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# REFORMING THE RENEWABLE FUEL STANDARD

BY JAMES H. STOCK

FEBRUARY 2018

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# EXECUTIVE SUMMARY

The Renewable Fuel Standard (RFS) was established by the Energy Policy Act of 2005 and was substantially expanded as part of the Energy Security and Independence Act (EISA) of 2007. The goals of the program, and of US biofuels policy more broadly, are threefold: to enhance energy security through additional domestic production of biofuels, to support rural economies, and to promote second-generation transportation fuels with low life cycle greenhouse gas footprints.

The RFS has achieved some but not all of these goals. Since the EISA was passed, domestic production and consumption of biofuels has more than doubled. In 2017, domestic consumption of biofuels displaced approximately one million barrels per day of refined petroleum product. This growth has supported farm incomes through the demand for ethanol made from corn starch and for biodiesel made from soybeans and other crops. However, second-generation biofuels have failed to live up to the early hopes of the program to use  feedstocks that are not food-competing as part of a broader transition to a low-carbon transportation sector. Moreover, the RFS has evolved into a complex program fraught with regulatory uncertainty and high and volatile compliance costs, which has impaired its effectiveness.

As stakeholders have struggled to work within the program, they have developed a variety of reform proposals intended to address their own perceptions of the program's shortcomings. This paper collects a number of these reform proposals into an integrated package and examines their interactions and collective economic consequences. The paper finds the following:

- Despite its success in promoting first-generation biofuels, flaws in the design of the RFS have led to a combination of high and variable compliance costs mixed with programmatic uncertainty. These costs and uncertainty encumber refiners, discourage the infrastructure investments needed to dispense ethanol in volumes exceeding 10 percent (that is, as E10), and fail to provide reliable incentives for the development of low–greenhouse gas (GHG) second-generation fuels.
- With an unreformed RFS and projected declines in gasoline demand, the most plausible scenario is one of continued politicization, rising and volatile compliance costs, increasing biodiesel imports, flat or declining domestic ethanol sales, and further stagnation of domestic second-generation technologies.
- The package of legislative reforms examined in this paper has three components:
    - Reduce sharply the compliance costs of blending ethanol into E10. This component builds on the recognition that ethanol has become the cost-effective choice for octane enhancement at a blend ratio of 10 percent.

- Promote sales of midlevel blends by removing regulatory roadblocks to their year-round sales.
- Transform the second-generation part of the RFS into a technology-pushing program that provides reliable, effective, and long-term support for nascent low-GHG renewable fuels, regardless of feedstock.

- This package of reforms, taken together, could address the range of obstacles to the success of the RFS. The RFS can be reformed to address nearly all stakeholder concerns, allowing the program a meaningful chance to achieve its original goals at a reasonable cost, without imposing a disproportionate burden on any set of stakeholders.

# A BRIEF REVIEW OF THE RFS: ACCOMPLISHMENTS, PROBLEMS, AND CHALLENGES AHEAD

The US Renewable Fuel Standard (RFS) was introduced in the Energy Policy Act of 2005 and expanded in both scope and duration in the Energy Independence and Security Act (EISA) of 2007. The policy goals of the RFS program are threefold:

1. enhance energy security through additional domestic production of biofuels,
2. support rural economies by expanding the demand for agricultural products, and
3. expand the development and production of second-generation low–greenhouse gas transportation fuels.

The RFS requires the blending of increasing quantities of biofuels into the US surface vehicle transportation fuel supply. These quantities are specified in the EISA but are subject to modification by the US EPA under certain conditions (“waiver authorities”).

The EPA issues annual rules specifying the overall fractions of renewable fuels in the fuel supply. The fractional requirements are specified by fuel category: cellulosic, advanced biomass-based biodiesel, other advanced fuels, and total renewable fuels. Compliance with the blending standards is demonstrated by obligated parties (petroleum refiners and importers) retiring electronic certificates, called renewable identification numbers (RINs), when they sell petroleum fuel into the surface transportation fuel supply. RINs, which become available when a renewable fuel is blended into the fuel supply, are tradable and bankable (with limitations). Thus obligated parties have the choice of either producing RINs themselves through blending operations or purchasing RINs on the open market.

## Accomplishments

The RFS, in conjunction with other federal and state biofuel policies, has resulted in a large growth in production of first-generation biofuels, primarily corn kernel ethanol and biomass-based biodiesel (BBD).[1] As figure 1a shows, from 2007 to 2016, fuel ethanol consumption more than doubled, and the required volume of conventional fuel is now at the statutory requirement of 15 billion gallons. Since 2012, nearly all gasoline sold at retail for surface transportation is 10 percent ethanol (E10). Domestic ethanol production capacity, almost all of which is corn starch ethanol, surged in the late 2000s (figure 1b), and nameplate fuel ethanol plant capacity reached 15.5 billion gallons per year in 2017.[2] From 2007 to 2016, consumption of biodiesel grew from 350 million gallons to more than 2 billion gallons. The resulting boost in demand has helped to support rural economies where corn, soy, and other feedstock crops are grown.

**Figure 1a:** US Fuel Ethanol and Biodiesel Consumption, 1981 - 2016

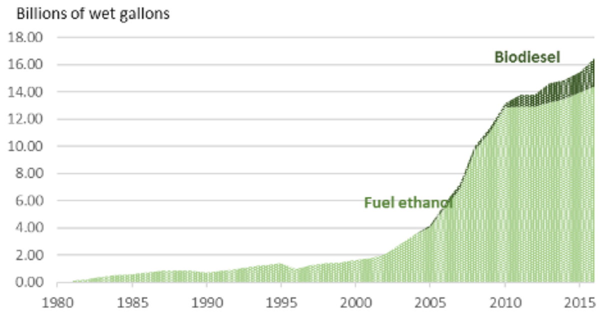
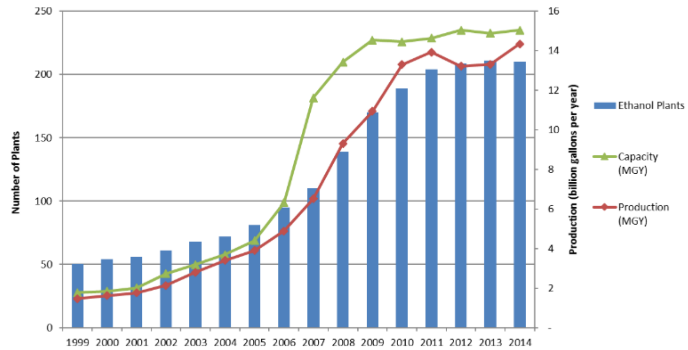


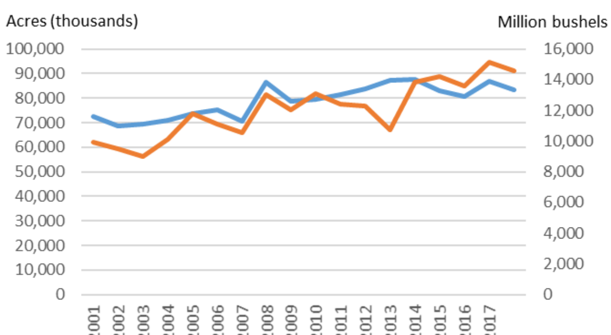

**Figure 1b:** US Ethanol Plants, Capacity, and Production




*Sources: EIA; Alternative Fuels Data Center*

As corn ethanol production increased in the late 2000s, so did farmland planted for corn (figure 2). Since 2013, however, corn acreage has declined, and preliminary estimates indicate that in 2017 fewer corn acres were planted than in 2007. Despite a reduction in acreage planted, production has increased because of the trend increase in corn yields, which grew at the annualized rate of 1.6 percent per year from 2006–2016.

**Figure 2:** Corn Acres and Production, 2000-2017 (Corn planted for grain)




*Source: USDA, Crop Production Historical Track Records, 2017 values are preliminary*

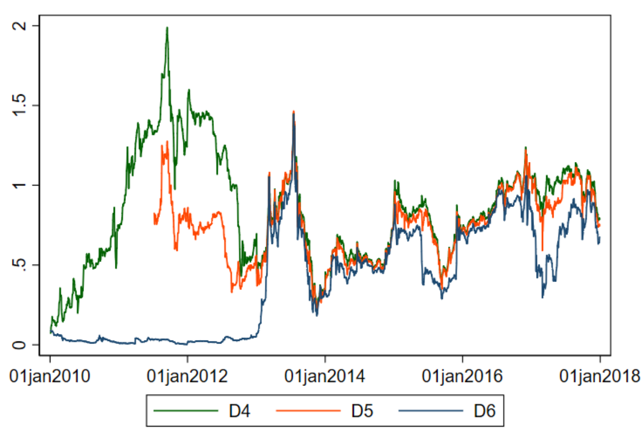
## Problems

Structural problems with the RFS have led to regulatory uncertainty, politicization of the program, and frustration among many stakeholders. These structural problems, along with developments in energy markets and the broader economy, have contributed to limited market penetration of higher ethanol blends beyond E10 and to high and volatile RIN prices, and thus to high and variable compliance costs. These problems have also stunted investment in second-generation technologies.

## High and volatile RIN prices

As shown in figure 3, RIN prices under the RFS have been both high and volatile. Since February 2013, the price of the D6 RIN (the RIN generated by conventional fuels, primarily corn ethanol) has fluctuated from less than $0.20 per gallon to more than $1.40 per gallon. The combination of high and volatile RIN prices is in a sense the worst of both worlds: because RIN prices are the vehicle for compliance, the total cost of compliance, as measured by the total cost of RINs, is high—but because those prices are volatile, producers and retailers of renewable fuels cannot count on a reliable RIN value when making capital expenditure decisions (RINs cannot be "taken to the bank").

**Figure 3:** RIN Prices, 2010–2017




*Source: OPIS, Bloomberg, EIA*

***RIN prices and the E10 blend wall.*** The jump in D6 RIN prices in the winter of 2013 was a regime change within the RFS. Through the end of 2012, D6 RIN prices were stably in the pennies. Nearly all light duty vehicles can burn fuel with up to 10 percent ethanol, and through 2012, the fraction of ethanol in the fuel supply was less than 10 percent (see figure 4a). With the end of MTBE's use as an oxygenate in 2006, ethanol became the cost-effective oxygenate and octane booster for blending into petroleum gasoline blendstock (BOB). As a result, 2006–2012 saw a surge in investment in ethanol production capacity, up to the statutory renewable volume obligation (RVO) of 15 billion gallons (bgal) of conventional fuels (figure 1b). Over this period, ethanol production and consumption doubled.

In 2013, market participants realized that ethanol consumption in excess of 10 percent of gasoline would be needed to meet RFS volumetric requirements using RINs generated by conventional ethanol. However, for a substantial fraction of vehicles, there are questions about whether the engine and fuel systems can handle ethanol blends in excess of E10 either because of vehicle age or because of explicit warnings by some manufacturers against using higher blends. Moreover, the overwhelming majority of retail outlets are set up to sell E10 but not higher ethanol blends. These practical challenges to selling fuel with an ethanol content exceeding 10 percent became known as the E10 blend wall.

**Figure 4a:** US Fuel Ethanol and Biodiesel Consumption, 2000-2016

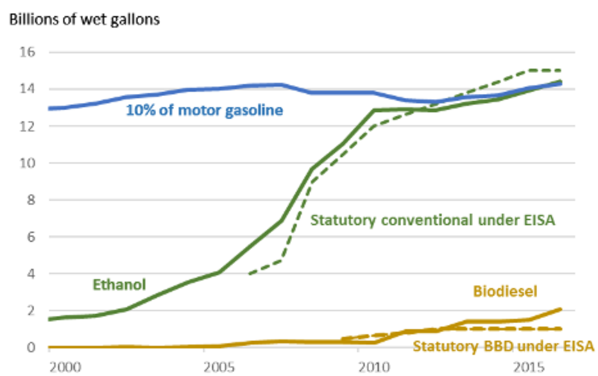
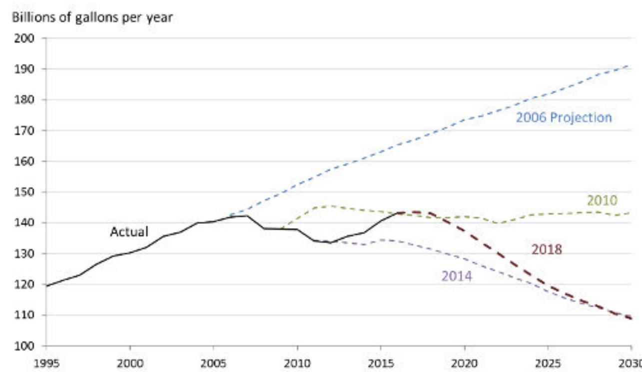



**Figure 4b:** US Consumption of Motor Gasoline, 1950-2030




*Sources: EIA, EIA Annual Energy Outlook 2006, 2010, 2014, 2018*

When the EISA was passed in 2007, it was not anticipated that the E10 blend wall would be reached using conventional ethanol alone. As can be seen in figure 4b, in 2006, the Energy Information Administration (EIA) projected gasoline consumption to be increasing steadily, exceeding 160 billion gallons in 2014, in which case the statutory 15 bgal RVO could comfortably be filled by conventional ethanol in E10. But the recession of 2008–09, higher oil prices, increasing fuel economy, and perhaps a shift in driving habits resulted in substantially lower gasoline demand. Although demand has increased recently with low gasoline prices and strong economic growth, it remains less than 145 bgal annually.

***Digression on the economics of RIN prices.*** The basic economics of RIN prices shows why RIN prices are both high and volatile for ethanol fractions above the E10 blend wall. Figure 5a illustrates the subsidy needed to sell ethanol when the RVO exceeds the ethanol capacity of E10 (Q0 in the figure). Because ethanol has a lower energy content than petroleum gasoline, and because higher blends are less available than E10, the consumer requires a price discount per gallon to use a higher blend. This price discount is the difference between the price at which the fuel is produced (the supply price) and the price the consumer is willing to pay (the demand price). Under perfect competition, this price incentive is provided by the RIN value, which is passed along to the consumer. Figure 5b illustrates a different way to comply with the conventional requirement, which is to use a more expensive fuel that does not confront a blend wall—in the figure, a D4 RIN from advanced biomass-based diesel. In this case, under perfect competition, the RIN subsidy accrues to the producer of the more expensive biofuel. When both paths are available for compliance, the cost of the marginal RIN is equated across the two markets, and the D4 and D6 RIN prices will be essentially the same. Indeed, for much of the 2013–2017 period, the D4 and D5 RIN prices closely tracked the D6 RIN price, during which excess D4 RINs were used to meet the conventional obligation.

**Figure 5a:** Corn Ethanol

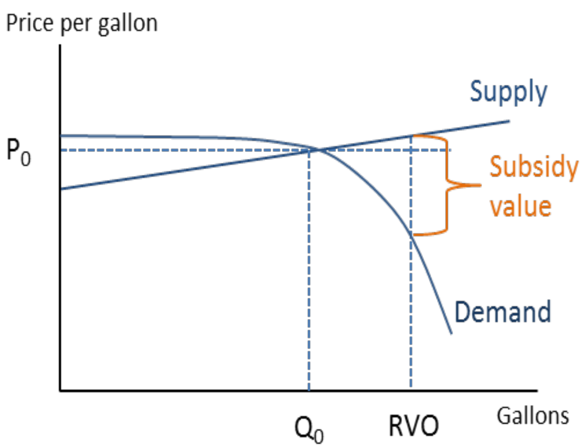
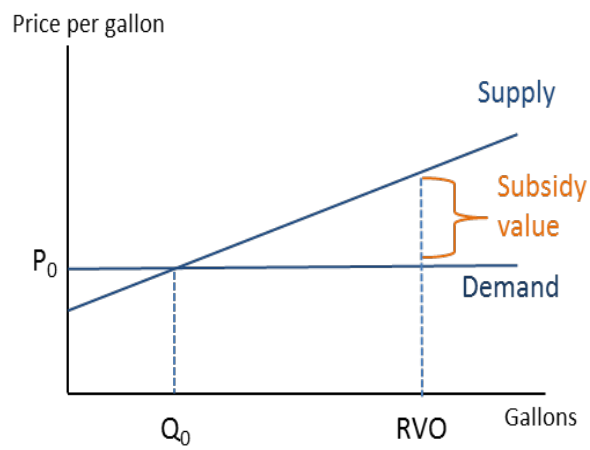



**Figure 5b:** Biomass-Based Diesel




To make this concrete, in 2017, US gasoline consumption was 143 billion gallons. After eliminating sales in Alaska (which is excluded from the RFS) and sales of E0 (0 percent ethanol) and allowing for rounding, these 143 billion gallons of blended gasoline support approximately 14.2 billion gallons of ethanol blended as E10. As specified in the statute, the EPA used the RVO of 15 bgal of conventional fuels to set its 2017 fractional standards. Thus, in 2017, the conventional gap—the difference between the RVO and the ethanol capacity of gasoline, were it all sold as E10—was approximately 800 million gallons. This gap can be filled with RINs generated by ethanol blended into higher blends (E15, which is 15 percent ethanol, or E85, which is between 51 percent and 83 percent ethanol), from non-ethanol fuels that generate a D6 RIN (such as conventional renewable diesel), or by fuels that generate a D5 or D4 RIN and are consumed in excess of their 2017 RFS percentage standards. All those options for filling the conventional gap are more expensive than blending ethanol into E10 and require a positive RIN price. As a result, D6 RIN prices jumped in 2013 from pennies to more than $1.00 and have been high thereafter.

Figure 5 also illustrates why RIN prices are so volatile. Above the blend wall, the marginal gallon must come either from a higher blend or from a non-ethanol fuel, either conventional BBD that generates a D6 RIN or BBD produced in excess of its RVO that generates a D4 RIN, which can be used to comply with the conventional RVO. However, there is limited awareness of and sales capacity for higher blends, so the demand curve for ethanol in excess of 10 percent drops off sharply. Thus, small changes in the conventional gap lead to large changes in RIN prices, where the size of the change depends on the elasticities of ethanol demand and BBD supply in this range. This low penetration of higher blends explains why a conventional gap of only 800 million gallons in 2017—less than 0.6 percent of total gasoline demand—resulted in high and fluctuating RIN prices. Moreover, quantitatively small changes in this gap can have outsized effects on RIN prices. Thus, seemingly minor events, such as speculation about whether the EPA will dial back the RVO by 200 million gallons or the potential availability of a new source of non-ethanol D6 RINs, can produce large fluctuations in RIN prices.[3]

***Summary of sources of RIN price volatility.*** The volatility of RIN prices is a consequence of the structure of the RFS as laid out in the EISA, combined with the basic economics of RIN prices.

1. Because of (a) the small markets for E15 and E85 and (b) the increasing cost of the marginal gallon of non-ethanol RINs, changes in the conventional gap that are small compared to the overall fuel supply induce large changes in RIN prices.

2. Because RINs are bankable, expectations of future changes in the conventional gap induce changes in current RIN prices. Thus, RIN prices are sensitive to rumors and market guesses about shifts in future RFS policy (Lade, Lin, and Smith 2016).

3. he annual rulemaking process is complex, requires the EPA's expert judgment about market productive capacity, and provides for discretionary waiver authorities. Because small changes matter to RIN prices, interested parties have a strong interest in engaging in the rulemaking process. As a result, the rulemaking process is highly politicized, with regular intervention from elected representatives. The politicization of what should be a technocratic calculation substantially increases policy uncertainty and thus uncertainty about the conventional gap. This politicization is a consequence of faulty design (RVOs and annual rulemakings) in the EISA.

4. The annual rulemaking process invites extensive and regular litigation, which frequently is not resolved until after the compliance year in question has ended. This litigation creates additional policy uncertainty and thus additional RIN price volatility.

5. Volatility in D6 RIN prices spills over into volatility in D5, D4, and D3 RIN prices because of the nesting structure.

6. Uncertainty in D3 prices is further confounded by uncertainty about future oil prices because of statutory requirements for how the cellulosic waiver credit price is determined.

7. Lack of data availability further adds to policy uncertainty. In particular, volumes of higher blends sold have major implications for D6 RIN prices, but those data are either not collected systematically (E15) or are only available as ex post annual rough estimates (E85).

***Total compliance costs.*** The total market value of RINs retired for compliance in 2016 was approximately $15.6 billion. Of this, $15.1 billion, or 97 percent, of the costs were for first-generation fuels.[4] The total market value of retired RINs is one measure of the gross cost of complying with the RFS. This gross cost measure has many limitations: because RINs represent a transfer to RIN generators or separators, gross costs neglect the benefits to recipients, and gross costs provide no indication of who ultimately pays for or receives the value from a RIN.[5] That said, total compliance costs are one measure of the economic scope of the program. By this measure, the program is large, and the compliance costs are overwhelmingly associated with first-generation fuels.

## Limited penetration of higher blends

Expansion of the use of ethanol beyond the E10 blend wall requires blending of ethanol into higher blends, most prominently E15 and E85. The expansion of higher blends of ethanol supports the first two goals of the RFS: increased domestic fuel production and supporting farm incomes. Looking further ahead, research suggests that midrange blends (25 percent to 40 percent ethanol) facilitate more energy-efficient combustion and improve overall fuel economy.[6]

Although there is not comprehensive data on sales of ethanol in higher blends, the data that does exist suggests that consumption of higher blends plateaued after an initial phase of growth in the 2000s. The Minnesota Department of Commerce (2017) reports statewide sales of approximately 13 million gallons of E85 in 2016, down from a peak of more than 22 million gallons in 2008. According to the EIA, the overall ethanol content of the US fuel supply in 2017 was 10.1 percent and is projected to increase to 10.27 percent in 2018 as additional blender pumps come online through the USDA Blender Infrastructure Program and the Prime the Pump program. These fractions correspond to additional volumes of ethanol in the low hundreds of millions of gallons, above and beyond the ethanol capacity of E10.

Much of the consumption of higher ethanol blends occurs in a few states, mainly in the Midwest, where there is the most dispensing infrastructure for higher blends. According to the Alternative Fuels Data Center, of the 3,112 stations nationally that sell E85, 32 percent are in Minnesota, Iowa, Wisconsin, and Illinois. In contrast, there are only 340 E85 stations in the 15 states along the Eastern Seaboard.

The key factors in the slow growth of sales of higher ethanol blends include:

1. Availability
    a. There are only a small number of dispensing stations, including essentially no dispensing stations in many densely settled sections of the country.
    b. There is limited availability of higher blends at many terminals outside the main higher-blend regions, and also limited availability of neat ethanol (E100) for splash blending.[7]
2. Pricing
    a. Pump pricing of E85 is often uncompetitive with E10 on an energy-adjusted basis and typically reflects incomplete pass-through of the RIN value to pump prices outside of the most mature and developed E85 markets.[8]

  b. It is difficult if not impossible for flex-fuel vehicle owners to compare E85 and E10 prices on an apples-to-apples basis. The ethanol content of E85 can range from 51 percent to 83 percent, varies seasonally, and typically is not posted at the pump. Even if the ethanol content were known, it is a complicated calculation to compare E10 and E85 prices on an energy content basis. This problem of opaque pricing is substantially less of an issue for E15 than E85, because the ethanol content and thus energy content of E15 is known.

3. Impediments to consumer acceptance

  a. Because the Reid Vapor Pressure waiver for E10 is not available to higher blends, E15 and midrange blends are not available in the summer in many densely populated areas.

  b. There is a lack of consumer education about higher blends, including limited consumer awareness of E15, confusion over what cars are E15 capable, and the related problem of consumers' concerns about potentially damaging their vehicles.

  c. The driving range on a tank of gas is noticeably less for E85 than for E10.

4. RIN price volatility

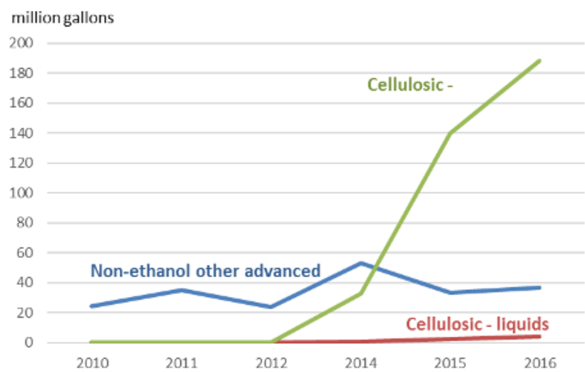
  a. In theory, retailers would use some of the RIN value to fund infrastructure modifications (pumps and possibly tanks) for selling higher blends and pass along some to the consumer to spur sales. However, RIN price volatility creates uncertainty about the value of the RIN incentive, which impedes investment

These factors are related. Lack of consumer awareness, the lack of stations offering higher blends, and the unavailability of higher blends at the rack constitute a chicken-and-egg problem that makes market penetration difficult. This chicken-and-egg problem is compounded by opaque E85 pricing, seasonal unavailability of E15, and programmatic and RIN price uncertainty.

## Disappointing progress of second-generation fuels

A centerpiece of the RFS was the development of a large pool of fuel derived from cellulosic feedstocks, such as corn stover (corn stalks, leaves, and cobs) and energy grasses. The cellulosic RVO in the EISA for 2016 is 5.5 billion gallons, with steady increase thereafter, but actual production of liquid cellulosic fuels was three orders of magnitude less, approximately 4 million gallons. Although cellulosic production has increased over the past few years (figure 6), nearly all of that increase is from a recently added non-liquid pathway, renewable natural gas (biogas) from landfills. The cellulosic ethanol industry has built a small number of demonstration plants and has made technological progress on multiple fronts, including improved material-handling methods for corn stover and pathways that use corn kernel fiber. However, after an initial wave of construction of commercial-scale plants, there has been little investment in cellulosic ethanol productive capacity. The EPA (2017) projects approximately 70 million gallons of liquid cellulosic biofuel productive capacity. Recent pathway approvals for corn kernel fiber ethanol coproduced with conventional corn starch ethanol could increase these volumes modestly in the short run. Other second-generation fuels include both ethanol and drop-in fuels produced with non-cellulosic feedstocks, which currently generate a D5 RIN. Volumes of second-generation D5 fuels, however, are also small.

**Figure 6:** Second Gen Fuels: RIN Generation




*Source: EPA RIN generation data (EMTS) and author's calculation.*

The development of second-generation fuels under the RFS has faced multiple impediments.

1. Economic factors

    a. The financial crisis and subsequent recession delayed investment across the board.

    b. Low oil prices since 2014 have dampened the long-term outlook for advanced biofuels, reducing the availability of financing.

2. Technological setbacks

    a. Scaling up second-generation technologies has been more difficult than anticipated; however, the industry has continued to make progress.

3. RIN price uncertainty and regulatory uncertainty

    a. Second-generation facilities require large up-front capital costs, which in turn require reliable long-term returns on the product. Especially in the development and initial plant stage, second-generation facilities rely on financial support provided through the RFS. This support is provided through RIN prices. However, RIN price uncertainty and uncertainty about long-term prospects of the RFS make it difficult or impossible to incorporate RIN price support into long-term financing decisions.

4. Additional problems with RFS design and implementation

    a. The feedstock-based definition of the D3 pool combined with the nesting structure disadvantages low-GHG second-generation fuels with a pathway that does not meet the strict EPA cellulosic standard. Thus, the RFS picks winners and losers among second-generation renewable fuels that have the same life cycle GHG footprint.

b. The feedstock-based definitions of the RFS, combined with limited EPA resources, make obtaining pathway approval for second-generation fuels long, complex, and costly.

## Prospects under an unreformed RFS

The projected decline in gasoline consumption poses an additional significant challenge for an unreformed RFS. As shown in figure 4b, the EIA (*Annual Energy Outlook* 2018) projects gasoline consumption to fall by 16 percent to 120 bgal by 2025 and to further fall to 109 bgal (E10-equivalent gallons) by 2030. As figure 4b shows, these projections have a great deal of uncertainty and are driven by unexpected changes in oil prices and business cycles. Still, some of the key elements driving these projections—improvements in fuel economy, inroads by electric vehicles, and demographic forces as baby boomers age and drive less—will plausibly persist despite swings in economic factors.

In the near future—likely 2018—the statutory RVOs will need to be reset by the EPA pursuant to a requirement in the EISA. If the reset conventional RVO remains at 15 bgal, then under the projections in the EIA's 2018 *Annual Energy Outlook*, the D6 gap would increase from 0.8 bgal in 2018 to 1.0 bgal in 2020 and to 2.8 bgal in 2025. Filling these gaps with additional ethanol from E15 sales would require converting 17 bgal of E10 sales to E15 in 2020, and converting 51 bgal of E10 sales to E15 by 2025. Although E15 sales have grown because of the USDA Blender Infrastructure Program, that program has ended, and filling these gaps with E15 is unrealistic, given the poor growth in midlevel and higher blends so far under the RFS. Thus, it is reasonable to expect that these increasing gaps would be filled with increasing volumes of imported conventional BBD and with advanced BBD. As an indication of magnitude, the projected increase in the conventional gap by 2 bgal from 2018 to 2025 would require approximately 1.3 bgal of additional wet BBD blended into the fuel supply, an increase of more than 50 percent compared to the 2018 RVO.

Thus, over the next several years, the projected decline in gasoline demand is poised to give rise to steadily rising D4 and D6 RIN prices, increasing BBD sales, including increasing biodiesel imports (both advanced and conventional). Absent the E10+ RVP waiver, the RFS has proven unsuccessful in stimulating sales of higher blends, and history does not suggest a reason for this to change. Existing low-GHG cellulosic pathways with proven technologies—in particular biogas and corn kernel cellulosic—will be able to generate D3 RINs and expand; however, without structural reforms, RIN prices will be volatile and cannot be counted on to provide support for commercialization of nascent second-generation liquid technologies. In short, with an unreformed RFS, the most plausible scenario is one of continued politicization, rising and volatile RIN prices, increasing biodiesel imports, flat or declining domestic ethanol sales, and stagnation of second-generation technologies domestically while those technologies are developed abroad.

# A PROTOTYPE RFS LEGISLATIVE REFORM PACKAGE

This section lays out a prototype package for legislative reform of the RFS. The package has three components:

1. Reduce substantially the total compliance costs, compliance cost uncertainty, and regulatory risk faced by obligated parties. This is achieved by sharply reducing the RIN cost of ethanol blended into E10 while maintaining the requirement of higher blends of ethanol and by adopting rule-based instead of discretionary methods for setting annual standards. One potential mechanism for reducing the compliance cost of blending ethanol into E10 is the “D6/D8 RIN” mechanism, described below.
2. Create a path so that after a transitional period, higher ethanol blends can compete in the marketplace on their merits. This is accomplished by extending the 1-psi E10 RVP waiver to higher ethanol blends, by providing RIN price support at levels sufficient to incentivize sales of midlevel blends, and through RIN price stability.
3. Provide reliable support for second-generation fuels regardless of feedstock. This is accomplished by separating the first- and second-generation pieces of the RFS, removing feedstock-based categories of renewable fuels, incentivizing new technologies with low carbon footprints, and providing reliable, stable, and long-term support for production of second-generation low-GHG fuels, with a cumulative volumetric production cap to protect consumers and obligated parties.

The prototype package takes advantage of existing RFS compliance mechanisms where possible.[9]

This section summarizes the package and its rationale; additional details are given in appendix A.

## The D6/D8 mechanism and first-generation reforms

The aim of the D6/D8 mechanism is to reduce compliance costs while maintaining a financial incentive for introducing higher ethanol blends into the marketplace.[10] If we put aside mechanics, the basic idea is simple. In 2017, approximately 14.2 bgal of ethanol was blended into E10, leaving a conventional gap of 0.8 bgal. Suppose that, somehow, E10 could simply be removed from the RFS and that the amount of E10 blended did not change, so the conventional gap remained 0.8 bgal. Then the total value of the RIN obligation of obligated parties would be reduced by the current value of the RINs detached when ethanol is blended into E10. For example, at a $0.75 D6 RIN, the total obligation for D6 RINs would be reduced from $11.25 bil (= 15 bgal × $0.75) to $600 million (= 0.8 bgal × $0.75)—a reduction of 95 percent. Because ethanol is the lowest-cost oxygenate and octane enhancer (Irwin and Good 2017a), it is reasonable to expect that ethanol will not need a RIN subsidy or a quantitative mandate to be blended into E10; indeed, as discussed in section 1, the price of the D6 RIN was essentially zero until the fraction of ethanol required to be blended hit 10 percent. Moreover, because fuels filling the conventional gap continue to detach a RIN upon blending, and filling that conventional gap does require RIN prices support (either for selling higher blends or for conventional or advanced BBD), the price of the RIN detached by renewable fuels filling the conventional gap would be positive and would in turn provide an incentive for sales of higher blends. Thus, the total compliance cost of the RFS would be a fraction of what it is now, without changing the economic incentive for blending ethanol into higher blends.

The D6/D8 mechanism is a concrete way to implement the idea in the previous paragraph. Under the D6/D8 mechanism, upon production ethanol would generate a "D6-8 parent RIN." The D6-8 parent RIN would travel with the ethanol to the blender, as it does now. Upon blending, the first 10 percent of ethanol blended into retail gasoline would separate a D6 RIN, while any ethanol blended above 10 percent would separate a D8 RIN. For example, blending 100 gallons of E15 would separate 15 D6-8 parent RINs into 10 D6 RINs and 5 D8 RINs. Ownership of the detached D6 and D8 RINs would be the same as currently is the case for detached D6 RINs. The detached D6 and D8 RINs could be sold, banked, and used for compliance just as other RINs are now.

**Figure 7:** Alternative D6/D8 Nestings for First Generation Fuels

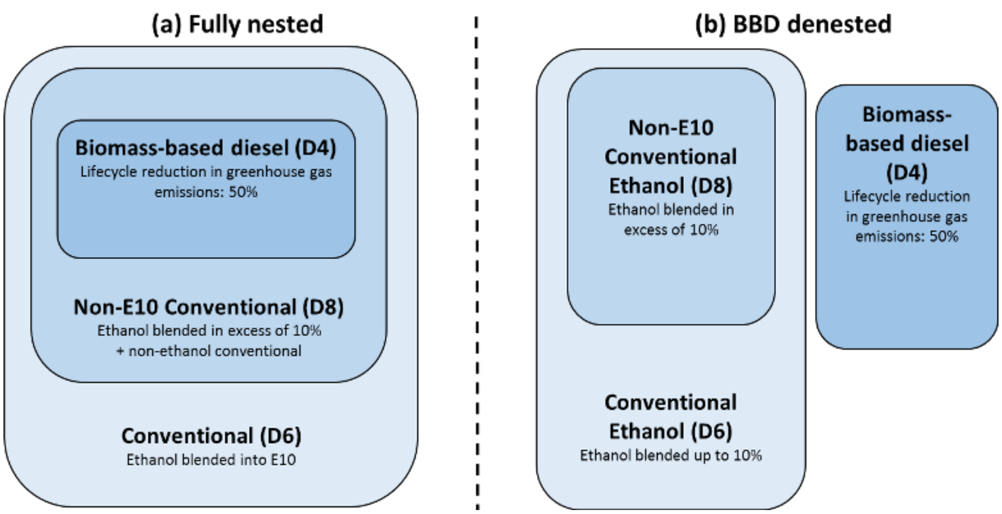



Figure 7 shows two different nesting structures that would implement the D6/D8 mechanism. In both, second-generation fuels are removed, and the nesting applies only to first-generation fuels.

***"Fully nested" D6/D8 structure.*** The first new RIN structure, in figure 7a, has the fewest changes from the existing structure. In this first "fully nested" structure, D4 RINs are generated by the same fuels just as they are today and can be used to satisfy the D8 obligation. A D4, D8, or D6 RIN can be used to satisfy the D6 obligation.

To ensure that the D6 RIN price is low, the D6 RVO would be set just below at the ethanol capacity of the gasoline supply, were all gasoline sold as E10, after adjusting for E0 sales. The aim of this part of the mechanism is for D6 RINs to be detached in excess of what is needed for compliance so that the price of the D6 RINs is driven to zero (except for small transaction costs). This regular generation of a small oversupply, combined with a conversion of legacy D6 RINs to ensure an ample incoming D6 RIN stock, would lead to low D6 RIN prices. The D8 RVO would be the difference between the (unchanged) 15 bgal conventional RVO and the D6 RVO. In our running example, the D6 RVO would be just under 14.2 bgal, and the D8 RVO would be just over 0.8 bgal. A formula for implementing this method is presented in appendix A. The D4 RVO would be determined as it is now, using the guidelines specified in the EISA.

Table 1 summarizes the RIN D-codes under the prototype package with fully nested first-generation fuels (figure 7a) and a prototype nesting structure for second-generation fuels, which is discussed in section 2.3.

Under the fully nested approach, the economics of the RFS would be very similar to what they are today, except that E10 is effectively removed from the RFS. The economics are discussed in more detail in the next section.

**Table 1:** Summary of "Old" and "New" D Codes

| | | New definition | |
|---|---|---|---|
| **D-Code** | **Existing definintion** | **First generation Fully nested (fig.7)** | **Second generation Two-tier nesting (fig.9a)** |
| D3 | Cellulosic advanced non-BBD | | Very low GHG liquid advanced |
| D7 | Cellulosic BBD | | n/a |
| D5 | Advanced noncellulosic, non-BBD | | Low-GHG liquid advanced |
| D9 | n/a | | Low-GHG biogas advanced |
| D4 | Advanced BBD | Advanced BBD (same as existing) | |
| D6 | Conventional (mainly corn kernal ethanol) | Conventional ethanol blended into E10 | |
| D8 | n/a | Conventional ethanol blended in fractions above 10 percent and non-ethanol conventional fuels | |

***"BBD denested" D6/D8 structure.*** Figure 7b shows an alternative nesting which, in a significant departure from the current RFS, separates the gasoline and diesel pools. In the BBD denested variant, D8 RINs can be used to satisfy the D6 obligation; however, D4 RINs cannot be used to satisfy either the D8 or D6 obligation. As in the figure 7a nesting, the D6 RVO is set to be just less than the ethanol capacity of the fuel supply, were all fuel supplied as E10 and after exemptions for E0, and the D8 RVO is the difference between 15 bgal and the D6 RVO. The D4 RVO would be determined as it is now, using the guidelines specified in the EISA. In the denesting in figure 7b, an entire category of first-generation fuel, conventional biodiesel, is removed from the RFS.

In the BBD denesting version, the entire D8 obligation must be met using RINs from detached ethanol blended into higher blends. Because of limited retail infrastructure for higher blends, this would not be possible upon implementation of this proposal, and if gasoline demand declines as projected, the marginal gallon of ethanol blended into a higher blend could be very expensive. Therefore, a D8 RIN price ceiling is needed as a backstop with BBD denesting. The value of the D8 RIN price ceiling represents a tradeoff between being high enough to incentivize installation of blender pumps and associated retail infrastructure, while controlling the cost exposure of consumers. Examples of the effect of different RIN price ceilings on E15 prices are given in the next section. It is important to recognize that for RIN price ceilings in the historical range of RIN prices, one would expect that the D8 RIN would be detached in short supply so that prices would trade at the ceiling, effectively eliminating RIN price volatility.

One way to implement a D8 RIN price ceiling would be to provide the EPA with the authority to issue a D8 waiver credit, which market participants could purchase from the EPA subject to demonstration that no wet D8 RINs are on offer at a price up to a specified D8 waiver credit price. Additional details are discussed in appendix A.

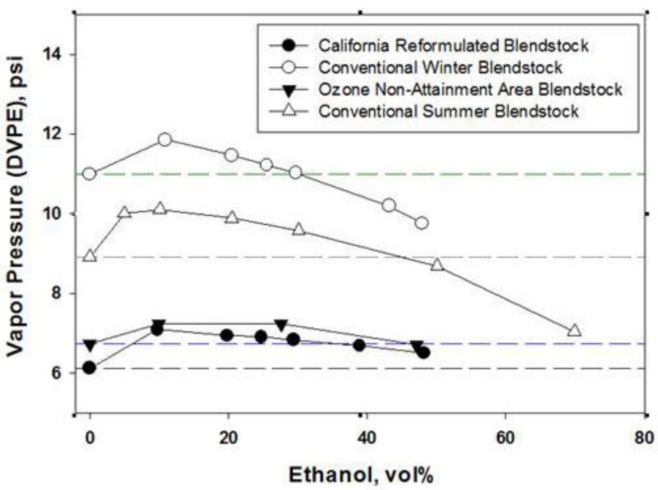
***E10/D8 RIN alternative.*** An alternative to the D6/D8 mechanism is simply to mandate that all blended gasoline have at least 10 percent ethanol, with specific and narrow exemptions for E0 sales (e.g., marina waivers). Under this alternative, all ethanol blended at a fraction above 10 percent would generate a D8 RIN. The mechanism for generating and separating D8 RINs would be similar to that under the D6/D8 proposal. The D8 RVO would be calculated as 15 bgal minus the ethanol capacity of the gasoline supply were it sold as E10, less E0 waivers. The E10/D8 alternative could be implemented in a nested way (like figure 7a) or denested. If nested, then BBD could fill the D8 RVO. If BBD is denested (figure 7b), then the D8 would initially be in short supply and could well be in short supply in the longer run as total gasoline demand declines. If so, a D8 waiver credit would be required. From a legal and perhaps enforcement perspective, the E10/D8 alternative is quite different than the D6/D8 mechanism; however, the economics of the two mechanisms are essentially the same.

***Compliance.*** All these options raise important issues for verifying compliance. A system in which different RINs are generated by selling 15 gallons of ethanol as 100 gallons of E15, or instead as 150 gallons of E10, appears to be one in which volumes of BOB also needs to be tracked. Complications to address include blending below the rack of E85 with E10 into E15 at a blender pump, blending E85 with BOB into E10, and the desire to avoid retail blender pump operators having compliance liability. Although the focus of this paper is the overarching structure and economics of reform, we flag the importance of a reliable compliance structure to implement these reforms.[11]

## The RVP waiver

E10 has higher evaporative emissions than petroleum gasoline. The standard measure of evaporative emissions is Reid vapor pressure (RVP). Higher RVP values imply more evaporative fuel emissions, which contribute to low-level ozone. As ethanol is added to petroleum blendstock, the RVP increases initially, plateaus at blends in the range of 10–15 percent ethanol, and then slowly declines (figure 8). The Clean Air Act limits gasoline to a maximum RVP of 9 pounds per square inch (psi) during the ozone season but grants a waiver (with restrictions) of an additional 1 psi to ethanol blended at 10 percent. Midrange blends, between 10 percent and 50 percent ethanol, have an RVP that exceeds the non-waiver standard but is the same or lower than E10; however, those blends are not eligible for the E10 RVP waiver. As a result, midrange blends—in particular E15—are generally unavailable during the summer ozone season.

**Figure 8:** RVP for Ethanol-Gasoline Blends




*Source: Johnson et al. (2015).*

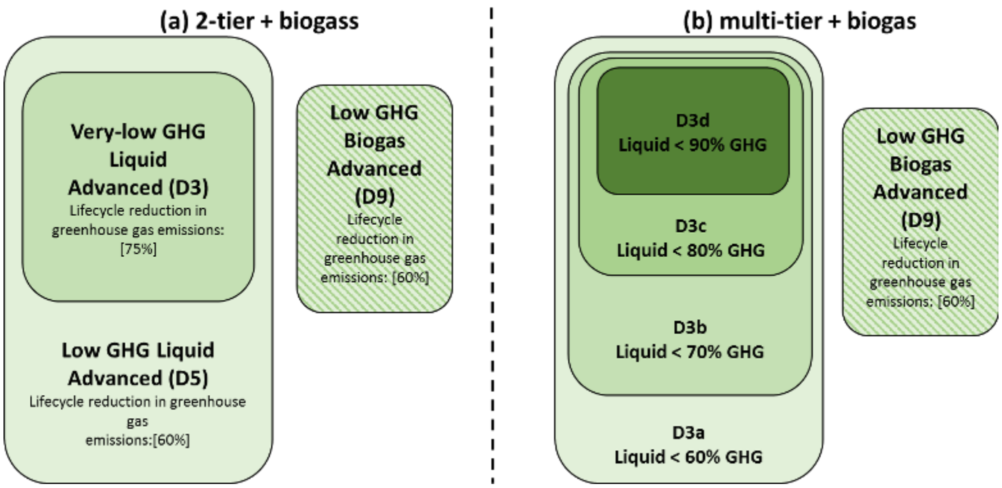
Because the RVP of E15 is essentially the same as E10 for a given blendstock, extending the waiver to E15 would not increase the RVP of fuels sold. However, it would permit the summer sale of E15 produced from the same blendstock as E10. This would facilitate year-round E15 sales—for example, via a blender pump with a two-tank system of E10 and E85.[12]

## Second-generation reform

The aim of the second-generation reforms is to provide the reliable, long-term RIN price support necessary to incentivize research, development, and commercialization of risky nascent low-GHG biofuel technologies and to reduce or eliminate many of the current regulatory restrictions in current pathway approvals, while limiting the cost to obligated parties and the consumer.

The mechanism for doing so considered here entails separating first- and second-generation fuels and setting up a new mechanism for providing RIN support for second-generation technologies. Two versions of this structure are shown in figure 9.

**Figure 9:** Alternative Nestings for Second Generation Fuels




The nestings in Figure 9 have the following features:

- Liquid fuels and biogas have separate nests. This preserves an incentive for development of nascent liquid fuels technologies, a key biofuels policy goal, while supporting approved and future biogas pathways.
- Feedstock based RIN definitions are replaced by performance definitions, subject to the requirement that the fuel be renewable and for use in the transportation system. Specifically, RIN pools are no longer defined by feedstock; instead, they are based on fuel characteristic (liquid or gas) and by life cycle GHG emissions relative to the petroleum fuel it replaces.
- The difference between the two nestings in figure 9 is the degree of differentiation among liquid fuels. The nesting in figure 9a has two bins, low and very low GHG fuels. The nesting in figure 9b has four bins, defined on life cycle GHG emissions. It is possible to have more than four bins. An advantage of more bins is that finer gradations reward additional GHG reductions for a technology or pathway. A disadvantage of more bins is that the life cycle reduction figures are estimates, so having additional bins creates a false sense of accuracy, in addition having finer gradations could complicate program administration.

Recall that a key aim of second-generation reform is to provide new producers with RIN price support that can be used to justify their financial decisions (“taken to the bank”). To this end, second-generation RINs—the D3, D5, and D9 in figure 9a—would have the following properties. For convenience, these properties are explained in the context a D3 RIN in figure 9a; however, the approach extends to the other RIN categories in figure 9:

- A plant with an approved pathway would be granted nontradable options to generate D3 RINs up to its nameplate capacity, for a given (long) number of years. A plant that fails to produce after a certain period of time would forfeit these options.

- The D3 RIN would have a price cap, and the D3 RVO would be managed so that wet D3 RINs trade at the price cap. As described in appendix B, this can be achieved using a D3 waiver credit issued by the EPA.
- The total number of D3 RINs would be capped, so that the second-generation program sunsets based on cumulative production. One way to implement this would be to deduct D3 RIN options when issued from the total number of D3 RINs under the program and to reinstate volumes from forfeited D3 RIN options.
- A key policy element is the price of the D3 (and D5) waiver credits. The waiver credits should be high enough to provide a meaningful and effective incentive for firms to tackle development and commercialization of risky second-generation technologies, while not providing an inordinate burden on gasoline consumers. Note that the cumulative volumetric cap also builds in price protection for consumers.
- Obligated parties would demonstrate compliance by retiring D3 RINs based on fractional standards, as is currently the case.

The nesting structure in figure 9 allows fuels with lower GHG emissions to fill the RVO for fuels with higher GHG emissions. Consider the nesting in figure 9a. Because the RVOs would be managed so that the RINs would trade at their caps, with the D5 waiver credit priced less than the D3 waiver credit, the operational impact of this nesting only arises when the cumulative volumetric cap for a pool is hit. For example, suppose the cumulative volumetric cap is hit for D3 RINs but not for total second-generation liquid RINs (D3 + D5). Then a new plant that qualifies for a D3 RIN could be granted D5 RIN options even though no D3 options remain.

## Sunset

Some stakeholders have called for sunsetting the RFS to be part of the reform package. The economic analysis here is silent on sunset provisions. However, general economic considerations provide a framework for evaluating sunset proposals.

The energy security and low-GHG goals of biofuels policy tackle four externalities: the energy security externality, the greenhouse gas externality, the network ("chicken and egg") externality of midlevel blends, and the research and development externality that the economic benefit of innovations cannot be entirely captured by the innovator (positive spillovers). From an economic perspective, integrated biofuels policy should address these four externalities efficiently.

The second two externalities—the network and R&D externalities—are temporary in the sense that once the dispensing infrastructure is in place, and once second-generation technologies are commercialized, those externalities no longer present. Thus, it is appropriate for incentives for transitioning to midlevel blends to be time limited. For example, the D6/D8 denested structure, with a D8 price ceiling of (say) $2.00, combined with the use of revenues from D8 waiver credits for an infrastructure program such as the USDA Biofuels Infrastructure Program, could be combined with a sunset of the D8 at a fixed date. Similarly, under the second-generation program laid out here, the total available RIN options available are capped, which provides an automatic sunset of the research, development, and commercialization support once the fuels have become successful.

In contrast, the first two externalities—the energy security and GHG externalities—persist and are benefits, not priced by the market, deriving from ongoing use of low-GHG domestic biofuels. Thus, from an economic perspective, an appropriate sunset would transition to a program that provides price support to fuels, where the support is calibrated to those ongoing externalities, and the support is provided through stable price channels instead of quantity targets or rate standards. Standard values for these externalities suggest that these externality values are well below the prices of D6 and D4 RINs since 2013 (see for example Baumeister and Kilian 2016). In addition, an argument could be made that the GHG externality is best addressed on an economy-wide basis through carbon pricing rather than on a narrower basis.

Separately, because ethanol is currently the most cost-effective octane booster and oxygenate, E10 enjoys a cost advantage over E0 with non-ethanol oxygenates (Irwin and Good 2017a). It is therefore expected that E10 would continue to be used without any RIN incentives. Thus a provision to guarantee the continued use of E10 ("no backsliding") would be expected to have no economic cost, barring major changes in the economics of corn and/or non-ethanol octane boosters.

# ECONOMICS OF THE REFORM PACKAGE

## D6 and D8 RIN prices and volumes of E10

Under the D6/D8 proposal, D6 RIN prices would be oversupplied on average annually. Paulson (2017) estimates 2017 fourth quarter D6 RIN stocks to be 975 million. Supposing the conventional gap to be 800 million gallons, the fD8 factor is 0.8/15 ≈ 5.3%. If the number of legacy D6 RINs equals Paulson's estimate, they would convert to an incoming new D6 RIN stock of approximately 925 million RINs. With a percentage obligation factor of 0.099 on estimated non-E0 gasoline volume, there would be approximately 140 million excess RINs generated each year on average. At this rate of growth, RIN stocks would increase by approximately 10–15 percent annually on average, so D6 RINs would be in excess supply. There would still be a D6 RIN market because some obligated parties are short and other parties are long; however, the D6 RIN price would be expected to be pennies, as it was through 2012.

The D6/D8 proposal makes it unlikely that lower ethanol blends such as E5 would be sold. If lower blends were sold in meaningful quantities, insufficient D6 RINs would be generated, the D6 RIN would be in short supply, and D6 RIN prices would rise. This would increase the RIN penalty from blending into E5 instead of E10, and the E5–E10 spread, along with the E0–E10 spread, would rise, reducing demand for blends lower than 10 percent. If the RVP waiver is extended only to blends of 10 percent or greater, concerns about lower blends such as E5 are moot.

The reform package continues existing RIN incentives for selling higher blends, and provides an additional growth opportunity for midrange blends by extending the RVP waiver to all ethanol blends. Under the fully nested version (figure 7a), D4 RIN prices provide a ceiling to D8 prices under the current system; that is, BBD backstops the D8.

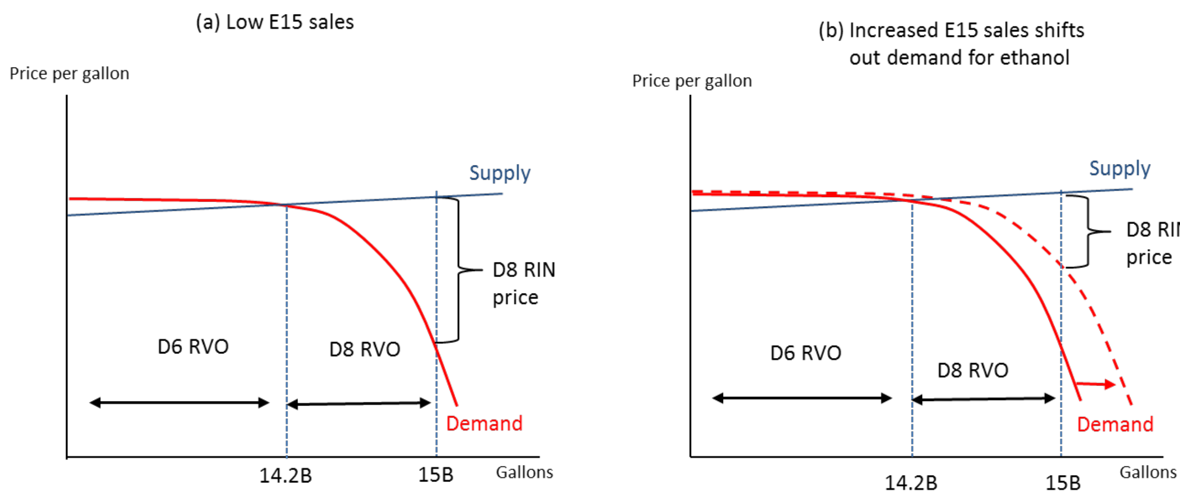
The specific path of D8 prices depends on multiple factors. Three of the most important factors are the potential expansion of E15, the path of overall gasoline demand (and thus the size of the conventional gap), and (under the fully nested variant) developments in the supply of non-ethanol fuels that can be used to meet the D8 RVO.

## The RVP extension and D8 RIN prices

As discussed in section 1, the prices of RINs are determined by supply and demand and, because RINs are bankable, by expected supply and demand.

Figure 10a depicts the economic fundamentals of D8 RIN pricing without and with the RVP waiver, under the fully nested structure of figure 7a. Figure 10a is a modification of figure 5a for the new D8 RIN. If the D8 RVO (the conventional gap) is nearly zero, the D8 RIN price would be expected to be negligible, because some higher blends will be sold even without a RIN subsidy. As the D8 RVO increases, however, an increasing RIN subsidy is needed to induce sales of higher blends.

**Figure 10:** RVP waiver extension, gasoline ethanol demand, and the D8 RIN price




The effect of extending the RVP waiver is to increase the demand for higher blends. Part of this increase arises simply because E15 can now be sold for more months, even if the rate of daily sales does not change. Advocates of E15 suggest, however, that when E15 is available for the full year, consumer habits will change, and the base of consumption (gallons/day) will increase. Both these considerations have the effect of shifting out the demand for ethanol in gasoline, as depicted in figure 10b, which has the effect of decreasing the price of the D8 RIN. Thus, all else equal, extending the E15 waiver increases the sales of ethanol blended into the fuel supply and exerts a downward pressure on the D8 RIN price.

Under the fully nested variant, the actual determination of the D8 RIN price is more complicated than shown in figure 10 because the D8 RVO can be filled by conventional non-ethanol fuels (conventional BBD), by D4 RINs generated in excess of the D4 percentage standard, and by drawing down RIN stocks. If it turns out that extending the RVP waiver has little effect on sales of higher blends, then the D8 price would likely rise to the D4 price, and RIN dynamics would be similar to those seen most of the time during 2013–2017, when the D4, D5, and D6 prices traded within a few cents of each other. If, however, the waiver extension (along with marketing efforts associated with the blender pump expansion of 2016–2017) results in a substantial increase in E15 sales, then the dynamics of figure 10b would come into play, and the D8 RIN price would separate from the D4 RIN price. In that situation, the D8 RIN price would be determined as the subsidy needed to equate a marginal gallon of higher blend demand with a marginal gallon of conventional non-ethanol D8 supply and, because the D8 RIN is bankable, expectations of those marginal costs in the future.

Under the BBD denested variant (figure 7b), if the amount of ethanol blended above 10 percent is less than the D8 RVO, then D8 RINs will be in undersupply, and the D8 RIN will trade at its price ceiling. The price would remain at its price ceiling unless E15 penetration were so substantial as to separate D8 RINs that satisfy the D8 RVO, in which case the D8 price would drop to the value needed to incentivize the marginal gallon of E15.

## A numerical illustration of the effects of RFS reform on RIN and fuel prices

We now turn to a numerical illustration of the effects of the reforms on RIN prices and on fuel prices. We consider both the fully nested and the BBD denested frameworks. Formulas for fuel prices and static equilibrium outcomes under the fully nested framework are given in appendix B (the calculations here use a simplified version of those formulas in which demand is fixed). The appendix B formulas are readily extended to the BBD denested framework.

For the fully nested structure, we make the following assumptions:

1. RVOs and gasoline and diesel consumption are at their 2018 values as set out in the 2018 final fractional standard rulemaking.
2. RIN prices are fully passed through to BOB and retail fuel prices.[13]
3. There is no expansion of sales of higher blends (we later relax this assumption).
4. No fuel categories are filled in excess of their RVOs (an assumption consistent with the D4 RIN exceeding the D8 RIN).
5. The D3, D5, and D9 waiver credits are assumed to be $3.00, $2.00, and $1.50, respectively.[14]
6. The D8 RIN price is $0.75, and the D4 RIN price is $0.90. These values are within the range in which the D6 and D8 traded in the second half of 2017. For the reasons discussed above, this assumption implicitly assumes that the D8 would trade at approximately the price of the current D6.

For the BBD denested structure, we adopt the first five assumptions above and modify the final assumption:

1. The D4 price is $0.85, the D8 is trading at its ceiling, and the D8 waiver credit price is $2.00.

Table 2 summarizes the effect of different RFS structures on RIN and fuel prices, and the value of the per-gallon RIN obligation, for various cases. The first column presents the calculations under the current RFS. Under the current RFS and with the assumed RIN prices, the value of the RIN obligation is approximately $0.09 per gallon of BOB or petroleum diesel. This implies a small increase the price of diesel at the pump (because it has a small fraction of renewable fuels) and a small decrease in the price of E10 at the pump. Under the current RFS and with the assumed RIN prices, the RIN value of E15, compared to E10, is $0.04, so that if RIN prices are fully passed through, E15 would sell for approximately $0.04 per gallon less than E10 at the pump. The RIN support for E85 is larger, with an E85–E10 retail price difference of −$0.53 with full pass-through.

**Table 2:** Fuel Price Effects of Different Versions of the Reform Package and Different Effects of the RVP Waiver

| | (a) Current RFS | (b) Fully Nested[a] | (c) Fully nested + 5 bgal E15 expansion[b] | (d) BBD denested[a] | (e) BBD denested + 5 bgal E15 expansion[b] |
|---|---|---|---|---|---|
| ***RIN price assumptions*** | | | | | |
| D4 | $0.85 | $0.85 | $0.85 | $0.85 | $0.85 |
| D6 | 0.75 | 0.03 | 0.03 | 0.03 | 0.03 |
| D8 | 0 | 0.75 | 0.70 | 2.00 | 2.00 |
| D3 | 2.80 | 3.00 | 3.00 | 3.00 | 3.00 |
| D5 | 0.85 | 2.00 | 2.00 | 2.00 | 1.50 |
| D9 | 0 | 1.50 | 1.50 | 0.85 | 1.50 |
| | | | | | |
| Refiner RIN obligation per gallon BOB or diesel | 0.086 | 0.028 | 0.028 | 0.034 | 0.034 |
| ***Retail Prices*** | | | | | |
| E10 | 0.002 | 0.022 | 0.022 | 0.027 | 0.027 |
| Diesel | 0.032 | -0.023 | -0.024 | -0.018 | -0.018 |
| E15-E10 difference | -0.042 | -0.039 | -0.037 | -0.102 | -0.102 |
| E85-E10 difference | -0.535 | -0.498 | -0.468 | -1.302 | -1.302 |
| E0-E10 diffeence | 0.084 | 0.003 | 0.003 | 0.003 | 0.003 |

*Notes: All prices and price effects are in dollars per gallon. Effects on retail prices assume full RIN pass-through to retail; the formulas are given in appendix B. Volumes of renewable fuels and fractional standards are taken to be those in the 2018 final rulemaking: 0.288 bgal of cellulosic, 2.1 bgal of advanced BBD, 0.852 bgal of D5 (advanced residual), and 15 bgal conventional. For the reform proposals in columns (b) through (e), the D5 RVO is reduced by 0.4 bgal (removal of cane ethanol, which is first generation), D9 is the biogas component of the 2018 cellulosic RVO (0.25 bgal), and D3 is the liquid component (0.038 bgal). Column (b) assumes that the volumes of higher blends and biofuels used are the same in the reformed and unreformed scenarios. Column (c) assumes conversion of 5 bgal of E10 to E15, which separates an additional 250 mgal of D8 RINs, and an equal decline in D8 RINs generated by conventional BBD (a decline of 156 mgal wet conventional BBD using a blended EV of 1.6); the D8 price decline is computed using the net conventional BBD import supply elasticity of −7.26 in Irwin and Good (2017b). Columns (d) and (e) assume a D8 waiver credit price of $2.00. Column (e) allows for conversion of 5 bgal of E10 to E15, which separates an additional 250 mgal of D8 RINs; however, the total number of D8 RINs remains below the D8 RVO of 800 mgal, so the D8 trades at its price cap. Calculations for full denesting assume that wet D8 RINs or D8 waiver credits must be retired up to the full D8 RVO.*

Columns (b) through (e) report prices under variants of the reform package. For each variant, the value of the RIN obligation falls by approximately two-thirds, to $0.03 per gallon of BOB or petroleum diesel. The effect of the reforms on the E10 price reflects two effects: the reduced obligation on the 90 percent BOB reduces the price of E10; however, separating a new D6 RIN has less value than the current D6 RIN. The net effect is a small increase in the price of E10, relative to the current system. Because diesel is now the renewable-rich fuel, its price falls by approximately $0.05, relative to the current system.

The differences among the reform variants are in some cases subtle. Columns (c) and (e) examine the effect of expansion of E15 sales by 5 bgal, thus adding 250 mgal of ethanol to the fuel supply and generating 250 mgal of additional wet D8 RINs. This expansion is modeled as a possible effect of extending the RVP waiver to E10+. Under the fully nested structure, the expansion of E15 produces additional D8 RINs, and their price falls because of decreased demand for conventional BBD imports. The drop in the D8 RIN price is relatively modest, from $0.75 to $0.70. In contrast, under the BBD denested framework, the 250 mgal of additional wet D8 RINs still is insufficient to fill the D8 RVO, so waiver credits are needed, and the D8 trades at its ceiling.

One significant difference between the fully nested and BBD denested frameworks is the price implications for higher blends. The denested structure provides a greater RIN incentive for sales of higher blends than does the fully nested structure. In the illustration in table 2, which presumes a D8 ceiling of $2.00, the full pass-through E15–E10 spread would be −$0.10 under the fully nested structure but −$0.04 under the denested structure, which is nearly the same as under the current system.

Under all versions of the reform proposal, the decline in the value of the RIN obligation implies that the spread between pump prices of E0 and E10 would narrow. To the extent that E0 would continue to be available at only a small fraction of retail outlets, the lack of competition in the E0 market could lead to a decline in the E0–E10 spread that is less than implied by the RIN calculations (consistent with the behavior of retailers in noncompetitive E85 markets). E0 requires non-ethanol oxygenates and octane enhancers, which are more expensive than ethanol, so in any event, E0 would plausibly be priced substantially above E10.[15] Although E0 sales would likely increase, one would expect that under the D6/D8 scenarios in table 2, the E0/E10 fuel mix would look like it was in the most recent episode in which the conventional component of the RFS was nonbinding, 2011–2012, when the total gasoline supply averaged 9.7 percent ethanol.

***How far would D8 RIN prices fall with the RVP waiver extension?*** The answer to this question depends on the extent to which extending the RVP waiver leads to more E15 sales. Such an extension has no direct historical analog, and there seem to be no econometric estimates of the demand for E15. Thus there is no solid empirical basis for estimating the quantitative boost to E15 sales from relaxing the RVP waiver. This said, there is some relevant quantitative evidence.

Producing 250 million gallons of additional D8 RINs from E15 would require converting 5 billion gallons of E10 sales to E15. Whether such an expansion is plausible is a matter of controversy. On the upside, the number of stations offering E15 increased substantially under the USDA Biofuel Infrastructure Program and the private Prime The Pump program; the EPA (2017, p. 65) estimates that the number of E15 stations could reach 2,700 in 2018. Korotney (2016) estimates 2017 E15 sales to be 687 million gallons, more than twice 2016 sales. These are nine-month sales and so would be expected to increase were the RVP waiver to be extended. Also, although E15 price data are poor, the limited available data suggests that E15 sells at a sufficient discount, relative to E10, to more than compensate for its 1.7 percent reduction in energy content (not taking into account its higher octane than E10).[16] On the downside, E15 confronts impediments to sales beyond the absence of the RVP waiver, as discussed in section 1.2.2. It seems likely that the extension of the RVP waiver to higher blends will need to be paired with aggressive marketing and consumer education by retailers to see large expansions in E15 sales.

As discussed above, the EIA projects declining total gasoline demand over the next decade. As an order of magnitude, filling a 1 billion gallon conventional gap in 2020 entirely with growth in ethanol in E15 would require selling a total of 17 billion gallons of E15 in 2020, or if filled by growth in E85, 1.5 billion gallons total of E85. Alternatively, filling this gap with excess D4 BBD would require approximately 650 million wet gallons of BBD above and beyond the D4 RVO. Under current EISA guidelines and under current regulation, the EPA has broad discretion to set the BBD RVO. In particular, the EPA could set the BBD RVO so that the sum of the BBD RVO plus additional RINs used to satisfy the D8 RVO could be reasonably supplied by the biodiesel industry. If so, BBD would still have sufficient capacity serve as a backstop for the D8 RIN under the fully nested structure.[17] As the conventional gap grows over time because of shrinking gasoline demand, under the denested structure, barring a transformative expansion of E15 comparable to the expansion of E10 seen from 2006–2012, one would expect D8 RINs to trade at their ceiling for the foreseeable future.

# CONCLUSIONS

The RFS is at a crossroads. Under the RFS and other biofuels policies, the United States has greatly expanded its use of first-generation biofuels. But despite five years of high RIN prices, there has been little growth in sales of blends higher than E10. Given this track record, domestic fuel ethanol consumption is likely to decline if gasoline demand contracts as the EIA projects. Moreover, with some isolated exceptions, the RFS has been largely unsuccessful in promoting the development and commercialization of low-GHG, second-generation fuels produced using nonfood feedstocks. Without changes, the RFS is not well suited to handle the challenge of declining gasoline demand, nor will it provide the support to low-GHG second-generation technologies needed as part of the transition to a low-carbon transportation sector.

Fortunately, through suitable reforms, it is possible to reduce and stabilize total compliance costs, to provide a path for increased market penetration of midlevel blends, and to provide meaningful and reliable support for second-generation fuels. The various parts of the package examined here interact with each other, so it is important to get the details right for the entire package to work. Taken together, these reform proposals have the potential to make US biofuel policy more efficient and more effective.

# NOTES

1. Other significant federal biofuels policies include the volumetric ethanol excise tax credit and the biodiesel income tax credit, which provide a tax credit for blending ethanol and biodiesel, respectively. The ethanol blender tax credit was available 2005–2011. The biodiesel tax credit was established in 2005 and was scheduled to expire in 2011; however, it has been extended annually since then, typically retroactively as part of the tax extenders package. A major force in the adoption of ethanol was the phase-out of MTBE as an oxygenate in the first half of 2006 as a result of the Energy Policy Act of 2005, which spurred the use of ethanol as an oxygenate. For a history of federal biofuels incentives through 2011, see Yacobucci (2012). Over the past 15 years, there have been a variety of state biofuels incentives, the largest of which is California's Low Carbon Fuel Standard. For a summary of state biofuels laws and incentives, see the Alternative Fuels Data Center at https://www.afdc.energy.gov/laws/state.

2. Energy Information Administration, "U.S. Fuel Ethanol Plant Production Capacity," June 20, 2017 at https://www.eia.gov/petroleum/ethanolcapacity/index.php.

3. It is plausible that the supply elasticity of BBD has increased in the past few years as international production capacity has increased, moderating RIN price volatility. Irwin and Good (2017b) estimated a supply elasticity of approximately 3 for domestic production and approximately 4 for combined domestic production and imports (including BBD imports that generate a D6 RIN). These elasticities are large; for example, an increase of 300 million wet gallons, corresponding to approximately 450 additional RINs to fill the D6 RVO, would be associated with a D6 RIN price increase of $0.05.

4. This calculation is based on RIN retirements from the EMTS times the average annual RIN price (unweighted daily average). Actual RIN expenditures could differ based on timing of purchases. I treat all fuels generating a D4 and a D6 RIN and all ethanol that generates a D5 RIN as first generation, with the remainder as second generation.

5. There is an active debate about who ultimately bears the compliance costs. Academic studies (Knittel, Meiselman, and Stock 2016, 2017) indicate that, on average, RIN costs are passed along to the consumer via a one-to-one increase in BOB prices when RIN prices rise. This view was also taken by EPA in Burkholder (2015) and in its denial of the petition to move the point of obligation (EPA 2017), where the issue is discussed extensively. On the other hand, some merchant refiners that generate insufficient RINs to cover their obligation, who thus must purchase RINs on the market, claim that they are unable fully to recoup RIN costs and that their bottom lines are eroded by large RIN expenditures. These views can be partially reconciled if BOB prices on national markets (e.g., NY harbor RBOB) move on average with RIN prices, but for some refiners local market conditions prevent them from fully passing through their costs, at least in certain periods. Even if RIN costs are fully passed through to wholesale, RIN price volatility can expose obligated parties to RIN price risk if they take open positions in the RIN market. Such RIN price-risk exposure is

an undesirable unintended consequence of the RFS.

6. For example, see Leone et al. (2015) and Oak Ridge National Laboratory (2016).
7. See Pouliot, Smith, and Stock (2017).
8. See Li and Stock (2017) and Lade and Bushnell (2017).
9. The reform package considered here requires legislative action. Although some components could potentially be achieved by regulation under existing statutory authority, doing so would have several disadvantages. Administrative reform would be subject to litigation, which would delay implementation, prolong uncertainty, and undermine some of the reforms. Because the reforms could be changed by a future administration, the program would remain politicized and uncertain.
10. Even if obligated parties can pass through RIN costs to wholesale prices for petroleum fuels, as discussed in footnote 5, those obligated parties are exposed to RIN price risk because of RIN price volatility. Reducing total compliance costs thus reduces the exposure of obligated parties to RIN price risk.
11. One way to phrase the compliance challenge is that although D8 RINs can flow into the D6 pool (the D8 can be used for D6 compliance), D6 RINs must not flow into the D8 pool; that is, a D6 RIN cannot masquerade as a D8 RIN. If a D6-8 parent RIN incorrectly is separated as a D8 RIN, D6 RINs will be in short supply, and the price of the D6 RIN will be driven toward the price of the D8. In the fully nested structure, this price would be capped by the price of the D4 RIN. In the BBD denested structure, this leakage could result in the D6 RIN price being driven up to the D8 ceiling (the D8 waiver credit price).
12. The E10 RVP waiver has exceptions and regional nuances. See the Congressional Research Service report on S. 517 and H.R. 1311 (Bracmort 2017) for details.
13. The empirical evidence supports this assumption for bulk wholesale markets and for retail E10. This assumption also is supported for E85 in mature markets; however, there is evidence of incomplete pass-through in remote and less mature markets. There has been no comprehensive study of pass-through to E15 prices; however, the studies of E85 pricing suggest that one would expect to see full pass-through in competitive E15 markets but not otherwise. See Lade and Bushnell (2017) and Li and Stock (2017).
14. This assumption has little effect on the results because volumes of these fuels are currently very low.
15. Irwin and Good (2017a) find that the energy penalty of ethanol and the octane premium of ethanol blended into E10 approximately offset each other on average from 2007–2016, compared with using aromatics as octane boosters and ignoring energy content changes of aromatics. Except for a brief spell in 2008, the octane premium of ethanol was positive compared to aromatics and averaged $1.06/gallon.
16. Source: E15 prices on E85prices.com, accessed July 8, 2017, and the Prime The Pump

Progress Report, June 15, 2017.

17. This said, there is some risk to D8 prices if gasoline demand falls substantially further than the AEO 2018 projection, if BBD production capacity does not increase and the floor on the BBD RVO remains 1.0 bgal as specified in the EISA.

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# APPENDIX A: PROTOTYPE REFORM PACKAGE (ADDITIONAL DETAILS)

## First-generation reforms

1. Separate compliance for E10 from compliance with the conventional gap (conventional RVO in excess of ethanol in E10). Mechanisms to accomplish this are *EITHER*

    a. D6/D8 RIN—fully nested variant

        i. Ethanol blended into petroleum gasoline at fractions up to 10 percent separates a D6 RIN.

        ii. Ethanol blended into gasoline in excess of 10 percent separates a D8 RIN.

            - For example, blending 15 gallons of ethanol into 100 gallons of E15 would separate 10 D6 RINs and 5 D8 RINs

        iii. Non-ethanol conventional fuels (e.g., conventional renewable diesel) separate D8 RINs at energy equivalent values.

    **OR**

    b. D6/D8 RIN—BBD denested variant

        i. Ethanol blended into petroleum gasoline at fractions up to 10 percent separates a D6 RIN.

        ii. D8 RINs are only separated upon blending ethanol into gasoline in excess of 10 percent.

    **OR**

    c. E10/D8 RIN

        i. All gasoline for surface transportation is required to have ethanol content of at least 10 percent, with specified exemptions for E0. Ethanol blended into gasoline at fractions up to 10 percent does not generate a RIN.

        ii. The D8 RIN could be handled either in a nested or BBD denested framework

2. RVOs

    a. The conventional RVO is fixed at 15 bgal.

    b. Under the D6/D8 mechanism:

        i. The D6 RVO would be the ethanol capacity of gasoline at E10 adjusted for E0 (details below).

ii. The RVO for fuels generating a D8 RIN would be the conventional gap = the conventional RVO minus the D6 RVO.

c. Under the E10/D8 mechanism

i. The RVO for fuels generating a D8 RIN would be the conventional gap.

d. The D4 (BBD) RVO is set as in the EISA.

3. D8 waiver credit under BBD denesting.

a. The D8 RIN would have a price ceiling, implemented via a D8 waiver credit.

b. EPA would issue a D8 waiver credit after the end of the compliance year (true-up period) once it is demonstrated that there are no wet D8 RINs available for compliance at or below the D8 waiver credit price.

c. In the event that the number of wet D8 RINs falls short of the D8 RVO, there are various options. One option is for EPA to sell D8 waiver credits up to the D8 RVO and to use the resulting revenue to support blender pump installation akin to the USDA Biofuels Infrastructure Program, with a specified sunset.

4. RVP waiver

a. The 1 psi Reid Vapor Pressure (RVP) waiver is extended to all ethanol blends of 10 percent and higher

5. Data

a. To ensure smooth functioning of the D8 market, the EPA and EIA would collect and report in a timely manner additional data including higher-frequency data on sales of E0, E10, E15, E85, other blends, ethanol provided to the market as E0, and other data as needed by participants to monitor obligations.

## Second-generation reforms

1. Create three second-generation (advanced) pools (figure 9a)

a. *Low-GHG Liquid Advanced*: second-generation liquid fuels with a [60 percent] life cycle GHG emissions-reduction requirement. These fuels generate a D5 RIN.

b. *Very low GHG Liquid Advanced*: second-generation liquid fuels with a [75 percent] GHG emissions-reduction requirement. These fuels generate a D3 RIN.

c. *Low-GHG Biogas Advanced*: biogas with a [60 percent] life cycle GHG emissions-reduction requirement. These fuels generate a D9 RIN.

i. Cellulosic biogas pathways currently producing a D3 RIN would go into the D9 pool.

d. Notes

   i. Liquid fuels could have a multi-tier nesting as in figure 9b.

   ii. Pools are defined by performance, not feedstock, as long as the fuel is renewable.

   iii. First-generation technologies are excluded from the D3 and D5 pools.

   - This requires a specific definition of "first generation" (e.g., based on recent performance or technology).

2. D3, D5, and D9 RVOs and RIN price caps

   a. The D3, D5, and D9 RVOs would be set to equal actual D3, D5, and D9 production, respectively, determined after the end of the compliance year when compliance-year RIN generation data are available.

   b. D3, D5, and D9 RINs would have a price cap, implemented through waiver credits available from the EPA.

      i. The D9 waiver credit is available at [$3.75] minus the wholesale price of RBOB in the compliance year, or [$1.50/gallon], whichever is greater.

      ii. The D5 waiver credit is available at [$4.25] minus the wholesale price of RBOB in the compliance year, or [$2.00/gallon], whichever is greater.

      iii. The D3 waiver credit is available at [$5.25] minus the wholesale price of RBOB in the compliance year, or [$3.00/gallon], whichever is greater.

      iv. The EPA shall issue D3 (D5, D9) waiver credits only at the end of the annual compliance period and if and only if no wet D3 (D5, D9) RINs are available at or below the waiver credit price.

3. Sunset

   a. To be eligible to generate a D3, D5, or D9 RIN, a production facility must be operational by [TBD].

   b. There will be a total of [TBD-D3 cap] RINs in the D3 pool, [TBD-D5 cap] billion RINs in the D5 pool, and [TBD-D9 cap] billion RINs in the D9 pool.

4. Eligibility and guarantee

   a. Upon reaching a defined trigger (e.g., pathway approval), a production facility will be granted facility-specific non-tradable RIN options for annual production up to its nameplate capacity over a period of [TBD] years. Those RIN options will be deducted from the total available RIN options under the program

   b. The RIN options are exercised (converted to RINs) on a production basis when wet gallons of the certified fuel are produced.

c. If a facility becomes eligible for D3 RIN options but no more D3 RIN options remain, but D5 RIN options remain, the facility would be granted D5 RIN options.

d. RIN option allocation should be managed with the intent that the RIN options be exercised. For example, a production facility that fails to meet certain production benchmarks in a timely fashion would forfeit some or all of its RIN options, which are then returned to the total available RIN pool.

## Nesting, conversion of legacy RINs, RIN banking, and RIN authentication

1. First generation, fully nested variant
    a. A D4 RIN can be used to meet either the D4, D8, or D6 obligations.
    b. A D8 RIN can be used to meet either the D8 or D6 obligations.
    c. In the E10/D8 variant A(1)(c), the D6 RIN drops out of this nesting.
2. First-generation, BBD denested variant
    a. A D4 RIN can be used only to meet the D4 obligations.
    b. A D8 RIN can be used to meet either the D8 or D6 obligations.
    c. In the E10/D8 variant A(1)(c), the D6 RIN drops out of this nesting.
3. Second generation (two tier)
    a. D3 RINs can be used to meet either the D3 or D5 obligation.
    b. D9 RINs are in a separate pool (not nested).
    c. Second-generation ethanol would additionally generate a D6-8 parent RIN.
4. Second-generation RINs cannot be used to satisfy first-generation obligations and vice versa
5. Treatment of legacy RIN stocks
    a. "Old D6" RINs (see discussion)
        i. Under the D6/D8 mechanism with full nesting: 1 "old D6" RIN converts to 1 "new D6" RIN and 1 "new D8"
        ii. Under the D6/D8 mechanism with BBD denesting and a D8 waiver credit (D8WC): 1 "old D6" RIN converts to 1 "new D6" RIN and f "new D8" RINs, where f is the ratio of the D6 RIN price at some historical date (for example, the average D6 RIN price in January 2018) to the price of the D8WC.
        iii. Under the E10/D8 mechanism with full nesting: 1 "old D6" RIN converts to 1 "new

D8" RINs.

iv. Under the E10/D8 mechanism with BBD denesting: 1 "old D6" RIN converts f "new D8" RINs where f is defined in (ii) above.

b. 1 "old D5" RIN converts to 1 "new D4" RIN,

c. 1 "old D4" RIN converts to 1 "new D4" RIN, and

d. 1 "old D3" RIN converts to 1 "new D4" RIN.

6. Banking and borrowing

   a. New D4, D6, and D8 RINs have the same banking and borrowing structure as in the current RFS.

   b. New D3, D5, and D9 RINs are neither bankable nor borrowable and so must be used for the compliance for the year in which they are generated, or are forfeited.

7. IIndexation. All dollar values are in real terms (indexed to the rate of inflation).

8. RIN authentication

   a. RINs purchased in good faith by an obligated party from a generator with an approved pathway will be treated as valid RINs for compliance purposes, even if those RINs subsequently turn out to be fraudulent. (EPA indemnifies arms-length RIN purchases from an approved generator.)

# SELECTED DISCUSSION

***A(1)(a) D6/D8 RIN.*** The purpose of the D6/D8 mechanism is to produce a negligible RIN price for ethanol blended into E10 while maintaining a financial incentive for higher blends. To produce a negligible price for the new D6 RIN, there must be an oversupply of D6 RINs on average across years so that with bankability D6 RINs are always in oversupply. The following method for setting the D6 RVO and percentage standard achieves this by requiring slightly fewer RINs to be retired each year than are generated by blending into E10.

Let $RVO_{D6,t}$ be the D6 RVO in year t and similarly for D8. The D6 and D8 RVOs are set as

$$RVO_{D6,t} = 0.099\times(\text{Total E10} - \text{equivalent gasoline}_{t|t-1} - E0_{t|t-1}) \quad (1)$$

$$RVO_{D8,t} = 15\text{ bgal} - RVO_{D6,t}. \quad (2)$$

where:

Total E10-equivalent $\text{gasoline}_{t|t-1}$ = EIA forecast of total gasoline consumption in year t, made in year t-1, in E10-equivalent gallons, and

$E0_{t|t-1}$ = EIA or EPA forecast of retail sales of E0 in year t, made in year t-1.

Given the RVOs, the percentage standards for D6 and D8 are is computed as in the current RFS. For example, the D6 percentage standard would be $RVO_{D6,t}$ divided by the 49-state projected volume of sales of petroleum diesel and petroleum gasoline after small refinery exemptions.

The conversion of old D6 RINs to new D6 and new D8 RINs ensures that there is an existing buffer stock of D6 RINs to smooth market functioning and to ensure an oversupply of D6 RINs from the outset.

If the forecasts, total E10-equivalent $\text{gasoline}_{t|t-1}$ and $E0_{t|t-1}$, are correct, then .001 excess D6 RINs will be generated for every gallon of E10 sold. If the forecasts are off, then either more RINs will be generated than expected (e.g., if E0 sales are less than forecasted or the ratio of gasoline to diesel sales is greater than forecasted) or fewer RINs will be generated than expected, respectively either increasing or drawing down the stock of banked D6 RINs. If the forecast is accurate on average, then over time the stock of banked D6 RINs would increase, ensuring oversupply.

An important point concerns E0 sales. If E0 sales are not subtracted out from the D6 RVO calculation, then the number of D6 RINs separated might be insufficient to meet the percentage standard, in which case D6 RINs would be in undersupply, and their price would rise inconsistent with the intention of this mechanism.

The EPA would have discretion to modify the formulas above (e.g., replacing 0.099 with a different factor), adjusting for past forecast errors, or providing a different treatment of E0, to balance the twin goals of ensuring that gasoline is predominately blended at 10 percent or greater, and that the D6 RIN price should be negligible.

***C(2) D3, D5, and D9 RVOs and RIN price caps.*** This section describes one way to implement the second-generation RIN mechanism described in section 2.3. For specificity this discussion focuses on the RVOs and percentage standards for very low GHG liquid fuels ("D3 fuels") in figure 9a.

- D3 RVO and percentage standards:
  i. A provisional D3 RVO estimate is provided prior to the compliance year in the usual annual RFS rulemaking that sets percentage standards for other fuels.
  ii. The provisional RVO is used to compute a provisional percentage standard.
  iii. The provisional RVO is revised after the compliance year but before the settlement period closes to equal the stock of outstanding RINs generated by very low GHG fuel production ("D3 fuels"), net of adjustments for exports, spillage, sale into the renewable chemical industry, etc., times a growth factor of 1.0025. This results in a revised RVO.
  iv. The revised RVO, along with actual 49-state sales of petroleum surface transportation fuels (with small-refinery adjustments), is used to compute a revised percentage standard for the now-completed compliance year.
- Compliance
  i. RIN producers set up an auction website, open to qualified parties, on which D3 RIN owners (potentially but not necessarily the RIN generator) post asking prices, obligated parties can post bid prices, and on which sales prices are conducted.
  ii. Upon announcement of the final D3 percentage standard for the compliance year, the EPA opens the window for selling D3 waiver credits (D3WCs) for the now-completed compliance year. When the window is open, the EPA stands ready to sell D3WCs at the (new) statutory price; however, it would do so if and only if there are no asking prices (valid offers to sell) on the website for the relevant compliance year that are at or below the statutory D3WC price. Upon close of the settlement period, the D3WC window closes.
- Because the growth factor is greater than 1 and D3 RINs would not bankable, D3 RINs would be in short supply. Thus they would trade at the price ceiling.
- The EPA would have the authority to change the growth factor and to adjust CWC trading rules or to adjust D3WC window operating rules, consistent with the intention that all wet D3 RINs that are sold and retired for compliance purposes are sold at or near the price cap and the market be smoothly functioning (liquid).
- This mechanism extends to D9 fuels.

***C(5)(a) Conversion of legacy D6s RIN.*** The conversion of legacy D6 RINs is a detail that merits further analysis. The overarching goal is transition to the new system that is fair to all parties and is not disruptive. This overarching goal suggests several specific related goals:

i. Owners of current RINs should not experience a windfall gain or loss as a result of the reform;

ii. Price support provided by the D6 RIN to the use of higher blends should be stable over the transition (a crash in the old D6 RIN price during the transition would undercut price incentives for selling higher blends, destabilize the system, and cause hardship for some stakeholders);

iii. New D4, D6, and D8 RINs should, on the effective date of the reformed program, have adequate RIN inventories to ensure the goals of smoothly functioning RIN markets and an oversupply of new D6 RINs.

The price stability goal in (ii) implies that the price of the old D6 should not jump or crash upon passage of the reforms. Because RINs are bankable, under risk neutrality the price of an old D6 upon passage is the discounted expected value of the price obtained by the new D6 to which it converts. Thus as a general principle, for a stable price path, the price of the old D6 RIN today should equal its discounted expected value upon conversion. Ignoring discounting, this implies that

$$P_{D6,0} = a_{D6}E(P_{D6,new}) + a_{D8}E(P_{D8}), \qquad (3)$$

where $P_{D6,0}$ is today's value of the (old) D6 RIN, $E(P_{D6,new})$ is the expected price of the new D6 RIN, and $E(P_{D8})$ is the expected price of the D8 RIN, and $a_{D6}$ and $a_{D8}$ are respectively the number of new D6 RINs and new D8 RINs into which an old D6 converts.

Note that if (3) holds, not only are RIN prices stable, there are no windfall gains or losses to holders of existing RINs upon passage of the reforms.

How to satisfy (3) depends on the nesting structure. First consider the full nesting. As discussed in Section 3, the expectation is that the new D6 RIN will have a value of essentially zero if it is managed to be in oversupply and if it has a sufficiently large initial new D6 stock. Also, the new D8 is expected to have a price of approximately the new D6. Thus the proposal that an old D6 converts to 1 new D6 and 1 new D8 implies that (3) would hold. This conversion would create a large incoming D6 RIN stock which would serve to ensure that the D6 is in oversupply. It would also create a large D8 RIN stock which would ensure smooth functioning of the D8 market. Note that if the expected new D6 RIN price is zero, aD6 is not determined, for example an old D6 could convert to 2 new D6 and 1 new D8 and (3) would still hold.

Under BBD denesting, the expectation is that D8 RINs would trade at the D8WC price (the price ceiling). Thus for (3) to hold, $a_{D8}$ should be the ratio of the current D6 price to the D8WC price. The proposal fixes the current price to be some historical value to support a stable transition path

These considerations apply to the E10/D8 variants, but with $a_{D6}= 0$.

# APPENDIX B: RIN AND FUEL PRICING UNDER THE D6-D8 PROPOSAL WITH FULL PASS-THROUGH

This appendix lays out a static model of RIN prices under the treatment of first-generation fuels laid out in section 2, with the fully nested structure in figure 7a. The model considers four retail fuels (E0, E10, E15, and diesel) and four wholesale (neat) fuels (BOB, denatured ethanol [E100], petroleum diesel, and biodiesel [BBD]. We abstract from the difference between biodiesel, renewable diesel, etc. and assume an energy equivalent value of 1.5). We assume full pass-through of RIN prices, although the equations could be modified for partial pass-through. The prices of corn and international refined products (without a RIN obligation) are taken to be exogenous. In addition, total gasoline and diesel demand, in energy units, is taken to be exogenous. This latter approximation simplifies the analysis and focuses on the fuel-switching effects of the relative price shifts imposed by RINs. This approach extends to including E85 as a retail fuel.

Consumer demand for retail fuels is given by the following equations:

$$Q_{E0} = \varphi_{E10} (P_{E0}, P_{E10}, P_{E15}) \quad (4)$$

$$Q_{E10} = \varphi_{E10} (P_{E0}, P_{E10}, P_{E15})$$

$$Q_{E15} = \varphi_{E15} (P_{E0}, P_{E10}, P_{E15})$$

$$e_{E0} Q_{E0} + Q_{E10} + e_{E15} Q_{E15} = Q_{E10e}$$

$$Q_D = Q_D$$

The penultimate equation says that the total fuel consumed, in energy units, is fixed and equal to $Q_{E10e}$ as measured in E10-equivalent gallons, where $e_{E0}$ and $e_{E15}$ are energy density conversion factors for E0 and E15 to place them on an E10 gallon-equivalent basis.

For simplicity, the model assumes perfect competition and complete pass-through of RIN prices. As is illustrated in figure 5, for ethanol the supply curve is essentially flat, so the RIN value is passed through to the consumer. In contrast, for BBD the demand curve is flat, so the RIN value is passed through to the producer. The refined product pricing equations are as follows:

$$P_{BOB} = P^*_{BOB} + P_{RIN} \quad (5)$$

$$P_{RIN} = r_{D4}P_{D4} + r_{D6}P_{D6} + r_{D8}P_{D8}$$

$$P_{E10} = 0.9P_{BOB} + 0.1P_{E100} - 0.1P_{D6}$$

$$P_{E15} = 0.85P_{BOB} + 0.15P_{E100} - 0.1P_{D6} - 0.05P_{D8}$$

$$P_{E0} = P_{BOB} + P_{OCT}$$

$$P_D = P^*_D + (1 - b_{ABBD} - b_{CBBD}) P_{RIN} - 1.5b_{ABBD}P_{D4} - 1.5b_{CBBD} P_{D8}$$

$$P_{E100} = kP^*_{CORN}$$

where $P^*_{BOB}$ , $P^*_D$ , and $P^*_{CORN}$ are respectively the international prices of BOB, petroleum diesel, and corn; ABBD denotes advanced BBD (BBD that generates a D4 RIN), and CBBD denotes conventional BBD (BBD that currently generates a D6 RIN); $P_{RIN}$ is the price of the RIN bundle that must be retired for each gallon of petroleum fuel sold into the fuel supply; and $P_{D4}$, $P_{D8}$, and $P_{D6}$ are the prices of D4, D8, and D6 RINs. The r coefficients are the fractional standards, the b coefficients are the blend ratios for biodiesel into diesel, and k is the number of bushels of corn required to produce one gallon of ethanol. For convenience, these equations omit constant markups. Fuel prices are in dollars per wet gallon; RIN prices are dollars per RIN gallon.

The equations in block (5) merit a brief discussion. Blending 0.1 gallons of ethanol into a gallon of retail fuel detaches 0.1 D6 RINs—that is, converts the D68 RIN into a D6 RIN—which can be sold, which delivers the second equation. Blending 0.15 gallons of ethanol into a gallon of E15 detaches and converts 0.15 D68 parent RINs into 0.10 D6 RINs and 0.05 D8 RINs, which can be sold, which delivers the third equation. To bring the suboctane BOB to retail grade requires adding a petroleum octane booster and oxygenate, which yields the E0 pricing equation. Petroleum diesel, when blended at the fractional rate $p_{BBD}$ with BBD, entails a RIN obligation for the amount of petroleum diesel but generates $1.5p_{BBD}$ D4 RINs, which delivers the penultimate equation. The final equation simplifies ethanol distillery economics so that the price of ethanol is proportional to the price of corn.

The quantities of RINs generated are as follows:

$$Q_{D4} = 1.5Q_{ABBD} \quad (6)$$

$$Q_{D6} = 0.10\,(Q_{ED} + Q_{E15})$$

$$Q_{D8} = 0.05Q_{E15} + Q_{CBBD}$$

where $Q_{ABBD}$ and $Q_{CBBD}$ are the quantities of advanced and conventional biodiesel, respectively.

The ABBD RVO (D4 obligation) is taken as exogenous, and the total conventional obligation is taken to be fixed at 15 bgal. The D6 and D8 RVOs are set as

$$RVO_{D6} = 0.99Q_{D6} \quad (7)$$

$$RVO_{D8} = 15 - RVO_{D6}$$

***RIN pricing.*** The role of RIN prices is to fill the gap between the demand price and the supply price at a given volume as shown in figure 4. For E100, denote the gap in figure 4a by the function $g_{E100}(Q_{E100} - 0.1\,(Q_{E10e} - E0))$, where $0.1\,(Q_{E10e} - E0)$ is the ethanol capacity of gasoline if all but E0 were blended at 10 percent ethanol. For values of the argument < 0, the function $g_{E100}$ equals 0. Similarly, the gap in figure 4b is denoted $g_{ABBD}\,(Q_{ABBD})$. A similar gap, not shown, applies to conventional BBD.

There are five possible cases. We lay out the equations for the first case; the equations for the other cases are analogous with inequalities.

**Case (a):** $P_{D4} > P_{D8} > P_{D6} = 0$. No excess BBD RINs are produced, no excess D8 RINs are produced, and D6 RINs are produced in surplus so that the D4 RIN exactly satisfies the BBD RVO, the D8 RIN exactly satisfies the D8 RVO, and the D6 RVO is oversatisfied. In that case

$$P_{D4} = g_{ABBD} (RVO_{ABBD}) \quad (8)$$

$$P_{D8} = g_{E100} (0.05Q_{E15}) = g_{CBBD} (Q_{CBBD})$$

$$P_{D6} = 0$$

In this case, D8 RINs are separated by selling E15 and conventional BBD.

The price of the RIN obligation is

$$P_{RIN} = a_{D4}P_{D4} = a_{D8}P_{D8} + a_{D6} P_{D6^*} \quad (9)$$

***Case (b):*** $P_{D4} = P_{D8} > P_{D6} = 0$.

***Case (c):*** $P_{D4} > P_{D8} = P_{D6} = 0$.

***Case (d):*** $P_{D4} = P_{D8} = P_{D6} = 0$.

***Cases (e) through (h)*** replace the final "= 0" with "> 0." For these cases, additional D6 RINs are not generated by switching E10 to E15; they are only generated by switching E0 to E10 (or E15). The D6 RIN price for these cases is determined by the price increase needed to discourage D0 demand. This operates by increasing the value of the D6 price so the value of the per-gallon RIN obligation (9) increases. Under the nesting structure, if the value of the D6 rises so that the D6 and D8 price are the same, then D8 will be produced in excess to satisfy the D6 obligation, and potentially all three RIN prices could be the same so that ABBD satisfies both the D8 and D6 obligation.

***An example.*** Figure B-1 shows three different example of the prices and quantities of D4, D8, and D6 RINs produced in the fully nested framework. The purpose of this illustration is to show

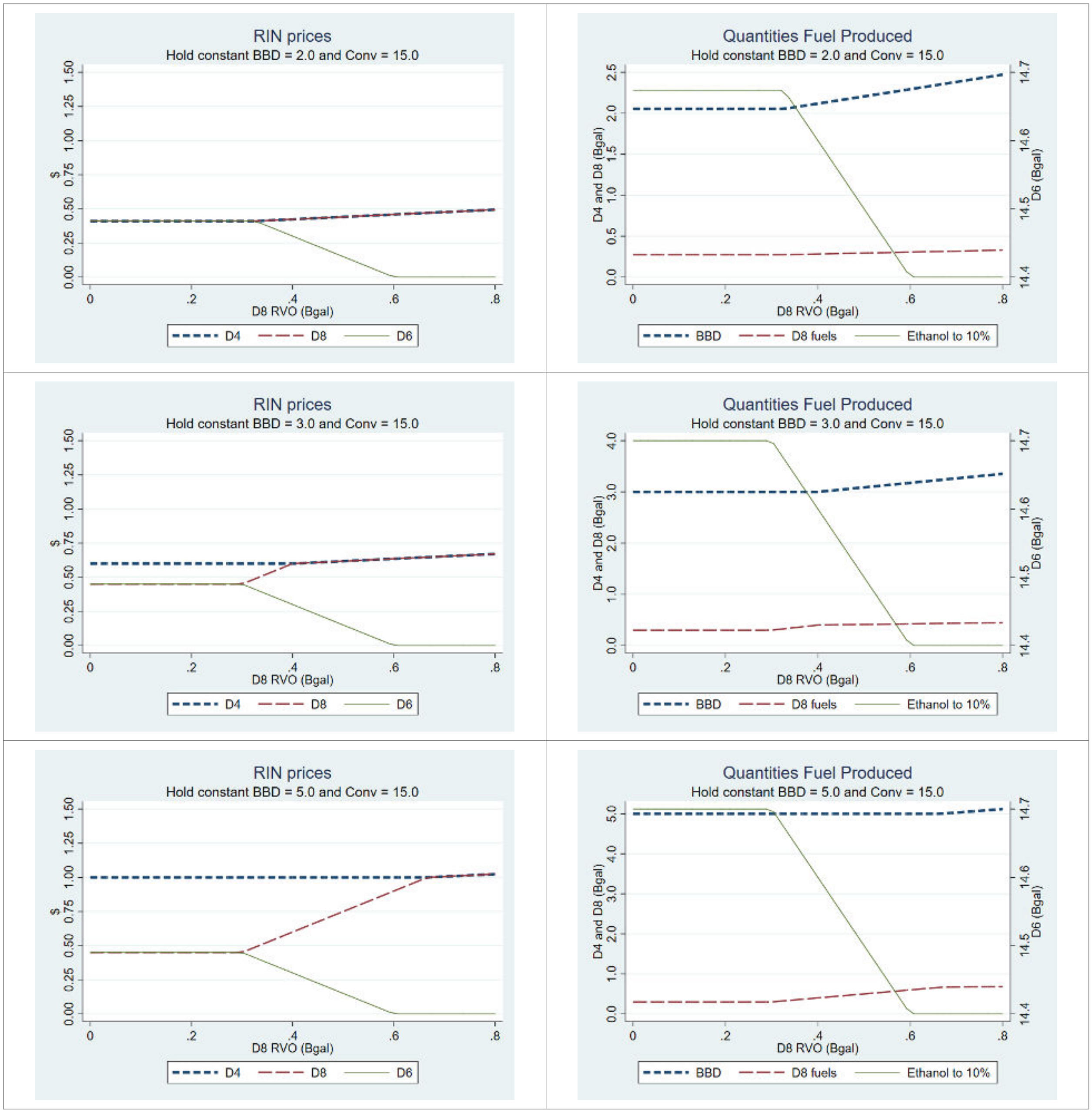
i. the sensitivity of the new D6 price to the setting of the D6 RVO, and in particular how the D6 price will be greater than zero if the D6 RVO is set too high;

ii. The interaction between the advanced BBD RVO in the fully nested framework and the D8 price. In particular, if the BBD RVO is set at a high level, the D8 price will be less than the D4 price and the D8 gap will be filled by ethanol from higher blends and conventional BBD. If the BBD RVO is set at a low level, then D4 is used to fill the D8 gap and the D4 and D8 RIN prices coincide.

For this illustration, we fix the ethanol capacity of E10e at 14.4 bgal and set the conventional RVO at 15 bgal. We also ignore possible effects on E0 and hold E0 fixed. The horizontal axis in Figure B-1 depicts the D8 RVO, which we treat here as a policy choice. When the D8 RVO is zero, there are no D8 RINs, so the only RINs are the D4 and D6; thus the case of a zero D8 RVO corresponds to the current system (ignoring the current D5 and D3). When the D8 RVO is 0.6 bgal or greater, the D6 RVO is the ethanol capacity of gasoline and blending E10 satisfies or over-satisfies the D6 RVO, so the D6 price is zero. The figures illustrate the effect of increasing the D8 RVO from 0 to 0.7 bgal. The dollar values are illustrative only. D8 RVOs less than 0.6 correspond to the D6 RVO being set too high, in the sense that the D6 price is greater than zero.

The three rows differ by the assumed value of the advanced (nested) BBD RVO, with the value of the BBD RVO increasing from the first to the third row. As the BBD RVO (the D4 RVO) increases, the D4 and D6 RIN prices separate in the current system (that is, at a zero D8 RVO). When the D8 RVO is 0.6 bgal so the D6 price is zero, at low values of the BBD RVO the D8 gap is filled in part by D4 RINs. At the highest value (final panel), the D8 gap is filled by ethanol blended into higher blends and by CBBD, but not by ABBD, and the D8 RIN price is less than the D4 RIN price.

**Figure B1:** RIN Prices and quantities, D4-D8-D6 nesting structure, as a function of the D8 RVO. Each row assumes a different value of the D4 RVO.




*Source: Authors' calculations. Numerical values are illustrative only.*

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