard include incentives for flex-fuel vehicles.

CONCLUSION

The goal of reducing US dependence on imported oil through low-carbon domestic alternatives remains as valid today as when the EISA was passed in 2007. Indeed, the sharp drop in oil prices since June 2014 makes the transition to a low-carbon transportation sector both more pressing and more challenging. At present there is no clear economically dominant technology among the multiple routes to a low-carbon transportation sector. The combination of GHG externalities, energy security considerations, and the spillover benefits of research and development therefore justify policies that support the development of a range of nascent alternatives to petroleum and thus keep technological options open. One such alternative is second generation biofuels, and because the Renewable Fuel Standard is the main tool of U.S. biofuels policy, the policy challenge facing the RFS is to provide support for domestic low-carbon advanced biofuels, while doing so as economically efficiently as possible.

This paper argues that the RFS can provide this support for domestic, low-GHG advanced fuels through adopting an expansive path for its volumetric obligations – increasing the amount of renewables in the fuel supply. But providing this support effectively and economically efficiently requires a combination of efforts and reforms both within and outside of the RFS. To support the necessary investment in production and distribution, the path must be credible and must reduce the uncertainty surrounding RFS policy. Over the next year or two, potential increases in non-ethanol biofuel imports combined with increased gasoline consumption spurred by low oil prices could ease the pressure of the E10 blend wall. Looking ahead, however, the key to making an expansive path economically efficient is to expand E85 consumption. While expansion of E85 will be encouraged in part by a credible RFS path, more is needed, including transparency of pricing and programs to support additional E85 dispensers. Absent replacing the RFS with a first-best alternative, legislative reforms should focus on making the RFS both more efficient economically and more effective in supporting advanced low-GHG domestic fuels, for example by enabling EPA to impose a price collar (both floor and ceiling) for RINs that reflects GHG externalities, energy security externalities, and nascent industry considerations.

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ENDNOTES

[1] See for example A. Rascoe, "UPDATE 1-Oil exec says ethanol RINs 'out of control', urges action," Reuters, 16 July 2013, http://www.reuters.com/article/2013/07/16/congress-gasoline-hearing-idUSL1N0FM0PP20130716; G. Morgenson and R. Gebeloff, "Wall St. Exploits Ethanol Credits, and Prices Spike," *New York Times*, 14 September 2013, http://www.nytimes.com/2013/09/15/business/wall-st-exploits-ethanol-credits-and-prices-spike.html?pagewanted=all&_r=0; D. Strumpf, "Lawmakers Examine Ethanol Credits' Affect on Gas Prices," *Wall Street Journal*, 14 March 2013, http://www.wsj.com/articles/SB10001424127887324532004578360341241306954; M. Parker, "Gasoline Price Inflated by Ethanol in Oil Boom: Energy Markets," Bloomberg, 21 March 2013, http://www.bloomberg.com/news/articles/2013-03-21/gasoline-price-inflated-by-ethanol-in-oil-boom-energy-markets

[2] The preamble to the EISA reads in full: "To move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes." (Public Law 110-140 at http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/content-detail.html.) This preamble could be interpreted as supporting clean (low-greenhouse gas) biofuels is a purpose of the act or alternatively that supporting clean biofuels production is a means to an end, with the purposes of the act being energy security and cleaner fuels; I adopt the latter interpretation.

[3] The EISA sets out annual volumetric targets for four categories of renewable fuels, which vary by type and by life-cycle greenhouse gas emissions reductions relative to petroleum gasoline. Because the statute specifies volumes and gasoline consumption has been running 12% below 2007 projections, the statutory renewable requirements comprise a considerably larger fraction of the fuel supply than originally projected. EPA is required to convert these volumes into fractions of renewables per gallon through annual rulemakings that can exercise waiver authorities granted in the statute. The waiver authorities and annual rulemakings provide flexibility but also open the door to revising RFS policy annually.

[4] Environmental Protection Agency, "Renewable Fuels: Regulations & Standards," epa.gov/otaq/fuels/renewablefuels/regulations.htm.

[5] Net imports of oil and petroleum products averaged nearly 12.6 million barrels per day (b/d) in 2005. For the first 10 months of 2014, they averaged 5.1 million b/d. EIA, "US Net Imports of Crude Oil and Petroleum Products," http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mttntus2&f=m.

[6] The White House Council of Economic Advisers noted that factors reducing net oil imports and improving economic resilience to oil shocks included lower domestic petroleum demand, increased domestic oil production, more efficient vehicles, and increased use of biofuels. "The All-of-the-Above Energy Strategy as a Path to Sustainable Economic Growth," May 2014, http://www.whitehouse.gov/sites/default/files/docs/aota_energy_strategy_as_a_path_to_sustainable_economic_growth.pdf.

[7] E85 can contain between 51% and 83% ethanol. EIA assumes the average ethanol content of E85 is 74% (*Annual Energy Outlook* 2014, p. A-5, fn. 9).

[8] The dominant diesel standard currently is B5, which permits up to 5% biodiesel content. In 2013 biodiesel constituted approximately 3% of diesel fuel. Some engines can use higher blends, such as B20. Renewable (non-ester) diesel constitutes slightly less than 1% of diesel fuel. See EPA (2007) and the DOE Alternative Fuel Data Center at http://www.afdc.energy.gov/fuels/biodiesel_basics.html and http://www.afdc.energy.gov/fuels/emerging_green.html. Whether there is a biodiesel blend wall is a matter of debate (for the case against, see the National Biodiesel Board at http://www.biodiesel.org/docs/default-source/ffs-basics/biodiesel-blend-wall-myth-fact-sheet.pdf?sfvrsn=8). At the volumes under consideration in this paper, I assume there is no biodiesel blend wall.

[9] C. Krauss, "Dual Turning Point for Biofuels," *New York Times*, April 14, 2014, http://www.nytimes.com/2014/04/15/business/energy-environment/dual-turning-point-for-biofuels.html?_r=0.

[10] 79 FR 42128.

[11] This list, and Figure 1, omits cellulosic diesel, which is its own separate regulatory category; however, no cellulosic diesel has yet been produced commercially.

[12] EPA has further argued that the statute requires that if EPA exercises the cellulosic waiver, it must do so by reducing the total renewable and total advanced standards by the same amount (74 FR 24914-15 and 78 FR 49810). EPA reasons that reducing the advanced standard by more than the conventional "would allow conventional biofuels to effectively be used to meet the standards that Congress specifically set for advanced biofuels" (78 FR 49810). Some commenters argued that reducing the total renewable standard by more than the advanced standard recognizes total biofuel shortfalls but achieves the environmental goals of the statute by allowing low-GHG advanced fuels to replace part of the shortfall in (low-GHG) cellulosic. Because EPA has not actually applied the cellulosic waiver authority to the total or advanced standard, this issue remains open in the sense that it has not been tested in the courts. This issue is potentially relevant for setting the 2014–2016 standards in a way that is consistent with the environmental goals of the statute and is returned to below.

[13] The statutory language for the two criteria allows waiving the statutory volumes either: (i) based on a determination by the administrator, after public notice and opportunity for comment, that implementation of the requirement would severely harm the economy or environment of a state, a region, or the United States; or (ii) based on a determination by the administrator, after public notice and opportunity for comment, that there is an inadequate domestic supply [42 USC §7545(o)(7)(A)].

[14] 42 USC §7545(o)(2)(B)(ii).

[15] *API* v. *EPA,* No. 12–1139, slip op. at 5–9 (D.C. Cir. January 25, 2013). The ruling vacated the 2012 cellulosic standard. See the discussion in the EPA 2013 final rule, 78 FR 49798 and 49800-49801.

[16] Schnepf and Yacobucci (2013).

[17] 42 USC §7545(o)(7)(F).

[18] The RFS obligations are stated in terms of cellulosic biofuels, advanced biomass-based diesel, total advanced, and total renewable (EPA 2013 RFS final rule, 78 FR 49826 [August 15, 2013], Table IV.B.3-2). The D5 RIN obligation is computed as the difference between the total advanced obligation and the sum of the advanced biomass-based diesel and cellulosic biofuel obligations, and the D6 RIN obligation is computed as the difference between the total renewable and total advanced obligation.

[19] A 2012 RIN can be sold in 2013 to satisfy a 2013 obligation, and a 2013 RIN can be purchased, effectively extending the 2012 RIN's lifetime for a year at the cost of the transaction.

[20] The EISA specifies that EPA make cellulosic credits available at a price which is the higher of $0.25/gallon or the amount by which $3.00 per gallon exceeds the average wholesale price of gasoline per gallon, adjusted for inflation (42 USC §7545(o)(7)(D); these cellulosic waiver credits, plus a D5 RIN, can be used to meet the cellulosic requirement (75 FR 14726-14728 and 78 FR 49826-49827).

[21] RBOB (reformulated blendstock for oxygenate blending) is petroleum motor gasoline intended for blending with oxygenates, such as ethanol, to produce finished reformulated motor gasoline, see eia.gov/dnav/pet/TblDefs/pet_move_wkly_tbldef2.asp.

[22] This is a sufficient but not necessary condition for the RFS mandate to

imply ethanol volumes exceeding the blend wall: because advanced ethanol (mainly sugarcane ethanol) is used to satisfy the total advanced RVO, the blend wall could be hit even if the mandated conventional pool is less than 10% of gasoline.

[23] The substantial volume of D6 RINs generated by conventional nonethanol fuels, specifically biodiesel and renewable diesel, is a new development. In 2012, conventional biodiesel and renewable diesel generated only 1 million D6 RINs. In 2013, this figure jumped to 250 million D6 RINs, and through the first 10 months of 2014 this figure is 300 million D6 RINs at an annual rate.

[24] There are now a number of good treatments of RIN pricing. Irwin provides a lucid description of the basic elements of RIN pricing in a series of posts in farmdocdaily.com and uses a quantitative model of RIN price fundamentals to estimate D4 and D6 RIN prices and to analyze current policy issues and market developments in real time; see in particular Irwin (2013b, 2013c, 2013d). Babcock (2011, 2012) and Babcock and Fabiosa (2012) develop a quantitative model of RIN pricing based on annual subsidy costs, stressing the importance of the blend wall in increasing those costs, and Babcock (2013) uses this model for analyzing the economic welfare costs of the RFS under various E85 penetration scenarios. Meiselman (2014) models the effect of the RFS nesting structure (with three fuels) on RIN prices and economic welfare. Lade, Linn, and Smith (2014) develop a two-period stochastic model with both subsidy values and time values arising from the bankability of RINs and the effect on RIN prices of uncertainty about future policy, and also consider the static implications of a nesting structure with two fuels. They provide additional references to the academic literature, much of which abstracts from the regulatory structure and blend wall details that are the focus of this discussion.

[25] Equating the actual RIN price to the subsidy value assumes that the subsidy is in fact passed along to the consumers, which would be the case in competitive markets but not necessarily in noncompetitive markets.

[26] Figure 6a shows the market equilibrium value Q_0 to be positive. However, because biodiesel is expensive, it is possible that Q0 = 0, that is, no biodiesel would be produced without the RIN subsidy. For example, Irwin (2013a) estimates that no biodiesel would be supplied at a diesel price of less than $4.00 for prices prevailing in the first half of 2013.

[27] Biofuels are not a final product demanded by consumers; rather, the demand curves in Figure 6 are derived from consumer demand for vehicle transportation services and the existing ethanol-related infrastructure, such as the number of flex-fuel vehicles and the penetration of E85 service stations.

[28] The full set of inequalities also includes the requirement that the quantity of fuel satisfy its RVO. For a static analysis of nonbankable RIN pricing with RFS fuel nesting, see Meiselman (2014) and Linn, Lade, and Smith (2014).

[29] The payoff function of a RIN has additional nonlinear features. Importantly, the RFS nesting structure implies that RIN prices are nonlinear functions of the annual subsidy value for other fuels higher in the nesting structure (the D5 RIN price depends on the conventional subsidy value, for example). An additional nonlinearity arises from the restriction that banked RINs can be at most 20% of the upcoming year's RVO

[30] Some have suggested that RIN market speculation, facilitated by a lack of market transparency, also contributed to price volatility, see Morgenson and Gebeloff, "Wall St. Exploits Ethanol Credits, and Prices Spike."

[31] Posts on *farmdocdaily* by Irwin and coauthors provide insightful real-time commentary on these developments, see for example Irwin (2014).

[32] For example, EPA Administrator Gina McCarthy stated in the context of the 2014 proposed RFS rule, "I have heard loud and clear that you don't think we hit that right" (e.g. Governors' Biofuels Coalition News, Feb. 5 2014 at http://www.governorsbiofuelscoalition.org/?p=8315).

[33] See for example NERA (2012), Babcock and Pouliot (2013), and RFA (2013).

[34] These calculations assume competition among retailers and throughout the supply chain results in fuel supply costs and savings being passed along to consumers. Previous research on pass-through of changes in oil prices to pump prices is consistent with eventual complete pass-through of oil prices to average pump prices. For example, EIA (2003) Burdette and Zyren (2003) finds 1:1 pass-through from wholesale to retail gasoline prices, although the lag for complete pass-through is long (up to ten weeks, depending on region). Although EIA (2003) finds no asymmetry in the total amount passed through, various researchers have found asymmetric speeds of pass-through, with price hikes passed through more quickly than price declines (see for example Borenstein, Cameron, and Gilbert (1997), Borenstein, S. and A. Shepard (2002), Radchenko and Shapiro (2011)). This asymmetry has been interpreted as some retailers having temporary local market power or temporary information delays among consumers. See Owyang and Vermann (2014) for a recent survey and evidence on regional variation in pass-through asymmetry.

[35] The AJW analysis is based on station-level data from E85prices.com, which consists of consumer-reported reported prices so is subject to potential issues associated with nonrandom sampling, however random samples of station-level E85 prices are to the best of our knowledge unavailable.

[36] For example, CBO (2012) discusses potential network effects of federal tax credits for electric vehicles.

[37] This is the central estimate for a ton of emissions in 2015 using a 3% discount rate, updated to 2015 dollars using the Personal Consumption Expenditure Price Index; see Office of Management and Budget (2013).

[38] Petroleum gasoline emits 19.6 lb CO_2 /gal, or 8.9 kg CO2/gal, with a monetized externality value of $0.375 at a social cost of carbon of $42/metric ton CO2. For a conventional biofuel with a 20% GHG emissions reduction, the externality reduction value is $0.075 on an energy-equivalent basis. Because ethanol has 68% the energy content of petroleum gasoline, this externality reduction value corresponds to $0.052/gal. The full calculation summarized in the text takes into account the interconnection of RIN prices through the RFS nesting structure (the values reported here use the mix of RINs obligated under the 2013 final rule) and ranges of emissions reductions by fuel.

[39] See EPA, *Renewable Fuel Standard Program Regulatory Impact Analysis*, February 2012, Table 5.2.6-1, p. 906, at epa.gov/otaq/renewablefuels/420r10006.pdf; following the RIA this estimate reflects energy security benefits only (not monopsony benefits). The first-round macroeconomic effect of an oil price shock on GDP is to increase the dollars sent abroad to pay for oil imports, which reduces the amount of money consumers have for domestic consumption and thereby reduces GDP. This effect scales with the net oil import share in GDP, so producing biofuels domestically reduces this first-round effect of an oil price shock on the economy. These benefits accrue whether or not biofuels prices commove with energy prices as long as the biofuels are domestically produced. Domestic energy production has energy security benefits beyond this effect of reducing the macroeconomic impact of oil price shocks. Although nonconventional oil production has contributed to lower net petroleum imports, the Energy Information Administration projects that the United States will remain a net importer and that net imports will eventually again increase. See CEA (2014) for additional discussion of net oil imports and economic security. The EPA estimates are used here without endorsement of the details of their construction; improving upon EPA's estimates of the monetized energy security benefits goes beyond the scope of the treatment here.

[40] The difficult of implementing a quantity regulation, like the RFS, in the face of a steep and uncertain demand curve is an implication of Weitzman's (1974) general theory of quantity vs. price regulation under uncertainty. Some might argue that casting the RFS as a price regulation also faces legal impediments

because the EISA is a quantity and rate-based regulation which should be implemented without regard to prices and costs (except to the extent that the EISA directs EPA to consider the price of BBD, among other considerations, when setting the BBD RVO, and to consider severe economic harm in the context of the general waiver authority). This view does not bind analysis of the economic effects of the program as is done here; whether it has legal basis in the context of EPA's implementation of fractional standards is a question for lawyers.

[41] In the 2013 final rule, EPA summarized the court ruling: "The Court found that in establishing the applicable volume of cellulosic biofuel for 2012, EPA had used a methodology in which 'the risk of overestimation [was] set deliberately to outweigh the risk of underestimation.' The Court held EPA's action to be inconsistent with the statute because EPA had failed to apply a 'neutral methodology' aimed at providing a prediction of 'what will actually happen' as required by the statute" (78 CFR 49798).

[42] Cane ethanol and corn ethanol are chemically equivalent but generate D5 and D6 RINs, respectively, because of their different pathways. For the price of round trip transportation to Brazil, cane ethanol can be substituted for corn ethanol, providing a long-run arbitrage that potentially caps the D5-D6 spread. Thus it is unclear in principle whether ambitious support for advanced and a conservative approach to conventional biofuels is feasible (putting aside any legal issues within the RFS).

[43] In the 2013 RFS Final Rule, EPA addressed the question of differential application of the cellulosic waiver reduction to the total advanced and total renewable RVOs (78 FR 49810) and argues that the general waiver authority would support differential application of reductions, but not the cellulosic waiver authority. However reducing the total renewable RVO by the full cellulosic waiver, and the total advanced RVO by less than the full cellulosic waiver, would be consistent with the environmental goals of the statute and with the policy goal of supporting low-GHG advanced biofuels including nascent advanced and cellulosic technologies.

[44] February 2015 STEO through 2016, AEO 2014 for 2017–2022, where the post-2016 AEO 2014 projection is adjusted in proportion to the relative STEO and AEO projections for 2016.

[45] Specifically, low and high gasoline projections were computed using the 2014 EIA Annual Energy Outlook reference case, adjusted up proportionally for the increase in 2014 gasoline consumption between the AEO 2014 and the February 2015 Short-Term Energy Outlook. EIA does not provide bands around the AEO projections, so gasoline forecast uncertainty was estimated by the root mean squared error of the annual revisions to the current-year projections in the January STEO from 2010–2014 (thus omitting the recession), which is 2%. The range of uncertainty about cellulosic fuel growth is necessarily more judgmental and is based on low- and high-growth scenarios. The low-growth scenario has 10% compounded growth of cellulosic, of which 10% is ethanol; the high-growth scenario has 60% compounded growth of cellulosic, of which 60% is ethanol (reaching 1.6 Bgal of cellulosic ethanol in 2022). Figure 9 freezes noncellulosic, nonethanol biofuel consumption at 2014 volumes.

[46] A rough calculation indicates that filling the D6 gap solely through expanding E15 would require converting approximately 70% of E10 sales to E15 sales by 2022, based on EIA gasoline consumption projections. Given the challenges facing E15 adoption to date this route seems even more ambitious than significantly increasing E85 sales. In any event, shifting to E15 simply swaps an E10 blend wall for an E15 blend wall and thus does not address the long-term goal of economically efficient production and consumption of advanced ethanol.

[47] For example, the supply curve in Irwin (Dec. 13, 2013) indicates an increase in the subsidy value of approximately $2.15 for an increase in domestic biodiesel production from 1.8 to 2.8 Bgal (wet). Because D4 RINs have been approximately $0.50 with production at the rate of 2.0 Bgal per year, adding 1.0 Bgal (wet) of domestic BBD would correspond to an increase in D4 RINs to $2.65. An alternative set of calculations based on soy oil supply elasticities in Hendricks, Smith, and Sumner (2014) and demand elasticities in Adjemian and Smith (2012) suggest lower D4 RIN prices increases for a comparable increase in domestic BBD, ranging from $0.40 to $0.85 (for RIN prices from $0.90 to $1.35). The greatest difficulty with all these estimates is that they entail extrapolating far outside the range of the data, even for 2015.

[48] The volumes of BBD in Figure 10a beyond 2015 exceed estimates of current industry capacity. For example, Irwin and Good, Dec. 4, 2013, assume capacity at 3.6 Bgal. EIA [Monthly Biodiesel Production Report, May 2014] estimates capacity at only 2.0 Bgal from currently producing plants. In addition, the projected volumes of BBD far exceed the quantity of biodiesel in B5, although whether that is an issue depends on the extent to which the B5 blend wall is binding (currently unclear) and on the amount of biodiesel that is renewable diesel.

[49] The calculations for Figure 10b require an assumption about the total advanced requirement. Here, it is assumed that the cellulosic waiver can be applied differentially to the total renewable and total advanced pool, consistent with the policy aims of the EISA. Specifically, the full cellulosic waiver is applied to the total renewable RVO, but the total advanced RVO is set to be the greater of (i) the previous year's actual production plus the expected increase in cellulosic or (ii) or the total advanced RVO reduced by the full cellulosic waiver. In these calculations the total advanced RVO ends up being determined by (i) through 2016 and by (ii) thereafter.

[50] Expanding E85 capacity raises a number of issues, one of which is the need for distribution facilities (stations that carry E85), which in turn requires investment in blender pumps and possibly additional tanks. Babcock and Pouliot (2014) estimate that supplying 2 Bgal annually in E85 would require installing E85 dispensers at 3,000 additional stations, with an associated estimated one-time capital costs of $390 million, or roughly $.20 per gallon of E85, if expensed in a single year. Babcock (2013) makes the point that these capital expenditures appear large, but making them would reduce total compliance costs by bringing down RIN prices by expanding E85 consumption (pushing out the demand curve nonlinearity in Figure 6b).

[51] See http://www.epa.gov/otaq/fuels/renewablefuels/documents/carbio-decision-document-2015-01-27.pdf and http://www.biodieselmagazine.com/articles/292077/epa-decision-on-argentine-biodiesel-imports-riles-us-industry.

[52] This discussion focuses on nonethanol imports. If cane ethanol imports were to expand to meet the total advanced shortfall, instead of expanding domestic BBD, as assumed in Figure 10b, additional E85 would need to be sold. If selling the additional E85 required high D6 RIN prices, then presumably both cane imports and domestic BBD would expand to fill the total advanced shortfall. Perhaps more significantly, conventional biodiesel and renewable diesel imports could continue to grow.

[53] This estimate uses a short-term elasticity of -0.37, estimated using state-level data with tax changes as instrumental variables, see Coglianese, Davis, Kilian, and Stock (2015). Even with an elasticity of only -0.2, the predicted increase in gasoline consumption is 4%, approximately twice the increase in the June 2014–February 2015 STEOs.

[54] For example, the Iowa Ethanol Promotion Tax Credit for biofuels retailers and the Minnesota Ethanol Fueling Infrastructure Grant programs. See the Alternative Fuel Data Center at http://www.afdc.energy.gov/laws/.

[55] The USDA had supported blender pump installation through its Rural Energy for America Program (REAP); however, the 2014 Farm Bill prohibited

using REAP funds for blender pumps. One argument made for removing blender pumps from REAP is that including them provided a subsidy for a mature ethanol industry. But this misses the point of network externalities associated with expanded E85 capacity as discussed in the previous sections.

[56] EPA, "New Fuel Pathways," http://www.epa.gov/otaq/fuels/renewablefuels/rfs2-lca-pathways.htm.

[57] Even with complete pass-through, parties with net RIN obligations would perceive RIN prices as a cost, in the sense that the RIN costs would appear on their balance sheets as a cost whereas the pass-through of those costs into RBOB prices would not have a comparable offsetting balance sheet line item.

[58] From an accounting perspective, RINs appear as a cost on the balance sheets of obligated parties with net RIN deficits without explicit revenue from RIN price pass-through. The RIN price risk of obligated parties with net RIN exposure could be addressed within the existing administrative structure by policies such as those discussed elsewhere in this section that would aim to reduce RIN price volatility (including forward guidance, resolving the blend wall problem, or a RIN price collar). Alternatively, the fundamental net RIN obligations of some current obligated parties might be addressed through changes in wholesale markets in which RINs are passed back to the seller of the petroleum component of the fuel. Another approach to this problem is to consider making blenders the obligated parties, because blenders come much closer to having a neutral RIN exposure. This switch has potential downsides, however, including making the RIN market even thinner because fewer market transactions would be needed, transferring RIN price exposure to specialized blenders, such as truck stop operators with net RIN exposure, and increasing administrative complexity (there are many more blenders than refiners and importers).

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