

August 31, 2017

The Honorable Scott Pruitt
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Re: Comments of the Renewable Fuels Association (RFA) in response to *Renewable Fuel Standard Program: Standards for 2018 and Biomass-Based Diesel Volume for 2019*; Proposed Rule (82 Fed. Reg. 34,206; July 21, 2017). Docket ID No. EPA-HQ-OAR-2017-0091

Dear Administrator Pruitt,

The Renewable Fuels Association (RFA) appreciates the opportunity to provide comments to the U.S. Environmental Protection Agency (EPA) relating to the EPA's proposed rule for 2018 Renewable Volume Obligations (RVOs) under the Renewable Fuel Standard (RFS).

RFA is the leading trade association for America's ethanol industry. Its mission is to advance the development, production, and use of fuel ethanol by strengthening America's ethanol industry and raising awareness about the benefits of renewable fuels. Founded in 1981, RFA serves as the premier forum for industry leaders and supporters to discuss ethanol policy, regulation, and technical issues. RFA's 300-plus members are working to help America become cleaner, safer, more energy secure, and economically vibrant.

In summary, RFA is pleased that the EPA maintained the statutory implied volume requirement of 15 billion gallons for conventional renewable fuels in 2018. In doing so, the Agency has sent a positive signal to the marketplace to continue the infrastructure investments necessary to grow the renewable fuel marketplace and expand the availability of gasoline blends containing more than 10 percent ethanol.

EPA correctly chose to exercise *only* its cellulosic waiver authority to reduce the cellulosic biofuel, advanced biofuel, and total renewable fuel required volumes from their statutory levels; the Agency properly avoided attempts to apply a general waiver. Indeed, the conditions that would allow EPA to use its general waiver authority are clearly absent from the marketplace. The proposal does not find that there is an "inadequate domestic supply" of conventional renewable fuel to meet the standards, nor could it. Similarly, EPA does not find that implementation of the RFS in 2018 would cause "severe harm" to the economy or environment; such a finding would not be possible.

Still, we are concerned that EPA's assessment of "reasonably attainable" renewable fuel levels in 2018 continues to inappropriately rely on demand-side factors, which is clearly barred by

the recent decision by the U.S. Court of Appeals for the District of Columbia. We encourage the Agency to adopt the intended approach of simply evaluating the physical supply of renewable fuels (and RINs) available to obligated refiners, blenders and importers relative to the statutory volume requirements.

Moreover, while RFA strongly agrees with EPA that a central policy objective of the RFS is to enhance domestic energy security by reducing fossil fuel consumption, we see no statutory basis for attempting to limit biofuel imports through the use of a general waiver. However, we do believe there are steps the Agency can take to remove unjustified incentives for ethanol imports and we encourage a careful review of our recommendations in that regard.

Additionally, we are concerned by the new methodology adopted by EPA to assess the availability of cellulosic biofuels, and we believe the Agency has erred by creating a backward-facing approach that will unnecessarily discourage investment in these emerging technologies. The RFS was intended to be a forward-looking, market-driving policy that would incentivize the commercialization of new technologies. Unfortunately, the proposed rule's cellulosic biofuel approach takes an inexplicable step away from that policy objective with very real marketplace implications. RFA urges EPA to return to the cellulosic biofuel projection methodology utilized in previous rulemakings (and early drafts of the 2018 proposal). We also recommend that EPA take a number of administrative actions to remove unnecessary regulatory barriers to increased production of cellulosic biofuels.

In closing, we strongly recommend that EPA finalize the RVO levels that were included in the initial draft proposal sent to the White House Office of Management and Budget for review in May 2017: **384 million gallons of cellulosic biofuel; 4.38 billion gallons of advanced biofuel; and 19.38 billion gallons of total renewable fuel.**

More detail on each of these issues and recommendations is provided in the attached comments. Thank you for the opportunity to comment on EPA's proposed rule for 2018 RVOs. We encourage the Agency to finalize this rule in time to meet the statutory deadline of November 30th, 2017.

Sincerely,

A handwritten signature in black ink, appearing to read "Bob Dinneen", with a long horizontal flourish extending to the right.

Bob Dinneen
President & CEO

COMMENTS OF THE
RENEWABLE FUELS ASSOCIATION (RFA)

IN REGARD TO

*RENEWABLE FUEL STANDARD PROGRAM: STANDARDS FOR 2018 AND BIOMASS-BASED DIESEL
VOLUME FOR 2019*, PROPOSED RULE

DOCKET ID No. EPA-HQ-OAR-2017-0091

82 FED. REG. 34,206 (JULY 21, 2017)

I. EXECUTIVE SUMMARY

The Renewable Fuels Association (RFA) submits these comments in response to the U.S. Environmental Protection Agency's (EPA) proposed rule for 2018 renewable volume obligations (RVOs) under the Clean Air Act's (CAA) Renewable Fuel Standard (RFS). EPA, *Renewable Fuel Standard Program: Standards for 2018 and Biomass-Based Diesel Volume for 2019*; Proposed Rule (82 Fed. Reg. 34,206; July 21, 2017).

RFA supports EPA's proposal to maintain the statutory implied volume requirement of 15 billion gallons for conventional renewable fuels in 2018. We believe EPA correctly chose to exercise only its cellulosic waiver authority to reduce the cellulosic biofuel, advanced biofuel, and total renewable fuel required volumes from their statutory levels.

In light of the recent decision by the U.S. Court of Appeals for the D.C. Circuit, EPA properly avoided attempts to apply the general waiver authority to reduce required volumes. Clearly, the conditions necessary to effectuate a general waiver are absent from the marketplace and no evidence has been provided to support the use of a general waiver on the basis of "inadequate domestic supply" or "severe harm." However, we are concerned that EPA's proposal continues to inappropriately consider demand-side factors in estimating "reasonably attainable"¹ levels of renewable fuel consumption.

Further, RFA believes EPA's proposed cellulosic biofuel RVO is based on a flawed methodology that fails to take a "neutral aim at accuracy." The Agency's proposed approach to assessing available supplies of cellulosic biofuels pessimistically assumes new and emerging cellulosic biofuel facilities and technologies—including cellulosic ethanol from corn kernel fiber—will not produce any material volume in 2018. This backward-looking methodology ignores marketplace realities and turns the market-driving purpose of the RFS on its head. EPA should abandon its proposed approach for projecting likely volumes of cellulosic biofuel and return to the methodology used for the 2016 and 2017 RVO rules (and early drafts of the 2018 RVO proposed rule). The

¹ "Reasonably attainable" is terminology EPA uses repeatedly throughout the proposal to describe levels of renewable fuel consumption that the Agency feels are achievable in light of perceived constraints on distribution and use.

Agency should also take additional administrative actions to remove unnecessary regulatory barriers that are impeding growth in cellulosic biofuel production.

Finally, we do not believe EPA’s general waiver authority was intended to address biofuel trade issues and we see no statutory basis for attempting to use a general waiver to limit biofuel imports. However, there are steps EPA can take to remove unjustified incentives for ethanol imports and level the playing field for domestic and imported biofuels.

In summary, RFA strongly recommends that EPA finalize the RVO levels that were included in early drafts of the 2018 proposed rule submitted to the White House Office of Management and Budget, as shown in Figure 1 below. Restoring the 2018 RVOs to these levels would support Congressional intent by returning the RFS program to a growth trajectory and driving continued investment in the biofuel sector.

Figure 1. Recommended Final Standards for 2018 RFS (Figures in Billions)

	Physical Gallons	Ethanol-equivalent Gallons (RINs)
Cellulosic Biofuel	0.384	0.384
Biomass-based Diesel	2.10	3.15
Advanced Biofuel	4.38	4.38
Renewable Fuel	19.38	19.38

These issues and others are discussed more fully in the comments that follow.

II. EPA’S PROPOSED RULE PROPERLY AVOIDS THE ILLEGAL MISAPPLICATION OF THE GENERAL WAIVER AUTHORITY

Although EPA proposes to use its cellulosic waiver authority to reduce the 2018 RVOs for cellulosic biofuel, advanced biofuel, and total renewable fuel from their statutory levels, the Agency states that “[w]e do not propose...to use the general waiver authority to further reduce the total renewable fuel volume requirement due to a finding of inadequate domestic supply.”² As a result, the implied volume requirement for conventional renewable fuels is 15 billion gallons—the level “...envisioned by Congress for 2018.”³

RFA strongly supports EPA’s proposal to use only its cellulosic waiver authority in establishing the 2018 RVOs, as the conditions necessary to effectuate a general waiver are clearly absent from the marketplace. EPA does not find that there is an “inadequate domestic supply” of renewable fuel to meet the standards, nor could it. Similarly, EPA’s proposal does not find that implementation of the proposed 2018 RVOs would cause “severe harm” to the economy or environment of a state, a region, or the United States. Such a finding would not be possible.

² 82 Fed. Reg. 34210

³ 82 Fed. Reg. 34213

However, as described below, we believe EPA’s assessment of “reasonably attainable” levels of renewable fuel continues to impermissibly consider consumption and other demand-side factors.

a. In *Americans for Clean Energy, et al. v. the Environmental Protection Agency*, the U.S. Court of Appeals for the D.C. Circuit established that EPA may not consider demand-side factors in determining whether the supply of renewable fuels is adequate to meet statutory volume requirements

As established in a recent decision by the U.S. Court of Appeals for the D.C. Circuit (“the Court”), the “inadequate domestic supply” provision associated with the general waiver “...does not allow EPA to consider the volume of renewable fuel that is available to ultimate *consumers* or the *demand-side* constraints that affect the consumption of renewable fuel by consumers.”⁴ Rather, the Court held that “...the term ‘inadequate domestic supply’ refers to the supply of renewable fuel available to refiners, blenders, and importers to meet the statutory volume requirements.”⁵

While EPA did not propose to use the general waiver to further reduce 2018 RVOs on the basis of “inadequate domestic supply,” it requests comment on “...whether it is appropriate to exercise the general waiver authority...” in determining the final 2018 RVOs.⁶ Further, the Agency clearly continued to consider demand-side factors and supposed constraints on distribution in subjectively determining “reasonably attainable” volumes of renewable fuel consumption in 2018.

In light of the recent Court decision, EPA’s concept of estimating “reasonably attainable” volumes of *consumption* is improper and violates the statutory intent of the program. The Court determined that “...Congress adopted a ‘market forcing policy’ intended to ‘overcome constraints in the market’ by creating ‘demand pressure to increase consumption’ of renewable fuels.”⁷ In other words, if the physical supply of renewable fuels is adequate to meet the statutory volume requirements, obligated parties are required by law to obtain the mandated volume of renewable fuel. Even though EPA did not propose to use the general waiver authority to reduce the RVOs on the basis of “inadequate domestic supply,” its “reasonably attainable” consumption concept reinforces the Agency’s mistaken notion that demand-side factors may be considered in the annual RVO rulemaking process.

Following the Court’s ruling, we strongly encourage EPA to abandon its “reasonably attainable” approach to determining appropriate RVO levels, and adopt the intended approach of simply evaluating the physical supply of renewable fuels available to obligated refiners, blenders and importers relative to the statutory volume requirements.

i. The so-called E10 “blend wall” and related factors are not appropriate considerations for determining whether the supply of renewable fuel is adequate to meet statutory volume requirements

⁴ *Americans for Clean Energy, et al. v. the Environmental Protection Agency*, U.S. Court of Appeals for the D.C. Circuit. No. 16-1005 (July 28, 2017), at 4.

⁵ *Id.*, at 17.

⁶ 82 Fed. Reg. 34213

⁷ *Americans for Clean Energy, et al. v. the Environmental Protection Agency*, D.C. Circuit. No. 16-1005 (July 28, 2017), at 31 (citing 80 Fed. Reg. at 77,423; *Monroe Energy*, 750 F.3d at 917).

EPA rightly acknowledges that “[e]thanol supply is not currently limited by production and import capacity, which is in excess of 15 billion gallons.”⁸ The Agency’s analysis of the adequacy of supply should end there. However, EPA continues to incorrectly suggest that the *supply* of ethanol available to obligated parties is somehow limited by “the E10 blendwall”; the “number of retail stations that offer higher ethanol blends such as E15 and E85”; the “number of vehicles that can...consume E15 and/or E85”; the “[r]elative pricing of E15 and E85 versus E10”; and the “ability of RINs to affect this relative pricing.”⁹

The recent Court decision holds that these factors are not relevant considerations in determining whether the physical supply of renewable fuel is adequate to meet the statutory volume requirements. The Court states, “Whether consumers have an adequate supply of renewable fuel to fill their cars is not relevant to whether refiners, blenders, and importers have an adequate supply of renewable fuel to meet the statutory volume requirements.”¹⁰ Similarly, the Court holds that “constraints on the infrastructure needed to distribute fuel”; “the number of retail outlets that offer renewable fuel blends”; “pricing of renewable fuel”; and “marketing efforts of those promoting renewable fuel products” are “*prohibited factors*” in considering whether the supply of renewable fuel is adequate to meet statutory requirements.¹¹

ii. E0 demand is not an appropriate consideration for determining whether the supply of renewable fuel is adequate to meet statutory volume requirements

Similarly, “the supply of gasoline without ethanol (E0)”¹² is not a relevant factor in considering whether the supply of renewable fuel is adequate to meet the statutory volume requirement. As part of its assessment of “reasonably attainable” renewable fuel consumption levels in 2018, EPA assumes demand for E0 will be approximately 500 million gallons, effectively reducing the pool of gasoline into which ethanol may be blended.¹³ While we agree that E0 will remain available in the marketplace as long as there is demand for it, the likely volume of E0 demand is irrelevant in the context of determining whether the physical supply of ethanol and other renewable fuels is sufficient to meet the required statutory volumes.

b. The domestic supply of conventional renewable fuel is more than adequate to meet the 2018 required volume prescribed by the statute

As underscored by the recent Court decision, an evaluation of the physical quantity of renewable fuel that is available to obligated refiners, blenders and importers is the *only* relevant factor in determining whether the supply of renewable fuel is adequate to meet the required statutory volumes. Indeed, the Court holds that “...‘supply’ as used in the ‘inadequate domestic supply’

⁸ 82 Fed. Reg. 34230

⁹ *Id.*

¹⁰ *Americans for Clean Energy, et al. v. the Environmental Protection Agency*, D.C. Circuit. No. 16-1005 (July 28, 2017), at 27.

¹¹ *Id.*, at 29.

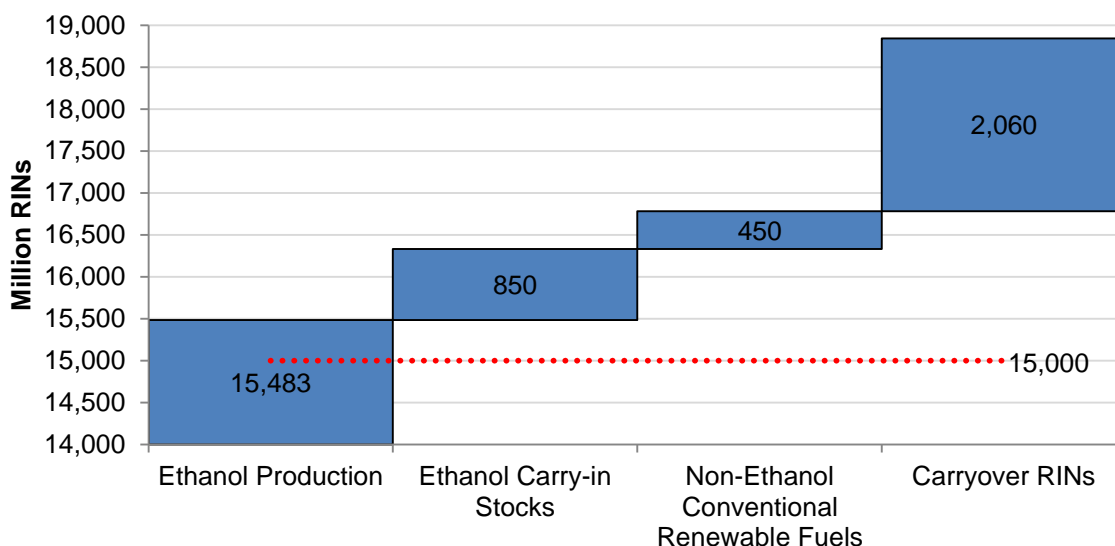
¹² 82 Fed. Reg. 34230

¹³ 82 Fed. Reg. 34231

provision refers to the ‘amount’ of renewable fuel that is ‘available for use’ by refiners, blenders, and importers in meeting the statutory volume requirements.”¹⁴

In this context, it is inarguable that the supply of conventional renewable fuel is more than adequate to meet the statutory 15-billion-gallon volume requirement in 2018. According to the U.S. Energy Information Administration (EIA), U.S. fuel ethanol production totaled 15.3 billion gallons in 2016 and is projected to reach 15.7 billion gallons in 2017 and 15.5 billion gallons in 2018.¹⁵ Further, the U.S. ethanol industry has the nameplate capacity to produce more than 16 billion gallons annually.¹⁶ Additionally, ethanol carry-in stocks have averaged approximately 850 million gallons in recent years.¹⁷

Figure 2. Supply Available to Meet 2018 Conventional Renewable Fuel Requirement



Moreover, 279 million gallons of non-ethanol conventional renewable fuels (i.e., primarily biodiesel and renewable diesel) accounted for the generation of 451 million conventional renewable fuel (D6) RINs in 2016, further adding to the supply available to meet the conventional renewable fuel volume requirement.¹⁸ The contribution of non-ethanol conventional renewable fuels was nearly identical in 2015, with 275 million gallons resulting in 452 million D6 RINs.

¹⁴ *Americans for Clean Energy, et al. v. the Environmental Protection Agency*, D.C. Circuit. No. 16-1005 (July 28, 2017), at 30.

¹⁵ U.S. Energy Information Administration. “Short-Term Energy Outlook,” Aug. 2017.

¹⁶ Renewable Fuels Association. “Biorefinery Locations,” accessed Aug. 29, 2017.

<http://www.ethanolrfa.org/resources/biorefinery-locations/>. We estimate that approximately 99% of the ethanol produced in the United States is conventional renewable fuel.

¹⁷ U.S. Energy Information Administration. “U.S. Ending Stocks of Fuel Ethanol,” accessed Aug. 29, 2017.

<https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MFESTUS1&f=A>

¹⁸ U.S. Environmental Protection Agency. “Public Data for the Renewable Fuel Standard,” accessed Aug. 28, 2017.

<https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard>

Finally, there are some 2.06 billion surplus carryover RINs available that may be used to demonstrate compliance with RVO requirements.¹⁹ Some of these carryover RINs may be retired to comply with 2017 RVOs, but many will remain available for compliance with the 2018 RVOs. In total, the supply available to obligated parties to meet the 2018 conventional renewable fuel RVO is expected to be nearly 19 billion RINs (Figure 2). Even though EPA has decided to ignore surplus carryover RINs in determinations of available supply, there is no question that surplus RINs are available to obligated parties for compliance. It would be inappropriate to exclude them here in our assessment of the supply available to obligated parties to meet 2018 RVOs.

In short, it is beyond dispute that the supply of conventional renewable fuel (and carryover RINs) available to obligated parties is more than adequate to meet the 2018 proposed volume requirement of 15 billion gallons. This is the only permissible consideration for EPA when determining the appropriate conventional renewable fuel volume requirement.

c. There is no basis whatsoever for finding that implementation of the proposed 2018 RVOs would cause severe harm to the economy or environment of a state, a region, or the United States

Aside from “inadequate domestic supply,” the only other statutory basis for granting a general waiver is a finding that implementation of the required RFS volumes would result in “severe harm” to the economy or environment of a state, a region or the United States. Such a proposed finding and grant by EPA—which would require separate public notice and comment²⁰—is not possible given current market dynamics and the high standard of proof established by Congress (and reinforced by EPA in previous denials of “severe harm” waiver requests).²¹

Still, EPA’s proposal states, “...in prior annual RFS rulemaking actions, some stakeholders have commented to EPA that the Agency should exercise its discretion to use the general waiver authority to reduce volumes to avoid severe harm to the economy or environment of a state, region, or the United States.”²² Thus, the Agency “...invites comment and data on these issues...that would support different use of the waiver authorities than we are proposing in today’s action, such as use of the general waiver authority to achieve greater reductions than proposed.”²³

There is absolutely no basis for a finding by EPA that the 2018 required volumes of renewable fuel, as proposed, would somehow cause “severe harm” to the economy or environment. Congress established—and EPA has correctly reinforced—a narrow and rigid standard for proving required volumes under the RFS will cause “severe harm.” In denying a waiver request from the Governor of the State of Texas in 2008, EPA properly interpreted the statute’s general waiver provisions to require petitioners to prove that the source of “severe harm” is the “...RFS program

¹⁹ 82 Fed. Reg. 34213

²⁰ 73 Fed. Reg. 47183 (“EPA *will not* grant a waiver *without such notice and comment...*”)

²¹ See 73 Fed. Reg. 47168 (Aug. 13, 2008); and 77 Fed. Reg. 70752 (Nov. 27, 2012)

²² 82 Fed. Reg. 34229

²³ *Id.*

itself...”, not other precipitating or related factors.²⁴ The EPA notice denying the Texas waiver request also established “...a high threshold for the nature and degree of harm by requiring a determination of *severe* harm.”²⁵ In recognition of the plain meaning of the statute, EPA further established that petitioners must demonstrate that the “*economy* of a state, a region, or the United States”—not a narrow sub-sector or specific industry—will be severely harmed. Using the same criteria that guided the denial of the 2008 waiver request, EPA subsequently denied general waiver requests claiming “severe harm” in 2012 and 2014.²⁶

Given the unambiguous meaning of the statutory “severe harm” provisions, and in light of EPA’s straightforward interpretation of those provisions in previous waiver request denials, it would be irrational for commenters to claim that the 2018 proposed RVOs would somehow cause severe harm to the economy or environment in 2018. No evidence of “severe harm” resulting from RFS implementation has been presented to the EPA because such evidence does not exist.

i. The RFS Significantly Benefits the U.S. Economy

Far from harming the economy or environment, the RFS is providing substantial economic and environmental benefits to American consumers. It is absurd to suggest that the RFS and ethanol are somehow harming the economy when ethanol is priced below gasoline and remains the lowest-cost source of octane available on the market (in early trading on Aug. 31, 2017, nearby ethanol futures prices were \$0.53 per gallon, or 25 percent, below nearby gasoline blendstock futures).²⁷

Many of RFS program’s macro-level benefits to the economy were documented in an economic modeling study soon to be published in *American Journal of Agricultural Economics (AJAE)* (Attachment A).²⁸ According to the study, “...the current RFS program considerably benefits the agriculture sector, but also leads to overall welfare gains for the United States.” In 2015, the welfare gain resulting from the RFS included a \$17.8 billion savings on gasoline expenses, a 200-million-barrel reduction in crude oil imports, and \$14.1 billion in value added to the agriculture sector.

EPA notes that “...some commenters suggested that standards that would result in ethanol use beyond the blendwall would cause severe economic harm.”²⁹ However, the *AJAE* study found that ethanol use beyond the so-called “blend wall” would further enhance the economic benefits of the RFS, rather than contribute to economic harm as suggested by some entities who petitioned EPA for a general waiver in the past. In any case, data from U.S. EIA show that ethanol consumption already breached the supposed “blend wall” nationwide in 2016 (see Attachment B).³⁰

²⁴ 73 Fed. Reg. 47169 (emphasis added)

²⁵ *Id.* (emphasis added)

²⁶ See, 77 Fed. Reg. 70752 (Nov. 27, 2012); and 80 Fed. Reg. 77428

²⁷ CME Group. RBOB Gasoline and Ethanol Futures Quotes. Aug. 31, 2017.

²⁸ G. Moschini, H. Lapan, and H. Kim. “The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects.” Center for Agricultural and Rural Development, Iowa State University. Working Paper 17-WP 575 (June 2017).

²⁹ 82 Fed. Reg. 34229

³⁰ Renewable Fuels Association. “Ethanol Consumption Breaks Through the ‘Blend Wall’ in 2016.” April 2017. http://www.ethanolrfa.org/wp-content/uploads/2017/04/RFA_Blend-Wall-Analysis.pdf

Simply put, there is no rational basis for assertions that the proposed 2018 RVOs would severely harm the economy or environment. EPA should reject out of hand any claims that the RFS is causing severe harm and deny any petitions requesting the use of the general waiver authority.

d. EPA’s proposal to apply the full amount of the cellulosic biofuel waiver to both the advanced biofuel standard and total renewable fuel standard is appropriate and consistent with statutory authorities

As allowed by the statute, EPA proposes to apply the full amount of the cellulosic biofuel waiver to both the advanced biofuel standard and total renewable fuel standard. In past annual RVO rulemakings, EPA has reduced the advanced biofuel standard and total renewable fuel standard by an amount less than the cellulosic biofuel waiver, effectively allowing increased volumes of non-cellulosic biofuels to “backfill” some portion of the shortfall in cellulosic biofuel. While allowing the “backfill” in previous annual RVO rules might have been warranted, in light of expected supplies of advanced biofuel in 2018, we believe EPA is justified in applying the full amount of the cellulosic biofuel waiver to both the 2018 advanced biofuel standard and total renewable fuel standard. This position is notwithstanding our belief that EPA should increase the cellulosic biofuel RVO above the level proposed, which is the subject of the next section of these comments.

III. EPA’S PROPOSED CELLULOSIC BIOFUEL RVO IS BASED ON A FLAWED METHODOLOGY FOR ASSESSING AVAILABLE SUPPLY THAT DOES NOT REPRESENT A “NEUTRAL AIM AT ACCURACY”

The proposed rule states that EPA is using the “same methodology” it used in previous RVO rulemakings to project the range of potential cellulosic biofuel volumes that may be produced by each facility in 2018. In reality, however, there is a fundamental difference in the methodology used by EPA in the 2018 proposal; EPA uses much lower percentile values for selecting a point estimate from within the range of projected cellulosic biofuel production. By adjusting the percentile values, EPA negatively biases the 2018 cellulosic biofuel RVO and effectively assumes that cellulosic biofuel producers that didn’t produce commercial volumes in 2016 will not produce commercial volumes in 2018. In other words, only those cellulosic biofuel facilities that produced commercial volumes in 2016 are assumed to produce meaningful commercial volumes in 2018. This backward-looking method for projecting cellulosic biofuel production not only ignores “bolt-on” cellulosic biofuel technologies that are being rapidly adopted in the marketplace today, but it also turns the market-driving intent of the RFS on its head.

Further, EPA has previously rejected recommendations from stakeholders that the cellulosic biofuel RVO be limited to actual production from the previous year, noting that such an approach would “...not...be consistent with EPA’s charge to adopt a neutral methodology.”³¹ Yet, the 2018 proposal adopts that very approach. By effectively ignoring volumes that will be produced by facilities that did not have cellulosic biofuel production in 2016, EPA’s proposed methodology fails

³¹ U.S. Environmental Protection Agency. “Renewable Fuel Standards for 2014,2015 and 2016, and the Biomass-Based Volume for 2017: Response to Comments” (Nov. 2015), at 571 (“...it is not appropriate to project future production from a new industry based exclusively on historic production data, nor would it be consistent with EPA’s charge to adopt a neutral methodology.”)

to “take neutral aim at accuracy” or “predict[]...what will *actually* happen.”³² Granted, projecting actual volumes of cellulosic biofuel production is a difficult task. But in the current proposal, EPA attempts to sidestep this task entirely by adopting an oversimplified assumption that producers without consistent production in 2016 will not produce any measurable cellulosic biofuel.

EPA’s proposed cellulosic biofuel projection for 2018 is as much of an “aspiration for a self-fulfilling prophecy”³³ as the Agency’s 2012 cellulosic biofuel RVO, which was ultimately vacated by the Court and remanded to EPA for being too ambitious. Only this time, the self-fulfilling prophecy advanced by EPA is that facilities that didn’t produce liquid cellulosic biofuel in 2016 will never produce liquid cellulosic biofuel. In the absence of a strong and growing cellulosic biofuel RVO, this unfortunate self-fulfilling prophecy would be realized and further investment in cellulosic biofuels would not materialize.

As described more fully below, we believe EPA must return to using the methodology and percentiles it has used in recent annual RVO rulemakings (and in the first draft version of the 2018 proposal submitted for interagency review).³⁴ This would better reflect a neutral aim at accuracy and support the statutory goals of the RFS program.

a. Actual and projected liquid cellulosic biofuel production in 2016 is not an appropriate basis for projecting likely supplies of cellulosic biofuels in 2018

For the purposes of projecting 2018 liquid cellulosic biofuel volumes, EPA proposes to replace the percentile values used in previous RVO rulemakings with percentile values based on actual production in 2016 relative to EPA’s initial high-end projection for 2016 production. This leads EPA to conclude that new facilities without prior consistent production will produce an amount of liquid cellulosic biofuels equivalent to just 1 percent of their production capacity. In effect, this means EPA assumes these new facilities, which have the combined capacity to produce 105 million gallons of liquid cellulosic biofuels, will not produce any biofuel in 2018. Meanwhile, based on actual 2016 production relative to projected production, facilities with prior “consistent commercial-scale production” are assumed to produce an amount of fuel equivalent to 43 percent of their aggregated capacity in 2018.

The methodology proposed by EPA for projecting liquid cellulosic biofuel production volumes in 2018 is inappropriate for several reasons. First, the adjusted percentiles are arbitrary in that they rely on information from a single year (2016) that is not indicative of likely liquid cellulosic biofuel capacity utilization in the future. Certain unique market and regulatory conditions that existed in 2016 (e.g., oil prices hit a 13-year low, ethanol prices were depressed, there was a sizeable surplus of D3 RINs carried in from 2015, etc.) served as constraints on cellulosic biofuel capacity

³² *American Petroleum Institute v. U.S. Environmental Protection Agency*, U.S. Court of Appeals for the D.C. Circuit. No. 12-1139 (January 25, 2013), at 4 and 10.

³³ *American Petroleum Institute v. U.S. Environmental Protection Agency*, D.C. Circuit. No. 12-1139 (January 25, 2013), at 10.

³⁴ U.S. Environmental Protection Agency. “EO12866 RFS 2018 Annual Proposed Rule 2060-AT04 NPRM FRN 20170510.” Docket folder EPA-HQ-OAR-2017-0091-0110 (Table I-1 on page 6 shows a proposed cellulosic biofuel volume of 384 million gallons).

utilization. These conditions were not present in previous years and should not be expected to be present in 2018 and beyond.

Second, the nature of emerging cellulosic biofuel technology and the universe of cellulosic biofuel facilities is much different today than in 2016, meaning it is incorrect to use 2016 as the basis for percentile values that will be applied to 2018 production capacity. Specifically, EPA's 2016 projections focused on a handful of larger, stand-alone facilities designed to exclusively produce cellulosic biofuel. In 2017 and 2018, however, the majority of new and imminent liquid cellulosic biofuel capacity is in the form of "bolt on" technologies and processes that are being added to existing corn starch ethanol facilities. Not surprisingly, there is much greater uncertainty surrounding the likely production volumes from larger, stand-alone facilities than there is from lower-cost "bolt on" corn kernel fiber conversion technologies that are supplementing current starch-based capacity. These new technologies, which can be rapidly integrated into existing facilities, are simply converting cellulosic material that already passes through the process into biofuel. Thus, there is a much higher degree of certainty that these facilities will in fact produce commercial volumes of cellulosic biofuel once the technology is installed. It is totally unreasonable, for instance, to suggest that the 80 million gallons of new Edeniq capacity that EPA expects to be available in 2018 will produce just 0.8 million gallons of cellulosic biofuel.

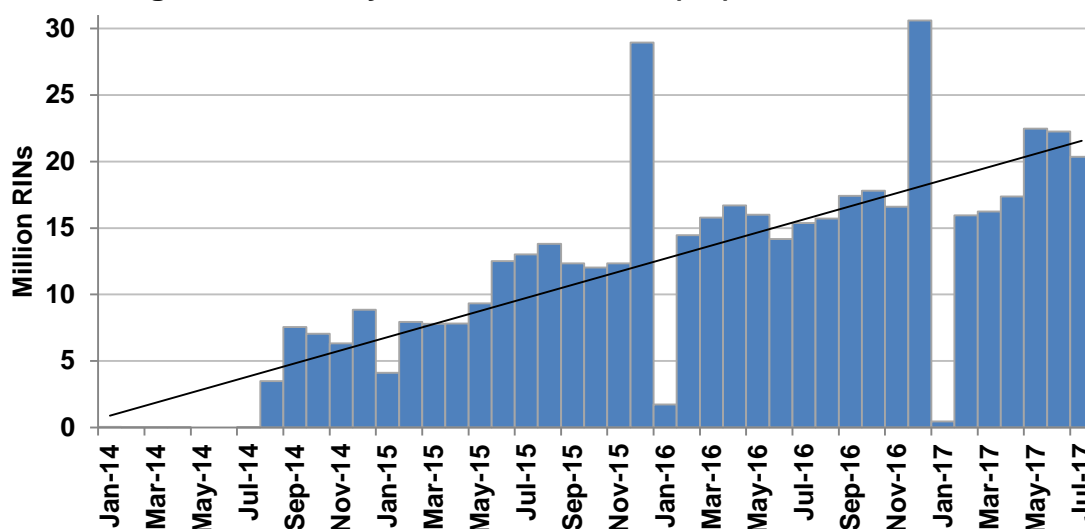
In early drafts of the 2018 RVO proposal, EPA appeared to recognize that the emergence of cellulosic biofuel production from corn kernel fiber would make a significant contribution to the RFS, stating, "In 2018, we anticipate that the majority of the liquid cellulosic biofuel production will be from facilities converting corn kernel fiber to cellulosic ethanol at existing ethanol production facilities."³⁵ The Agency further acknowledged that the relative certainty of corn kernel fiber cellulosic ethanol volumes meant the methodology and percentiles used for the 2016 and 2017 RVOs should be maintained for the purposes of establishing the 2018 cellulosic biofuel RVO. According to EPA, "We...believe it is prudent to continue to use our existing projection methodology rather than to adopt a new methodology that would result in lower production estimates as doing so could result in inappropriately low production projections for a commercially successful technology (corn kernel fiber conversion) based on historic scale-up difficulties at facilities using a largely unrelated technology."³⁶ RFA agrees with this synopsis by EPA. We note, however, that this language was deleted from subsequent drafts of the proposed rule and does not appear in the official proposal that was released for public comment.

Third, EPA's methodology for proposing the 2018 cellulosic biofuel RVO ignores historical growth rates in cellulosic biofuel production. The proposal assumes cellulosic biofuel output will *decrease* in 2018, when all available data and information show steady growth in the production of both liquid and non-liquid cellulosic biofuels since 2014 (Figure 3).

³⁵ *Id.*, at 28.

³⁶ *Id.*

Figure 3. Monthly Cellulosic Biofuel (D3) RIN Generation



Fourth, by using 2016 as the basis for projecting what will happen in 2018, EPA’s proposed methodology ignores recent developments in the cellulosic biofuel (D3) RIN market that are providing strong incentives for increased cellulosic biofuel production. According to daily price data from the Oil Price Information Service, 2016 vintage D3 RIN prices averaged \$1.87 during calendar year 2016. So far this year, 2017 vintage D3 RIN prices are averaging \$2.69 and recently hit a record high of \$3.06. These values are providing a strong incentive to the marketplace to increase cellulosic biofuel production, and liquid biofuel production in particular is responding to this signal. Generation of D3 RINs for liquid cellulosic biofuels between January and July 2017 (4.34 million) has already significantly surpassed D3 RIN generation for liquid cellulosic biofuels for the entire 2016 calendar year (3.81 million).³⁷ EPA’s projection for 2018 cellulosic biofuel volumes should take into account the stronger incentive for increased production that exists in the market today and is expected to exist in 2018.

b. EPA should abandon the proposed percentiles for assessing likely supplies of cellulosic biofuel in 2018, and return to percentiles that better reflect a “neutral aim at accuracy” and account for continuation of demonstrated growth in cellulosic biofuels

As discussed above, it is inappropriate to use 2016 actual and projected cellulosic biofuel production as the basis for developing percentile values that will apply to 2018 cellulosic biofuel projections. We encourage EPA to abandon the proposed percentile values and return to the percentile values used in establishing the 2016 and 2017 final cellulosic RVOs (i.e., 25th percentile for new facilities without prior consistent commercial-scale production and 50th percentile for facilities with prior consistent commercial-scale production). Maintaining the percentile values used for the 2016 and 2017 rulemakings would better reflect a “neutral aim at accuracy.” Indeed, the term

³⁷ U.S. Environmental Protection Agency. “Public Data for the Renewable Fuel Standard,” accessed Aug. 28, 2017. <https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard>

“neutral” means “impartial” or “unbiased,” and neutrality suggests selecting a percentile that is somewhere near the midpoint between low-end and high-end projections. EPA’s assumption that newer facilities without consistent cellulosic biofuel production in 2016 will not produce cellulosic biofuel in 2018 could hardly be viewed as “neutral.” Further, restoring the previous percentile values would result in a cellulosic biofuel RVO that better reflects historical growth trends and takes into account the incentives for increased production resulting from evolution of the D3 RIN market.

We note that EPA itself initially retained the previously used percentile values in early versions of the 2018 proposed rule that was sent to the White House Office of Management and Budget for interagency review.³⁸ Accordingly, early drafts of the proposed rule included a 2018 cellulosic biofuel RVO of 384 million gallons, a reasonable volume that represented a modest increase over the final 2017 cellulosic biofuel RVO.

In an internal analysis of the accuracy of 2015 and 2016 cellulosic biofuel projections, EPA found that it under-estimated actual production in 2015 and over-estimated actual production in 2016. EPA concluded that “...the methodology overall has resulted in reasonably accurate projections in these years and is *appropriate for use in 2018*.”³⁹ Further, EPA’s analysis stated “...we do not believe there is sufficient information to suggest that a change in our cellulosic biofuel production methodology is warranted.”⁴⁰ Yet, without explanation, later drafts of the proposed rule (and the version that was ultimately released for public comment) went against the EPA staff recommendation and adopted a new methodology that used unreasonable percentile values for selecting a point estimate from within the range of projected cellulosic biofuel production.

RFA strongly encourages EPA to abandon the proposed percentiles for assessing likely supplies of cellulosic biofuel in 2018, and return to the percentiles used for 2016 and 2017, which better reflect a “neutral aim at accuracy” and account for continuation of demonstrated growth in cellulosic biofuels. We recommend that EPA finalize the cellulosic RVO of 384 million gallons that it initially proposed in early drafts of the 2018 RVO proposed rule.

IV. ADDITIONAL ADMINISTRATIVE ACTIONS SHOULD BE TAKEN TO REMOVE UNNECESSARY BARRIERS TO GROWTH IN CELLULOSIC BIOFUEL PRODUCTION

EPA’s proposal points out that the “slower-than-expected development of the cellulosic biofuel industry” has hampered progress toward meeting the RFS cellulosic and advanced volumetric requirements envisioned by Congress.⁴¹ While a number of complex factors have created barriers to more rapid development of cellulosic biofuels, EPA’s handling of certain regulatory provisions has itself been an obstacle to increased cellulosic biofuel production. RFA continues to believe EPA can and should take the actions described below to remove unnecessary barriers to broader commercialization of cellulosic biofuels.

³⁸ U.S. Environmental Protection Agency. “EO12866 RFS 2018 Annual Proposed Rule 2060-AT04 NPRM FRN 20170510.” Docket folder EPA-HQ-OAR-2017-0091-0110.

³⁹ U.S. Environmental Protection Agency. “Assessment of the Accuracy of Cellulosic Biofuel Projections in 2015 and 2016 (May 2017 Update) 5.22.17.” Docket folder EPA-HQ-OAR-2017-0091-0110. (emphasis added)

⁴⁰ *Id.*

⁴¹ 82 Fed. Reg. 34207

a. EPA’s administration of the Cellulosic Waiver Credit program should be modified to better align with the goals of the statute

EPA is required by Clean Air Act section 211(o)(7)(D)(ii) to issue cellulosic waiver credits (CWCs) whenever it acts to waive any part of the RFS cellulosic biofuel volumetric standard pursuant to its authorities and obligations under section 211(o)(7)(D)(i). The purpose of the CWC is to allow obligated parties a means of complying with their cellulosic biofuel blending requirements even in the event that the actual physical availability of cellulosic biofuels and D3 RINs is lower than the standard finalized by EPA.

One of the key questions raised by stakeholders in recent years is how much authority EPA has to control the number of CWCs issued in any given year. While section 211(o)(7)(D)(iii) clearly specifies that the number of CWCs made available may not exceed the applicable volume of cellulosic biofuel (i.e., the cellulosic biofuel RVO for that calendar year), it clearly *does not* establish a minimum number of CWCs that must be made available by EPA. Congressional intent would suggest that EPA should only issue an amount of CWCs that would be equal to the difference between the final cellulosic biofuel standard and the amount of physical cellulosic biofuels and D3 RINs available to comply with the standard. In other words, the CWC was intended to narrowly serve as a means of offsetting any shortfall in the availability of cellulosic biofuels and D3 RINs to meet annual standards.

Unfortunately, EPA has interpreted the statute as allowing the Agency to issue an amount of CWCs that is “equal to” the cellulosic biofuel RVO for that year.⁴² Thus, EPA’s administration of the CWC program allows obligated parties to secure CWCs in lieu of securing available physical cellulosic biofuel gallons and/or D3 RINs. This potentially results in an oversupply of compliance instruments (D3 RINs and CWCs), which devalues physical cellulosic biofuel gallons and D3 RINs.

In essence, obligated parties are not truly required to secure physical gallons and/or D3 RINs and can instead comply with the cellulosic biofuel requirements by securing CWCs from EPA. For instance, the 2015 cellulosic biofuel RVO was 123 million gallons and actual D3 RIN generation was 142 million RINs.⁴³ This means D3 RIN generation was 15 percent greater than the annual D3 RIN requirement in 2015. Yet, even with an oversupply of D3 RINs to meet the 2015 cellulosic biofuel RVO, obligated parties chose to purchase 13 million CWCs rather than securing 13 million RINs to demonstrate compliance. “Stranding” D3 RINs in this way results in an artificially inflated supply of compliance instruments, devalues the RINs, and discourages investment in cellulosic biofuels.

⁴² See CFR §80.1456, accessed at 75 Fed. Reg. 14892. U.S. EPA states that “[t]he total cellulosic biofuel waiver credits available will be equal to the reduced cellulosic biofuel volume established by EPA for the compliance year.”

⁴³ U.S. Environmental Protection Agency. “Public Data for the Renewable Fuel Standard,” accessed Aug. 28, 2017. <https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard>

RFA and other stakeholders⁴⁴ have repeatedly raised this concern with EPA and proposed a simple solution: EPA should only issue an amount of CWCs annually that coincides with any shortfall in the availability of physical gallons of cellulosic biofuels and RINs to meet the final standards. For example, if the combination of actual production of cellulosic biofuel and available RINs exceeds the final cellulosic biofuel RVO in a given year (as it did in the 2015 example above), EPA should not issue any CWCs at all. Ensuring that the maximum volume of CWCs issued corresponds with the shortfall in physical gallons or RINs needed to meet the RVO would sharpen the incentive for obligated parties to secure offtake of actual cellulosic biofuel gallons, which is inarguably the purpose of the statute.

b. EPA should ensure that grain ethanol producers using Efficient Producer Pathways to generate D6 RINs are able to simultaneously generate D3 RINs for cellulosic ethanol derived in situ from corn kernel fiber

Roughly 40 percent of existing corn ethanol plants have applied for, and received EPA approval of, conventional renewable fuel (D6) RIN generation pathways for new or expanded ethanol production capacity (i.e., above “grandfathered” limits). Many of these facilities have utilized EPA’s Efficient Producer Pathway Petition (EP3) process, which was intended to reduce the administrative burden and reduce the wait time associated with applying for a new pathway.

RFA was recently made aware that several ethanol plants considering adoption of corn kernel fiber cellulosic ethanol technologies have been advised by EPA that they would not be able to use their approved EP3 pathway to generate D6 RINs while concurrently generating D3 RINs for corn fiber cellulosic ethanol produced in situ. This preclusion apparently stems from EPA’s rigid interpretation of the EP3 approval letters and the Agency’s belief that current lifecycle GHG accounting methods and verification practices are unable to appropriately allocate energy use and emissions to both ethanol streams (i.e., corn starch and in situ corn kernel fiber).

This decision by EPA is discouraging innovation in the biofuels industry and undermining investments in “bolt-on” technologies to expand cellulosic ethanol production. We strongly encourage EPA to rectify this situation as soon as possible so that ethanol plants can simultaneously generate D3 RINs for cellulosic ethanol and utilize EP3 pathways to generate D6 RINs. As we recommended in our comments responding to EPA’s solicitation for comments in response to Executive Order 13777, the simplest way to remedy this situation would be to revise EPA’s “baseline” lifecycle GHG analysis of corn ethanol.⁴⁵ This would make the EP3 program no longer necessary or relevant since an updated analysis would surely show *all* dry mill corn ethanol (e.g. whether grandfathered or not) reduces GHG emissions by far more than 20 percent relative to 2005-era petroleum.

⁴⁴ See memorandum from RFA and Advanced Biofuels Business Council. “Issuance of Cellulosic Biofuel Waiver Credits as part of the RFS.” Jan. 7, 2015. Submitted to Christopher Grundler, Director of EPA Office of Transportation and Air Quality, Jan. 16, 2015.

⁴⁵ Renewable Fuels Association. “Comments on Executive Order (EO) 13777, ‘Enforcing the Regulatory Reform Agenda.’ (EPA-HQ-OA-2017-0190; 82 Fed. Reg. 17793).” May 15, 2017. http://www.ethanolrfa.org/wp-content/uploads/2017/05/EO-13777-comments_RFA.pdf

c. The registration process and required RIN accounting methods for producers of cellulosic ethanol from corn kernel fiber should be streamlined and simplified

EPA's onerous registration requirements and the lack of clarity on acceptable methods for quantifying volumes of cellulosic biofuel from corn fiber versus non-cellulosic biofuel (i.e., starch) is creating an unnecessary barrier to broader adoption of cellulosic biofuel technologies.

The proposal's projection of 2018 cellulosic biofuel production excludes potential cellulosic biofuel output from companies that have not yet registered with the Agency. EPA notes that "none of these companies have successfully registered a facility to generate cellulosic RINs using their technology."⁴⁶ The Agency suggests that "[i]f the outstanding technical issues related to these processes are resolved prior to the final rule, EPA anticipates including production projections from these technologies in our projection of cellulosic biofuel production for 2018."⁴⁷

We strongly encourage EPA to simplify and streamline the process for registering corn kernel fiber pathways, much like the Agency did with its EP3 process for corn ethanol producers seeking D6 RIN generation for volumes above their grandfathered limits. Further, we believe the Agency should issue detailed guidance on acceptable methodologies for RIN generation and accounting when multiple feedstocks (i.e., corn starch and corn fiber) are processed simultaneously to generate multiple fuel types (i.e., conventional and cellulosic) and RIN D-codes.

V. A DESIRE TO LIMIT BIOFUEL IMPORTS DOES NOT JUSTIFY THE USE OF EPA'S GENERAL WAIVER AUTHORITY. HOWEVER, THE AGENCY CAN TAKE CERTAIN ACTIONS TO REMOVE UNJUSTIFIED INCENTIVES FOR ETHANOL IMPORTS

In the proposed rule, EPA notes that obligated parties have relied in part on imported biofuels to meet advanced biofuel and biomass-based diesel RVO requirements in recent years. The Agency states that a Congressional goal of the RFS is to "bolster energy security and independence," and asserts that "...imported renewable fuels may not have the same impact on energy independence as those produced domestically."⁴⁸ EPA then solicits comment "...on whether and to what degree these considerations could support the use of the general waiver authority, inherent authority or other basis consistent with general construction of authority in the statute to reduce the required volume of advanced biofuel (with a corresponding reduction to the total renewable fuel requirement) below the level proposed for 2018."⁴⁹

While RFA strongly agrees that a central policy objective of the RFS is to enhance domestic energy security by reducing fossil fuel consumption, we see no statutory basis for attempting to limit biofuel imports through the use of a general waiver. There is no preclusion in the Energy Independence and Security Act (EISA), or the resulting statute, on the use of imported renewable fuels to help meet the annual RFS volume requirements. It is also likely that using RFS waiver

⁴⁶ 82 Fed. Reg. 34216

⁴⁷ *Id.*

⁴⁸ 82 Fed. Reg. 34212

⁴⁹ *Id.*

authorities in an attempt to limit exports would be perceived as a non-tariff trade barrier, which could run afoul of U.S. obligations under World Trade Organization rules and/or standing trade agreements.

One could argue that the statute allows EPA to use a general waiver to reduce the advanced biofuel standard if the “domestic supply” of advanced biofuels is found to be inadequate to meet the volumetric requirements. However, a counterargument is that the “domestic supply” of advanced biofuel is the total quantity of advanced biofuel from all sources that is available in the United States for procurement by obligated parties; this total quantity could be comprised of both imported biofuel volumes as well as domestically produced biofuel volumes. In other words “domestic supply” does not equate to “domestic production.” Consider the following corollary: the U.S. Department of Agriculture includes corn imports from foreign sources in its estimate of the total U.S. corn supply available to users.⁵⁰

In any case, it is unlikely that using a general waiver to reduce the advanced biofuel standard would have the intended effect of limiting biofuel imports. Further, there are other avenues available to U.S. biofuel producers to pursue recourse of biofuel trade barriers and international market distortions. However, to the extent EPA is interested in taking action to remove unjustified incentives for certain biofuel imports, there are certain actions the Agency could take.

a. It is unlikely that reducing the advanced biofuel and total renewable fuel RVOs would significantly curtail biofuel imports

As EPA notes in the proposal, the overwhelming majority of biofuel imports in recent years have been in the form of biomass-based and renewable diesel. Ethanol imports, on the other hand, have been rare and accounted for less than 1 percent of U.S. ethanol consumption since 2014.⁵¹

In the case of biomass-based and renewable diesel, imports are often available to obligated parties at a lower cost than some sources of U.S.-produced product (likely due to subsidization of biodiesel and renewable diesel production by certain exporting nations). Thus, reducing the biomass-based diesel and/or advanced biofuel standard likely would have the effect of shutting marginal (i.e., higher-cost) U.S.-made product out of the marketplace, rather than curtailing imports. In this way, reducing the biomass-based diesel and/or advanced biofuel standard may have the perverse effect of actually *increasing* the share of U.S. advanced biofuel consumption that is comprised by imports.

b. Other means are available to the U.S. biofuel industry for resolving trade distortions and are likely more effective than reducing RVOs

RFA does not believe Congress intended for EPA to use its RFS waiver authorities as a tool for influencing global biofuels trade or remedying distortions in the international marketplace. A number of avenues outside of the RFS are available to U.S. biofuel producers to pursue recourse of biofuel trade barriers and international market distortions. For example, as referenced in EPA’s proposal, the U.S. Department of Commerce is pursuing countervailing and antidumping duties

⁵⁰ U.S. Department of Agriculture. “World Agricultural Supply and Demand Estimates.” August 10, 2017, at 12.

⁵¹ Renewable Fuels Association. “2016 U.S. Ethanol Exports and Imports: Statistical Summary.” February 2017. <http://www.ethanolrfa.org/wp-content/uploads/2017/02/2016-US-Ethanol-Trade-Statistics-Summary.pdf>

against biodiesel imported from Argentina and Indonesia. This type of remedy is a more direct and effective approach for addressing trade distortions than attempting to limit biofuel imports through the use of a general waiver.

c. EPA’s lifecycle greenhouse gas analysis of Brazilian sugarcane ethanol incorrectly assumes *all* sugarcane ethanol meets the 50 percent GHG reduction threshold required of advanced biofuels, resulting in an unjustified incentive for ethanol imports. The Agency should revise its lifecycle analysis.

EPA treats *all* imported sugarcane ethanol as an advanced biofuel, meaning those imports generate more valuable advanced biofuel (D5) RINs. Sugarcane ethanol’s status as an advanced biofuel and its ability to generate more lucrative D5 RINs serves as a powerful incentive for the importation of sugarcane ethanol from Brazil. EPA should not simply assume that all sugarcane ethanol meets the 50 percent GHG reduction threshold required of advanced biofuels.

Indeed, EPA’s own lifecycle GHG analysis, which was conducted in 2009-2010 as part of the RFS2 rulemaking process, suggests this incentive is not justified for all volumes of sugarcane ethanol. In the RFS2 final rule, EPA suggests that “...it is more than 50% likely that the actual performance of ethanol produced from sugarcane exceeds the applicable 50% [GHG] threshold [required to qualify as advanced biofuel].”⁵² This necessarily implies that it is also likely that some sugarcane ethanol does not meet the 50 percent GHG reduction threshold and would be more accurately classified as conventional biofuel.

Further, more recent lifecycle analysis by the Department of Energy’s Argonne National Laboratory found that the range of GHG reduction attributable to sugarcane ethanol is 40-62 percent, with a midpoint of 51 percent (Figure 4).⁵³ This means it is likely that roughly *half* of the sugarcane ethanol imported into the United States is not in fact meeting the statutory 50 percent GHG reduction required for classification as “advanced biofuel.” Yet, EPA continues to allow all sugarcane ethanol imports to generate advanced biofuel (D5) RINs, creating an unjustified incentive for biofuel imports.

Figure 4. Table 7 from Wang *et. al* (2012) “Well-to-wheel GHG reductions for five ethanol pathways (relative to well-to-wheel GHG emissions for petroleum gasoline). (Note: Values in the table are GHG reductions for P10-P90 (P50), all relative to the P50 value of gasoline GHG emissions.)”

WTW GHG emission reductions	Corn	Sugarcane	Corn stover	Switchgrass	Miscanthus
Including LUC emissions	19–48% (34%)	40–62% (51%)	90–103% (96%)	77–97% (88%)	101–115% (108%)
Excluding LUC emissions	29–57% (44%)	66–71% (68%)	89–102% (94%)	79–98% (89%)	88–102% (95%)

⁵² 75 Fed. Reg. 14790

⁵³ Wang et al. (2012). “Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use.” *Environ. Res. Lett.*, 7 (2012) 045905 (13pp).

EPA could remedy this unfounded incentive for biofuel imports by requiring sugarcane ethanol producers and importers to demonstrate on an individual biorefinery basis that their ethanol does in fact meet the requisite 50 percent GHG reduction threshold. This individual demonstration could be conducted in the same way that EPA requires U.S. corn ethanol plants to submit site-specific pathway analyses as part of the Efficient Producer Pathway Petition (EP3) process. If individual sugarcane ethanol producers are able to credibly demonstrate their ethanol meets the 50 percent GHG reduction criteria, they could continue to generate D5 RINs. On the other hand, if other individual producers are not able to make this demonstration, they should be allowed to generate only conventional biofuel (D6) RINs.

Holding sugarcane ethanol producers and importers more accountable for the actual GHG performance of their fuels (as EPA does with corn ethanol producers via the EP3 process) would help level the playing field and remove unjustified incentives that stimulate biofuel imports.

Attachment A

G. Moschini, H. Lapan, and H. Kim. “The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects.” Center for Agricultural and Rural Development, Iowa State University. Working Paper 17-WP 575 (June 2017).

The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects

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The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects

GianCarlo Moschini, Harvey Lapan and Hyunseok Kim ¹

Abstract

We construct a tractable multi-market equilibrium model designed to evaluate alternative biofuel policies. The model integrates the US agricultural sector with the energy sector and it explicitly considers both US ethanol and biodiesel production. The model provides a structural representation of the renewable fuel standard (RFS) policies, and it uses the arbitrage conditions defining the core value of renewable identification number (RIN) prices to identify the relevant competitive equilibrium conditions. The model is parameterized, based on elasticities and technical coefficients from the literature, to represent observed 2015 data. The model is simulated to analyze alternative scenarios, including: repeal of the RFS; projected 2022 RFS mandates; and, optimal (second best) mandates. The results confirm that the current RFS program considerably benefits the agriculture sector, but also leads to overall welfare gains for the United States (mostly via beneficial terms of trade effects). Implementation of projected 2022 mandates, which would require further expansion of biodiesel production, would lead to a considerable welfare loss (relative to 2015 mandate levels). Constrained (second-best) optimal mandates would entail more corn-based ethanol and less biodiesel than currently mandated.

Key words: Biodiesel, biofuel policies, carbon tax, ethanol, greenhouse gas emissions, mandates, renewable fuel standard, RINs, second best, welfare.

JEL codes: Q2, H2, F1

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Over the last decade the United States has implemented major policies to promote biofuel use. The key provisions, set forth in the Energy Independence and Security Act (EISA) of 2007, are centered on the so-called Renewable Fuel Standard (RFS) which mandates certain amounts of renewable fuels to be blended into the US transportation fuel supply. These ambitious RFS “mandates” have been rationalized as pursuing a variety of objectives, including reduction of GHG emission and reduction of the US dependence on foreign energy sources (Moschini, Cui and Lapan 2012). Arguably, however, one of their most important impacts has been on agriculture. By sizably expanding demand for some agricultural products (e.g., corn to produce ethanol), the RFS is credited with having contributed substantially to increased commodity prices (Wright 2014; de Gorter, Drabik and Just 2015). These price increases have benefited farmers, and led to large land price increases, but biofuel policies’ impact on land use has led to controversies, including the food versus fuel debate (Rosegrant and Msangi 2014) and whether biofuels yield actual net environmental benefits (Searchinger et al. 2008). In addition, development and production of cellulosic biofuel—one of the RFS’s signature features—has severely lagged the mandates schedule set out in EISA. Furthermore, the current economic environment of relatively low oil prices, coupled with an unexpectedly strong domestic expansion of fossil fuel production, makes the energy security argument somewhat moot. The RFS remains controversial, and there is considerable interest in a comprehensive assessment of the current and future economic impacts of the RFS (Stock 2015).

In this article we construct a tractable multi-market competitive equilibrium model suitable to evaluate alternative biofuel policies. The model, which integrates the US agricultural sector with the energy sector, pays particular attention to a careful structural representation of the RFS biofuel support policies, and it is amenable to calibration and simulation to produce theoretically-consistent estimates of the market and welfare impacts of these policies. Unlike previous analyses that focused exclusively on ethanol (e.g., de Gorter and Just 2009, Cui et al. 2011), we develop a model that captures all of the various mandates envisioned by the RFS (Schnepf and Yacobucci 2013). These mandates are enforced by the US Environmental Protection Agency (EPA) via Renewable Identification Numbers (RINs), which are tradeable. A novel contribution of this article is to show how the arbitrage conditions for RIN prices derived from the behavior of distributors that blend biofuels with fossil fuels, including the RIN price inequalities implied by the hierarchical structure of the RFS mandates, can be embedded in a competitive equilibrium model.

One of the fault lines of the current RFS implementation is the rising role of biodiesel (Irwin and Good 2016). Insofar as biodiesel may be the biofuel of choice to meet the advanced biofuel

portion of the RFS mandates, as suggested by recent EPA rulemakings (EPA 2016), an economic evaluation of current and prospective US biofuel policies needs to consider the interactions between US ethanol and biodiesel production. The model we present captures this essential connection by an explicit system representation of the feedstock used in biofuel production. For conventional ethanol produced in the United States, corn is the chosen feedstock in virtually all plants. Biodiesel production, on the other hand, uses a variety of feedstocks, including animal fats, recycled fats (yellow grease) and vegetable oils. The latter are the most important primary input, accounting for about 71% of biodiesel feedstock in 2015, with soybean oil being the most widely used (almost three fourths of all vegetable oils used in biodiesel production). Given the constraints on the availability of other more marginal feedstocks (Brorsen 2015), we assume that further expansions of biodiesel production would have to rely on redirecting vegetable oils from other uses. In this article, therefore, we develop a structural model of ethanol production from corn and biodiesel production from soybean oil.¹ The model captures the competition of primary agricultural products for scarce land, can trace the impact of biofuel mandates on equilibrium prices at various market levels, and can produce a coherent welfare assessment of the overall impact of RFS mandates.

The topic of this article is of considerable importance from a policy perspective. Biofuel policies, and the future of the RFS mandates, while likely to remain controversial, have a crucial impact on the agricultural sector (Cui et al. 2011, Pouliot and Babcock 2016). We find that the RFS has indeed proved to be a remarkably effective tool for farm support. Relative to the scenario of no biofuel policies, the 2015 level of mandates entails a 34% increase in corn price and a 9% increase in soybean price. The mandates' impact on energy prices is smaller in absolute terms, with crude oil price decreased by 1.4%. Because the United States is a net importer of crude oil, and a net exporter of corn and soybean products, these terms of trade effects contribute significantly to the finding that, overall, the welfare impact of the RFS has been positive. The RFS impact on reducing carbon emission, on the other hand, turns out to be nil once we account for the leakage effect (due to the induced increase in the rest of the world's fossil fuel consumption). Aggregate welfare at current mandate levels is larger than in the "No RFS" scenario by about \$2.6 billion. To further improve welfare from the 2015 mandate levels, the model suggests that corn ethanol production should be increased, whereas biodiesel production should be decreased. The additional welfare gains from such constrained optimal mandates, however, are somewhat limited. Finally, implementation of the 2022 RFS statutory mandate levels—adjusted for a projected realistic expansion of cellulosic biofuels, consistent with EPA's recent waivers—would lead to sizeable welfare losses.

The RFS: Current and Prospective Mandates

The biofuel mandates of the RFS codified by EISA considerably extended the earlier provisions of the 2005 Energy Policy Act (Schnepf and Yacobucci, 2013). This legislation laid out a hierarchical set of quantitative minimum requirements for different types of biofuels, as well as a schedule for these mandates to increase over time, with final mandate levels being reached in 2022. The RFS defines an overall “renewable fuel” mandate, to be met with qualifying biofuels that achieve at least a 20% reduction in greenhouse gas (GHG) emissions (relative to fossil fuel), on a lifecycle basis. Furthermore, the RFS specifies a number of nested mandates as subsets of the overall renewable fuel mandate. The largest sub-component is that of “advanced biofuels.” Such biofuels must achieve at least a 50% GHG emission reduction (relative to the conventional fuel) and encompass a variety of biofuels, including sugarcane ethanol and biodiesel (but corn-based ethanol is excluded). A portion of the advanced biofuel mandate is explicitly reserved for biomass-based diesel (biodiesel for short). The largest portion of the advanced biofuel mandate was supposed to be accounted for by cellulosic biofuels, identified as reaching a GHG emission reduction of at least 60% relative to the conventional fuel.

The EPA is responsible for implementing the RFS. To do so, prior to each year the EPA determines the fractional requirements that “obligated parties” (e.g., importers and refiners of fossil fuels) have to meet. These fractional requirements are calculated so that the mandates volumes of biofuel are achieved, given expected demand conditions. The fractional requirements determine the individual parties’ renewable volume obligations (RVOs), given their sales of transportation fossil fuel. As noted earlier, these RVOs are enforced via the RIN system.² In addition to setting appropriate fractional requirements each year to implement the scheduled RFS mandates, the EPA has had to contend with the essential failure of cellulosic biofuel production: technology and production capacity are nowhere close to permit the fulfillment of the ambitious mandates envisioned by EISA. Hence, in the last several years, the EPA has exercised its waiver authority and drastically reduced the statutory RFS mandates accordingly.

Table 1 reports RFS mandate levels for the years 2015-2017, and for year 2022 (when biofuel mandates are supposed to reach their final levels). The columns labeled “EISA” contains the statutory mandates, for the overall renewable fuel and its subcomponents: advanced biofuel, biodiesel and cellulosic biofuel. It is useful to supplement these statutory mandates, reported in the first four rows of table 1, with two additional “implied” mandates. Note that there is no explicit mandate for corn-based ethanol. But given that this biofuel is the most cost-effective, at present, the

implicit mandate for corn-based ethanol can be obtained as the difference between the renewable fuel mandate and the advanced biofuel mandate. This is reported in the last row of table 1, which shows that corn-based ethanol is effectively capped by EISA to a maximum of 15 billion gallons (from 2015 onward). Also, a portion of the advanced biofuel mandate, not reserved for cellulosic biofuels, can be met by a variety of biofuels (including sugarcane ethanol and biodiesel). This implied “non-cellulosic advanced” biofuel mandate, computed as the difference between advanced biofuel mandates and cellulosic biofuel mandate, is reported in the second-last row of table 1.

The columns labeled “EPA” reflect the agency’s exercise of its waiver authority. It seems clear that the EPA has been systematically and drastically reducing the cellulosic biofuel mandate to levels that are feasible given current capacity, and simultaneously scaling back the overall renewable fuel mandate. At the same time, EPA rulemaking shows a clear intention to abide by the statutory mandates for the other components of the RFS. Also, the EPA is clearly signaling that biodiesel provides the avenue for meeting this non-cellulosic advanced biofuel mandate. The 2017 biodiesel mandate is almost sufficient to satisfy the other advanced biofuel mandates.³ From these observations, we generated a reasonable projection of how the 2022 statutory mandates may be adjusted, and this is reported in the last column of table 1. This projection assumes that: (i) the non-cellulosic portion of the advanced biofuel mandate (5 billion gallons) will be fully implemented; (ii) the cellulosic biofuel mandate will continue to be scaled down based on available capacity (our projection relies on a linear trend of past EPA rulemakings); and, (iii) the overall renewable fuel mandate will be set so that, given (i) and (ii), the implied corn-ethanol mandate is held at the 15 billion gallons cap. As for biodiesel, our working assumption is that this is the marginal biofuel to meet the advanced biofuel mandate, and so the extrapolation as to its level is not required for the model that we discuss next (the biodiesel mandate, *per se*, is not binding).⁴ The last column of table 1 constitutes the “2022 scenario” that is analyzed in our counterfactual simulations, along with a few other scenarios discussed below.

The Model

The model consists of the following parts: US supply for corn and soybeans, consistent with equilibrium conditions in the land market; US oil supply; transformation sectors that produce ethanol and biodiesel from agricultural crops, and gasoline and diesel from domestic and imported crude oil; imports of crude oil and exports of corn and soybeans (including soybean oil and meal); rest of the world’s demands for corn and soybean products imports; US demand for food products,

transportation fuels and other fuels. The model allows for the endogeneity of crude oil, corn and soybean product prices, in addition to representing equilibrium in the US markets for food products and transportations fuels. The equilibrium conditions used to close the model are based on a novel representation of the arbitrage conditions for RIN prices.

Domestic Production

The model represents three domestically produced primary products: corn, soybeans, and crude oil. Concerning the two agricultural outputs, we conceive of their production as arising from an equilibrium allocation of (finite) cropland across three alternatives: corn, soybean, and all other uses. Given the purpose of this analysis, in our model it is important to represent not just the responsiveness of the supply of each product of interest to changes in its own price, but also the substitutability between corn and soybean, i.e., the cross-price effects. Consistent with recent work addressing agricultural supply response to price changes induced by the biofuel expansion (e.g., Hendricks et al. 2014, Berry 2011), we postulate both a land allocation response and a yield response. Consequently, the supply functions for corn and soybeans are represented as:

$$(1) \quad S_i(p_i, p_j) = y_i(p_i) L_i(p_i, p_j), \quad i, j = c, s \text{ and } i \neq j$$

where p denotes prices and the subscripts c and s indicate corn and soybeans, respectively. Hence, the yield functions $y_i(p_i)$ are presumed to respond to own price only, whereas the acreage allocation functions $L_i(p_i, p_j)$ depend on both corn and soybean prices (which are endogenously determined in the model). Provided the symmetry condition $\partial S_c / \partial p_s = \partial S_s / \partial p_c$ holds, the supply functions $S_c(p_c, p_s)$ and $S_s(p_c, p_s)$ are integrable into an aggregate profit function $\Pi(p_c, p_s)$ and thus satisfy $S_c = \partial \Pi / \partial p_c$ and $S_s = \partial \Pi / \partial p_s$ (by Hotelling's lemma).

As noted, the acreage functions $L_i(p_i, p_j)$ are meant to represent an equilibrium allocation of cropland to three alternatives, but we specify them as depending only on the prices of corn and soybeans. Two rationalizations can be invoked for this procedure: the price of the outside option (other uses) is constant; or, these functions should be interpreted as *mutatis mutandi* supply relationships (i.e., allowing for equilibrium response in the markets for products other than corn and soybeans). Computation of the producer surplus, as done in this article, is possible for either rationalization, although the interpretation of such measure might differ in subtle ways (Thurman 1991). In any case, the price of inputs other than land are held constant (across scenarios), except for

energy inputs (because the model will solve for different equilibrium fuel prices across scenarios). Still, under the ancillary simplifying condition that energy inputs are used in fixed proportion with land,⁵ it follows that the supply functions of interest can in fact be represented simply as depending on the prices of the two commodities (corn and soybeans). The supply of the other domestically produced primary product, crude oil, is written as $S_R(p_R)$.

Transformation sectors. The refining of crude oil yields gasoline x_g , diesel x_d , and other refined petroleum products x_h . We assume a Leontief (fixed proportions) production technology:

$$(2) \quad x_g = \beta_g \text{Min}\{x_R, z_g\}$$

$$(3) \quad x_d = \beta_d x_g / \beta_g$$

$$(4) \quad x_h = \beta_h x_g / \beta_g$$

where $x_R \equiv S_R + \bar{S}_R$ is the total supply of crude oil to the US market (\bar{S}_R denotes US imports of crude oil), and z_g represents other inputs used in the refining process.

Domestically produced corn has three uses in the model: it can be exported; it can be transformed into ethanol; and it can meet domestic demand for all other uses (e.g., animal feed). Corn-based ethanol production x_e is represented by the following Leontief production functions:

$$(5) \quad x_e = \alpha_e \text{Min}\{\tilde{x}_c, z_e\}$$

where \tilde{x}_c is the quantity of corn, and z_e denotes all other inputs, used in ethanol production. We note at this juncture that the model will allow for byproducts—such as distilled dried grains with soluble—that can be valuable as animal feed (Hoffman and Baker 2011). The endogenously determined animal feed products in our model are corn and soybean meal. To account for the feedback effects on these markets of varying ethanol production (across scenarios), the quantities of byproducts which substitute for corn and soybean meal used in livestock feed are represented as $\delta_1 \tilde{x}_c$ and $\delta_2 \tilde{x}_c$, respectively.

Similarly, domestically produced soybeans have two uses: they can be exported as beans; or, they can be crushed to produce oil and meal. In turn, some of the meal and oil that is domestically produced by the crushing process is exported. Given the constant returns to scale technology in the crushing process, and assuming that there are no particular comparative advantages in this process, without loss of generality we can simplify the model and assume that each bushel of soybeans that is

exported is really a fixed-proportion bundle of soybean oil and meal.⁶ Hence, we presume that the entire domestic production of soybeans is converted into soybean oil x_v and meal x_m by the following Leontief technology:

$$(6) \quad x_v = \alpha_v \text{Min}\{S_s, z_v\}$$

$$(7) \quad x_m = \alpha_m x_v / \alpha_v$$

where S_s is domestic soybean supply, and z_v denotes other variable inputs used in the production of vegetable (soybean) oil. Next, soybean oil can be exported, it can be converted into biodiesel, or it can meet domestic demand for all other uses. Conversion of soybean oil into biodiesel x_b takes place according to this Leontief technology:

$$(8) \quad x_b = \alpha_b \text{Min}\{\tilde{x}_v, z_b\}$$

where \tilde{x}_v is quantity of soybean oil, and z_b denotes all other variable inputs, used in the production of biodiesel.

Demand

For the analysis of various scenarios, the model endogenizes both agricultural product prices and fuel prices. We explicitly model the demand for transportation fuels (gasoline and diesel), as well as the demand for other energy products produced by refining crude oil. Because transportation fuels in our model blend fossil and renewable fuels, it is important to account for their energy content. Our maintained assumption is that consumers ultimately care about miles traveled (de Gorter and Just 2010). Having accounted for their different energy contents, ethanol is considered a perfect substitute for gasoline and biodiesel a perfect substitute for diesel. To permit an internally consistent welfare evaluation of alternative policy scenarios, domestic demand functions are obtained from a quasi-linear utility function for the representative consumer, which is written as:

$$(9) \quad U = I + \Phi(p_{gf}, p_{df}) + \Psi(p_h) + \Theta(p_c, p_m, p_v) - \Lambda(E)$$

where I denotes monetary income which, along with all prices, is expressed in terms of a numeraire good whose price is normalized to one. Subscripts gf and df here denote gasoline fuel and diesel fuels, respectively (i.e., blends of fossil and renewable fuels). Thus, we are postulating additive separability between transportation fuels, heating oil, and food/feed products. This property assumes that a number of cross-price elasticities are equal to zero. But some critical substitution relations (between food/feed products, and between various fuels) are modeled explicitly. Note also

that these preferences include the externality cost of transportation fuel consumption via the term $\Lambda(E)$, where E denotes total world GHG emissions associated with the consumption vector of all energy products (accounting for the fact that biorenewable energy products entail savings on emission).

The foregoing approach of modeling biofuels and fossil fuels as perfect substitutes, once expressed in equivalent energy units, is consistent with other recent studies (e.g., Holland et al. 2015), but some additional discussion may be warranted vis-à-vis the “blend wall” issue. The latter refers to the maximum amount of ethanol that can be sold via the so-called E10 gasoline blend (which contains a maximum of 10% ethanol). As noted by Stock (2015, p. 13) “...this is more accurately not a ‘wall’ but rather a situation in which additional ethanol must be provided through higher blends.” When that is the case, it may be important to represent separately consumers’ demand for E10 and E85, the higher-ethanol blend that can be used by flexible fuel vehicles (FFVs) (Anderson 2012, Salvo and Huse 2013). As discussed in more detail below, feasibility of the RFS mandate is not an issue in the benchmark 2015 year, nor for the 2022 scenario. Feasibility may be an issue for the higher ethanol levels of the optimal mandates that we calculate, in which case the putative welfare gains of optimal mandates need to be properly qualified.

Demand functions for corn, soybean oil and soybean meal are written as $D_c(p_c, p_m, p_v)$, $D_v(p_c, p_m, p_v)$, and $D_m(p_c, p_m, p_v)$, respectively, and satisfy $D_c = -\partial\Theta/\partial p_c$, $D_v = -\partial\Theta/\partial p_v$ and $D_m = -\partial\Theta/\partial p_m$. Similarly, domestic demand functions for blended gasoline fuel and blended diesel fuel, $D_{gf}(p_{gf}, p_{df})$ and $D_{df}(p_{gf}, p_{df})$, satisfy $D_{gf} = -\partial\Phi/\partial p_{gf}$ and $D_{df} = -\partial\Phi/\partial p_{df}$. Again, in principle the specification can handle some substitution possibility between gasoline and diesel. Such a possible substitution is however not maintained for non-transportation petroleum products, the demand for which is $D_h(p_h) = -\partial\Psi/\partial p_h$. The actual parameterization of these demand functions will assume a quadratic structure for the functions $\Phi(\cdot)$, $\Psi(\cdot)$ and $\Theta(\cdot)$, such that the implied demands are linear. Demand functions for agricultural products exported to the rest of the world (ROW), written as $\bar{D}_c(p_c)$, $\bar{D}_v(p_v)$ and $\bar{D}_m(p_m)$, are also assumed to be linear. As for the externality cost $\Lambda(\cdot)$, we will assume that the social cost is linear in total carbon emission.

Equilibrium

The equilibrium conditions represent the situation where the United States is a net importer of crude oil, a net exporter of corn, and a net exporter of soybean oil and meal (as noted earlier, exports of soybeans *per se* are treated as exports of soybean oil and meal). These trade flows are endogenously determined by the equilibrium conditions that solve for the equilibrium prices. To exactly match the data of the benchmark 2015 year, all other trade flows (because they are of minor importance) are treated as exogenous. Similarly, our equilibrium conditions reflect observed stock changes in the benchmark year, although these quantities are treated as exogenous across scenarios.

It is useful to separate the equilibrium conditions that apply in any one scenario into market clearing conditions and arbitrage conditions. The latter arise from the competitive (zero profit) conditions that apply to the transformation sectors (oil refining, soybean crushing and ethanol production), together with the presumed Leontief production functions. Arbitrage conditions also arise because of policy interventions in the biofuel market, as discussed below. Unlike Cui et al. (2011), none of our scenarios considers the possibility of using border measures (i.e., tariffs). Hence, the arbitrage conditions that link domestic and foreign prices are directly maintained in our model. Which market equilibrium conditions apply, however, does depend on which policy tools (e.g., mandates, taxes, subsidies) are in place. Here we present the equilibrium conditions for the case with binding mandates (the *status quo*).

The statutory mandate levels are: x_{rf}^M for the overall mandate for renewable fuel, x_a^M for the advanced biofuel mandate, x_b^M for the biodiesel mandate, and x_{ce}^M for the cellulosic biofuel mandate (following the RFS convention, all of these mandates, except x_b^M , are measured in ethanol units).⁷ These mandates define a hierarchical structure: cellulosic biofuels and biodiesel can be also used to meet the advanced biofuel mandate; and all biofuels can be used to meet the overall renewable fuel mandate (Schnepf and Yacobucci 2013). Consistent with the 2015 benchmark year used to calibrate the *status quo*, there are three binding mandates: x_{rf}^M , x_a^M and x_{ce}^M . Specifically, the binding cellulosic biofuel mandate is met with domestic production, which is exogenous to our model. The advanced biofuel mandate is met by imports of sugarcane ethanol, the quantity of which is exogenous, and biodiesel, either domestically produced or imported (domestic biodiesel produced from feedstock other than vegetable oil, and the imported amount of biodiesel, are treated as exogenous). More specifically, the equilibrium conditions that we characterize below pertain to the

case where the quantity of biodiesel exceeds that required to meet the biodiesel mandate, i.e., the “marginal” fuel to meet the advanced biofuel mandate is biodiesel. Hence, the biodiesel mandate, *per se*, is not binding. Finally, the presumption is that the marginal biofuel for the total renewable mandate is corn ethanol (recall that there is no specific corn ethanol mandate *per se*).

The market clearing conditions can now be stated as follows:

$$(10) \quad S_c(p_c, p_s) - \Delta_c = D_c(p_c, p_m, p_v) + \bar{D}_c(p_c) + (1 - \delta_1) \frac{x_e}{\alpha_e}$$

$$(11) \quad \alpha_m [S_s(p_c, p_s) - \Delta_s] - \Delta_m = D_m(p_c, p_m, p_v) + \bar{D}_m(p_m) - \delta_2 \frac{x_e}{\alpha_e}$$

$$(12) \quad \alpha_v [S_s(p_c, p_s) - \Delta_s] - \Delta_v = D_v(p_c, p_m, p_v) + \bar{D}_v(p_v) + \frac{x_b}{\alpha_b}$$

$$(13) \quad x_g - X_g + \zeta_e (x_e - X_e + \mu_{ce} x_{ce}^M + M_{se}) = D_{gf}(p_{gf}, p_{df})$$

$$(14) \quad x_d - X_d + \zeta_b (x_b + M_b + N_b) = D_{df}(p_{gf}, p_{df})$$

$$(15) \quad x_h - X_h = D_h(p_h)$$

Equation (10) represents equilibrium in the corn market. The term Δ_c here represents change in year-ending (carryover) stocks. The last term on the right-hand-side (RHS) of equation (10) represents the net amount of corn devoted to the production of ethanol, where the coefficient $(1 - \delta_1)$ accounts for the quantity of byproducts from ethanol production that substitute for corn as livestock feed. Equation (11) represents equilibrium in the soybean meal market. In this equation, the terms Δ_s and Δ_m represent variations in stocks for soybeans and soybean meal, respectively, whereas the term $\delta_2 x_e / \alpha_e$ accounts for the quantity of ethanol production byproducts that substitute for soybean meal as animal feed. Equation (12) represents equilibrium in the soybean oil market. In this equation, the term Δ_v represents change in stocks of soybean oil. The last term on the RHS of equation (12) represents the amount of soybean oil that is processed into biodiesel. Equation (13) represents equilibrium in the gasoline fuel market, where X_g denotes exports of unblended gasoline. Note that ethanol from all origins—domestically produced corn-based ethanol x_e , net of export X_e and imports of sugarcane ethanol M_{se} , as well as domestically produced cellulosic ethanol—is blended with gasoline, with everything expressed in gasoline energy equivalent units via the coefficient ζ_e . Because only a very small portion of the cellulosic biofuel mandate is

met with cellulosic ethanol, however, only the latter amount (denoted $\mu_{ce}x_{ce}^M$) is presumed blended with transportation fuel.⁸ Equation (14) represents equilibrium in the diesel fuel market. Here X_d represents exports of refined diesel, M_b represents imports of biodiesel and N_b represents biodiesel domestically produced with feedstock other than vegetable oil. Finally, equation (15) represents equilibrium in the market for the composite third product of refining crude oil.

The quantity of corn ethanol and biodiesel in these market clearing conditions must be consistent with the binding mandates, that is, the following identities will hold at the equilibrium:

$$(16) \quad x_e \equiv x_{rf}^M - x_a^M + X_e$$

$$(17) \quad x_b \equiv (x_a^M - x_{ce}^M - M_{se}) / \vartheta - M_b - N_b$$

where ϑ is the coefficient that, as per the RFS regulation, converts biodiesel quantities into ethanol units ($\vartheta = 1.5$ for traditional biodiesel). The quantities of petroleum products in these market clearing conditions, on the other hand, must satisfy the postulated production relationships, where the total supply of crude oil to the US refining sector depends on the oil price:

$$(18) \quad x_g \equiv \beta_g [S_R(p_R) + \bar{S}_R(p_R)]$$

$$(19) \quad x_d \equiv \beta_d [S_R(p_R) + \bar{S}_R(p_R)]$$

$$(20) \quad x_h \equiv \beta_h [S_R(p_R) + \bar{S}_R(p_R)]$$

In equilibrium, prices must also satisfy arbitrage relations that reflect the zero-profit conditions implied by competitive equilibrium in constant-returns to scale industries. Specifically:

$$(21) \quad \alpha_v p_v + \alpha_m p_m = p_s + w_v$$

$$(22) \quad \alpha_e p_e + \delta_2 p_m = p_c (1 - \delta_1) + w_e$$

$$(23) \quad \alpha_b p_b = p_v + w_b$$

$$(24) \quad \beta_g p_g + \beta_d p_d + \beta_h p_h = p_R + w_g$$

Equation (21) represents the zero profit in soybean crushing (the value of all outputs equal the cost of all inputs). Similarly, equations (22), (23) and (24) represent the zero profit conditions in ethanol production, bio-diesel production and crude oil refining, respectively.

Finally, to close the model, the prices of blended fuels p_{gf} and p_{df} need to be linked to the prices of endogenous fossil fuel inputs (gasoline and diesel) and the prices of endogenous renewable fuels (ethanol and biodiesel). These relationships need to reflect the fact that gasoline and diesel

blends are subject to federal and state motor fuel taxes (represented by the per-unit terms t_{gf} and t_{df}), and that biodiesel enjoys a per-unit blending subsidy ℓ_b . More importantly, these arbitrage relationships must reflect the cost that obligated parties (refiners and blenders) face for complying with the binding mandates, which are mediated by RIN prices.

RIN Prices and Arbitrage/Zero Profit Conditions

Our model is specified in terms of absolute mandate quantities, consistent with the RFS statutory requirements laid out in the EISA legislation. As noted earlier, however, the implementation of these RFS mandates takes the form of “fractional requirements” (determined annually by the EPA) imposed on obligated parties (e.g., importers and refiners). These fractional requirements define how much of each renewable fuel must be blended in the fuel supply for each gallon of refined fossil fuel that is marketed. Obligated parties can meet their RVOs by purchasing renewable fuel themselves, or can show that others have done so by purchasing RINs. In fact, because obligated parties are typically not those who produce and/or blend biofuels in the fuel supply, an active market for RINs has emerged, and the associated RIN prices data can prove useful for empirical analyses (Knittel, Meiselman and Stock 2015, Lade, Lin Lawell and Smith 2016). The purpose of this section is to show explicitly that this, somewhat intricate, RFS enforcement mechanism can be fully rationalized in the context of a model, such as ours, that is specified in terms of absolute mandates.

Let R_{rf} , R_a , R_b and R_{ce} denote the RIN prices for generic renewable fuel (e.g., corn-based ethanol), advanced biofuel, biodiesel and cellulosic biofuel, respectively. The nested nature of the RFS mandates imply that $R_{ce} \geq R_a \geq R_{rf}$, and also that $R_b \geq R_a \geq R_{rf}$. Our working assumption that soybean-oil-based biodiesel is the marginal fuel for the purpose of meeting the advanced biofuel mandate implies that the RIN price of advanced biofuels is equal to that of biodiesel, $R_a = R_b$. Furthermore, the presumption that the marginal biofuel for the total renewable mandate is corn ethanol means that R_{rf} is effectively the RIN price for corn-based ethanol. Next, let the fractional requirements that obligated parties are required to meet for total renewable fuel, advanced biofuel and cellulosic biofuel be represented, respectively, by s_{rf} , s_a and s_{ce} . Then, given the foregoing assumptions on the marginal fuels, it follows that the implicit RFS requirement for corn-based ethanol is $\hat{s}_e = s_{rf} - s_a$, and the implicit RFS standard for biodiesel $\hat{s}_b = s_a - s_{ce}$.

To close the model using the arbitrage conditions from RIN prices, we interpret the latter as representing what has been termed as the “core value” of RINs (McPhail, Westcott and Lutman 2011). In particular, we abstract from the fact that obligated parties can borrow RINs from the next year and/or they can save RINs to be used next year (Lade, Lin Lawell and Smith 2016). These core RIN prices are derived as follows. Given that consumer demand is represented in energy units, a blender can choose to sell one unit of pure ethanol as gasoline fuel and earn $\zeta_e p_{gf}$, upon incurring the motor fuel tax cost t_{gf} . Because the RFS envisions obligations only when using fossil fuels, this strategy does not require the seller to turn in RINs. Hence, the blender would be free to sell the RIN that is “separated” when the unit of ethanol is sold as fuel. The minimum price this agent would accept, at given prices, for one generic renewable fuel RIN therefore is:

$$(25) \quad R_{rf} = p_e + t_{gf} - \zeta_e p_{gf}$$

Analogously, a blender selling one unit of biodiesel can earn $\zeta_b p_{df}$ upon incurring the motor fuel tax cost t_{df} . This strategy would separate \mathcal{G} RINs. The minimum price this agent would accept, at given prices, for one biodiesel RIN therefore is:

$$(26) \quad R_b = \frac{p_b - \ell_b + t_{df} - \zeta_b p_{df}}{\mathcal{G}}$$

To make the foregoing operational for the purpose of closing the model, next we consider the demand side for RINs. The zero profit conditions for an obligated party who sells only fossil-based gasoline and/or diesel, and buys all needed RINs, are:

$$(27) \quad p_{gf} - p_g - t_{gf} = \hat{s}_e R_{rf} + \hat{s}_b R_b + s_{ce} R_{ce}$$

$$(28) \quad p_{df} - p_d - t_{df} = \hat{s}_e R_{rf} + \hat{s}_b R_b + s_{ce} R_{ce}$$

These two conditions can be combined to provide the zero-profit condition that must apply to the overall refining/blending industry which, as in Lapan and Moschini (2012), is assumed to be competitive and operating under constant returns to scale. To this end, we need to express the RFS fractional requirements s_i in terms of mandated quantities. Assuming binding mandates x_{rf}^M , x_{ce}^M and x_a^M , and exogenously given trade flows (recall: fossil fuel exports are not subject to the fractional RFS requirement), then

$$(29) \quad s_{ce} = \frac{x_{ce}^M}{x_g + x_d - (X_g + X_d)}$$

$$(30) \quad \hat{s}_e = \frac{x_{rf}^M - x_a^M}{x_g + x_d - (X_g + X_d)}$$

$$(31) \quad \hat{s}_b = \frac{x_a^M - x_{ce}^M}{x_g + x_d - (X_g + X_d)}$$

Using equations (25)-(31), the zero-profit condition for the integrated refining-blending industry can then be written as:

$$(32) \quad (p_{gf} - t_{gf} - p_g)(x_g - X_g) + (p_{df} - t_{df} - p_d)(x_d - X_d) = (p_e + t_{gf} - \zeta_e p_{gf})(x_e - X_e) \\ + (p_b - \ell_b + t_{df} - \zeta_b p_{df})(x_b + M_b + N_b) + \frac{M_{se}}{g} (p_b - \ell_b + t_{df} - \zeta_b p_{df}) + x_{ce}^M R_{ce}$$

The two terms on the LHS of equation (32) can be interpreted as the industry profit from selling fossil gasoline and fossil diesel, respectively. This profit balances the net industry cost of having to meet the (binding) mandates. Specifically, the first term on the RHS of (32) represents the net loss from selling $(x_e - X_e)$ units of corn-based ethanol; note that the motor fuel tax is levied on the volume of ethanol sold, whereas the revenue portion adjusts the price of (blended) gasoline fuel by the energy content of ethanol. The second term on the RHS represents the net loss from selling $(x_b + M_b + N_b)$ units of biodiesel; in addition to the role of the motor fuel tax and energy content, similar to the case of corn-based ethanol, this term also accounts for the biodiesel blending subsidy. The third term on the RHS represents the cost of marketing the (exogenous amount of) sugarcane ethanol M_{se} . Because this ethanol contributes to meeting the advanced biofuel mandate, and because the marginal fuel for meeting this mandate is biodiesel, then the implicit compliance costs associated with sugarcane ethanol is given by the core value of biodiesel RINs. Finally, the last term of the RHS represents the cost of complying with the cellulosic biofuel mandate (both the quantity mandate x_{ce}^M and the corresponding RIN price R_{ce} are exogenous to the model).

Because the model endogenously determines two renewable fuel prices—corn ethanol and biodiesel—the zero-profit condition for the integrated refining-blending industry in equation (32) is not sufficient to close the model (unlike in Cui et al. 2011, for instance). The additional price arbitrage condition is derived by combining equations (27) and (28):

$$(33) \quad p_{gf} - p_g - t_{gf} = p_{df} - p_d - t_{df}$$

This equilibrium price relation embeds a critical implication of the RFS: marketing a gallon of fossil gasoline entails the same compliance cost as marketing a gallon of fossil diesel (i.e., the RHS terms

of (27) and (28) are the same). In conclusion, therefore, the equilibrium conditions are given by equations (10)-(24), along with equations (32) and (33). These 17 equations are solved for 17 endogenous variables: $p_c, p_s, p_m, p_v, p_R, p_{gf}, p_{df}, p_g, p_d, p_h, p_e, p_b, x_e, x_b, x_g, x_d$ and x_h .

Equilibrium Conditions for Other Scenarios

Equilibrium conditions for scenarios other than the *status quo* will need to be appropriately adjusted. For example, without binding mandates and with no biodiesel subsidy, the equilibrium conditions would not require the arbitrage relations (32) and (33). Instead, the required arbitrage relations (for an interior solution) would be

$$(34) \quad p_g = p_{gf} - t_{gf}$$

$$(35) \quad p_d = p_{df} - t_{df}$$

$$(36) \quad p_e = \zeta_e p_{gf} - t_{gf}$$

$$(37) \quad p_b = \zeta_b p_{df} - t_{df}$$

The set of equilibrium conditions for this case would then be given by equations (10)-(15), equations (18)-(24), and equations (34)-(37). These conditions also characterize the *laissez faire* scenario, provided that $t_{gf} = t_{df} = 0$. The supplementary appendix online shows how the equilibrium conditions for the case of no RFS mandates can be adjusted to maintain the assumption that some ethanol is likely to be required, even without RFS mandates, as an oxygenate for gasoline fuel to meet desired octane levels (a scenario that we explicitly consider in the policy evaluation section).

Parameterization

The parameters of the model are calibrated to represent the most recent available consistent benchmark data set (the year 2015), in order to capture current conditions in agricultural and energy markets. Specifically, the data for crop variables are based on the 2014/2015 marketing year, whereas crude oil and fuel variables (fossil and renewable) are based on calendar year 2015.⁹ The purpose of calibration is to choose parameter values for the functional forms of demand and supply so that: (a) the equilibrium conditions using the parameterized functions, along with the observed values of exogenous variables, produce the values of endogenous variables actually observed in the 2015 benchmark year; and, (b) the parameterized functions imply elasticity formulae that, once evaluated at the 2015 benchmark data, match assumed elasticity values. The functions that we

parameterize are the domestic supply functions for corn and soybean; the domestic demand functions for corn, soybean meal and soybean oil; the foreign import demand functions for corn, soybean meal and soybean oil; the domestic supply and foreign export supply functions for crude oil; the domestic demand functions for gasoline fuel and diesel fuel; and, the domestic demand function for other refined petroleum products. All of these functions are postulated to be linear.

Table 2 reports the assumed elasticity parameters used to calibrate the model, along with a brief description of sources/explanations. The remaining coefficients used to calibrate the model are reported in tables A1 and A2 in the Appendix.

Elasticities

The elasticity values used to calibrate the model, summarized in table 2, are based on the literature, whenever possible, or assumed to reflect consensus on their qualitative attributes. A full discussion of sources and elasticity derivations is included in the supplementary appendix online. A crucial set of parameters, given the objective of the study, concerns the own and cross-price supply elasticities for corn and soybeans. Given the postulated structure discussed earlier, such elasticities reflect both acreage allocation decisions as well as yield response effects: $\eta_{ii} = \eta_{ii}^L + \eta_{ii}^Y$ ($i = c, s$) and $\eta_{ij} = \eta_{ij}^L$ ($i = c, s, i \neq j$). For acreage elasticities Hendricks, Smith and Sumner (2014) provide a useful benchmark. Consistent with previous work, they find an inelastic response for both corn and soybeans, and also a relatively large cross-price elasticity. As we show in the supplementary appendix online, this means that the implied elasticity of land allocated to these two crops, when both corn and soybean prices are scaled together, is almost completely inelastic. As noted by the AJAE editor, these elasticities may not be representative of the country as a whole because they are based on data from only three states of the central corn belt (where most of the cropland is already allocated to these two crops). To proceed, we have estimated an acreage response model based on national data for the period 1970-2015 (see the supplementary appendix online for details). The estimates we obtain imply a somewhat more elastic acreage response than the long run estimates of Hendricks, Smith and Sumner (2014), and these are the values in table 2 used to calibrate the model. As for yield elasticities, Berry (2011) provides an extensive review of existing empirical evidence. The broad consensus is that virtually all of the crop supply response comes from acreage response, not from yield response. Here we use a set of point estimates for yield response to price from Berry and Schlenker (2011).

The own-price elasticity of domestic corn demand is the same as used by de Gorter and Just (2009) and Cui et al. (2011), and similar values are assumed for soybean oil and meal demands. Cross-price demand elasticities are calculated based on these own-price elasticities and one additional parameter that restrict all of the Allen-Uzawa elasticities of substitution to be the same. Import elasticities for the rest of the world (ROW) notionally reflect both ROW demand and supply responses. To keep the model tractable, we do not explicitly model such underlying functions, nor do we represent cross-price effects. But in the supplementary appendix online we develop the structural relations between demand and supply elasticities and the import demand elasticity, and use such relations to guide the choice of our baseline import elasticity values. For soybean products, our baseline elasticities are broadly consistent with those reported by Piggott and Wohlgenant (2002), whereas for corn our ROW import demand is more elastic than that postulated by Cui et al. (2011).

Another crucial set of elasticities relates to fuel markets. A considerable body of literature, succinctly reviewed in Difiglio (2014) and Greene and Liu (2015), has documented that gasoline demand is very inelastic. Indeed, Hughes, Knittel and Sperling (2008) find that it has become more inelastic in recent years. We conservatively assume the elasticity of gasoline demand estimated by Bento et al. (2008), who use a microeconomic model that allows consumers to respond to price changes with both car choice and miles traveled. This value is also close to the estimate obtained, with a completely different methodology, by Coglianese et al. (2017), and actually more elastic than other recent estimates (e.g., Lin and Prince 2013). Consistent with findings in the literature (Dahl 2012, Winebrake et al. 2015) we postulate that the demand for diesel fuel is more inelastic than that for gasoline fuel, while the demand for other refined fuel products is specified as relatively more elastic. Similar to demand elasticities, the consensus is that the crude oil supply is very inelastic (Difiglio 2014, Greene and Liu 2015). Our baseline parameterization relies on the crude oil supply elasticity used by the US EIA National Energy Modeling System (EIA 2014). As for the ROW export supply of crude oil to the United States, again this reflects both ROW supply and demand responses. Concerning the latter, for the United States our model presumes elasticities of demand for refined products, not crude oil. But using the structural (Leontief) production relations between refined products and crude oil, and the equilibrium arbitrage relation between prices in (24), the supplementary appendix online shows that, for the 2015 calibration year, the implied US crude oil demand elasticity is -0.20. If the ROW has a similar demand elasticity, and its crude oil supply elasticity is the same as in the United States, as assumed in EIA (2014), then we can obtain the ROW export supply elasticity value reported in table 2.

Technical Coefficients

The full set of technical coefficients is reported in table A1 in the Appendix. For ethanol, we assume that one bushel of corn yields 2.8 gallons of ethanol, just as in Cui et al. (2011). What we do differently in this article is provide a more careful account of the byproducts from ethanol production. In particular, we recognize that a variety of such byproducts may be produced, and that their use as animal feed substitutes for both corn and soybean meal (Mumm et al., 2014). This is important in our context, because the quantities and prices of both corn and soybean meal are endogenous in the model. Mumm et al. (2014) conclude that byproducts of ethanol production return 30.7% (in weight) of the corn used as feed equivalent, with 71% of these byproducts replacing corn in animal feed, and the remaining 29% replacing soybean meal. Our calibrated parameters δ_1 and δ_2 maintain these proportions, while adjusting to the units used (bushels for corn and short tons for soybean meal). Production of biodiesel is assumed to require 7.65 pounds of soybean oil per gallon of biodiesel (EIA), and we ignore the byproducts for this process (which have limited value, compared with those arising from ethanol production). The Leontief coefficients for the production of soybean oil and meal by crushing soybeans are obtained from the actual 2015 data for the soybean complex, which shows that 1,873 million bushels of soybeans produced 45.1 million short tons of soybean meal and 21,399 million pounds of soybean oil.

Finally, to represent blended fuels in coherent energy units, for the purpose of modeling demand, the British Thermal Unit (BTU) conversion factors of the various fuels are used (EIA). By using the coefficients ζ_i thus obtained, we are able to express blended gasoline fuel in gasoline energy-equivalent gallon (GEEG) units, as in Cui et al. (2011). By a similar procedure, blended diesel fuel is expressed in diesel energy-equivalent gallon (DEEG) units, and other refined petroleum products are expressed in kerosene energy-equivalent gallon (KEEG) units.

GHG Emissions and Social Cost

Total GHG emission relevant for assessing the alternative biofuel policies scenarios include those associated with US consumption of transportation fuel and other refined petroleum products. But, because we are dealing with a global externality, it is important to account for the induced change in ROW emission induced by the RFS (the so-called leakage effect). Hence, total emission is computed as $E = \sum_j q_j E_j + \bar{D}_R E_R$, where q_j denotes the quantity of individual fuel types consumed in the United States, E_j denotes the corresponding emission rate, \bar{D}_R is the ROW crude oil consumption,

and E_R is the associated emission rate. These (lifecycle) emission rates, measured as kg/gallon of carbon dioxide equivalent (CO₂e) and reported in table A2 in the Appendix, are taken from EPA (2010) and reflect consensus estimates of GHG emission savings provided by biofuels.¹⁰ As for GHG emissions rate of other refined petroleum products, the coefficient we computed is based on five major products of this category.¹¹

To translate GHG emission into a social cost, we assume a constant marginal social damage of pollution, and thus write $\Lambda(E) = \gamma E$. Regarding γ , the marginal social cost of carbon dioxide emissions, the large body of existing work has produced a bewildering array of estimates (Tol 2009), a reflection of the conceptual and practical complexities of such an endeavor. In addition to the familiar difficulties of choosing the baseline value for this parameter, we also need to address the question of what we intend to measure. Our model is predicated on a US-centered welfare criterion. For internal consistency, therefore, our model suggests that only the carbon-emission implications of US biofuel policies for the US economy are relevant. Hence, we follow Cui et al. (2011), who rationalize the use of a benchmark global social cost of \$80/ tCO₂, based on the *Stern Review* (Stern 2007), and then apportion this cost based on the share of US share of the world economy to obtain the adopted value of $\gamma = \$20/ \text{tCO}_2$.¹²

Other Baseline Variables

Data on prices and quantities used to calibrate the model are reported in the supplementary appendix online, which includes sources and calculation methods. Many of these values are also reported in the *status quo* column of table 3 below (given that parameters were correctly calibrated, simulation of the *status quo* reproduces the benchmark variables). For most variables, the data pertains to observed representative values for the benchmark (2015) year, but for some variables the benchmark values are calculated to be consistent with the model. These include gasoline fuel and diesel fuel prices, of course. Also, the reported values for the net export of soybean meal and soybean oil are the sum of actual net exports and implied net exports from the export of soybeans (as discussed earlier). The price of biodiesel is also calculated. It turns out that a representative biodiesel price, such as that reported by the USDA,¹³ would imply an unreasonably low “core value” for the corresponding RIN price, if one assumed that the biodiesel blending subsidy was fully expected, as maintained in equation (26). But in fact this subsidy was passed into law only on December 18, 2015, although it retroactively applied to the entire 2015 calendar year. The considerable uncertainty surrounding the availability of the biodiesel blending subsidy throughout

2015, as well as contractual arrangements that many market operators put in place to deal with that (Irwin 2015), suggests that it is unwise to use the observed biodiesel price in the context of a model that presumes the certainty of such a subsidy. Therefore, we elected to compute the biodiesel price that would be implied by the observed 2015 RIN prices.¹⁴

Other variables of interest reported in the *status quo* column of table 3 also include motor fuel taxes and RIN prices. Concerning motor fuel taxes, we note at this juncture that these taxes, in virtually all cases, are levied on volume basis (Schroeder, 2015), a feature that we have maintained in our structural model. For gasoline, the assumed per-unit tax is the sum of the federal tax (¢18.40/gallon) and a weighted average of state taxes (¢26.49/gallon). For diesel, the assumed per-unit tax is the sum of the federal tax (¢24.40/gallon) and a weighted average of state taxes (¢27.24/gallon). The RIN price for ethanol is the 2015 average of D6 RIN prices, whereas for biodiesel it is the average of the 2015 annual averages of D4 and D5 RIN prices (\$0.7475 and \$0.707, respectively), all from OPIS data.¹⁵

Market and Welfare Impacts of the RFS: Alternative Scenarios

The model outlined in the foregoing sections is used to evaluate a number of policy scenarios, specifically: 2015 RFS mandate levels (the *status quo*); implementation of the 2022 RFS mandates, with projected adjustments for cellulosic biofuels as discussed in section 2 (table 1); and, repeal of biofuel mandate policies (No RFS).¹⁶ In addition to evaluating the above scenarios, because we have an explicit welfare function, the model permits us to characterize optimal biofuel mandates (a second best policy, in this setting), for both biodiesel and corn-based ethanol. Finally, for the purpose of benchmarking the welfare implications of these policies, we also evaluate the *laissez faire* scenario (i.e., no biofuel policies and no taxes on transportation fuels).

For each of these five scenarios the model permits computation of market effects (e.g., prices and equilibrium quantities), as well as an assessment of the welfare impacts. Because of its structure, the model accounts for potential welfare gains accruing to the United States through the impact that alternative biofuel policies can have on the US terms of trade for oil, corn and soybean products. Our welfare calculations also identify important distributional effects by breaking down welfare changes for individual components. We specifically identify net benefits accruing to US consumers, measured as consumer surplus from the integrable system of demand equations derived from the indirect utility function in equation (9); net benefits accruing to the domestic agricultural sector (with aggregate producer surplus consistently calculated as discussed in the supplementary

appendix online); net benefits accruing to domestic producers of crude oil; net government tax revenue; and, the monetary value of GHG emission savings.

Results

In table 3 and table 4, results pertaining to the various scenarios are reported by column in the following order: *laissez faire*, no RFS, 2015 mandates, projected 2022 mandates, and optimal mandates. The top portion of table 3 reports the value of the active policy variables for each scenario. Note that, with the exception of the *laissez faire*, all scenarios envision motor fuel taxes at the baseline level. In addition to the relevant mandates, the *status quo* also includes the \$1/gallon biodiesel subsidy (technically, a tax credit). This subsidy is omitted from the optimal mandates and 2022 scenarios (this is without loss of generality, because the biodiesel mandate is binding in those scenarios). Next, table 3 reports the equilibrium prices and quantities for all scenarios that are considered. Whereas table 3 focuses on the market impact of policies in the various scenarios, table 4 pertains to the computed welfare impacts, which are reported as changes from the “No RFS” scenarios, i.e., the *status quo* before biofuel policies. The estimated aggregate welfare effects are decomposed into several subcomponents to describe the distributional impacts of RFS policies (including on domestic agricultural producers, domestic crude oil producers, and consumers). The impacts on consumer surplus in transportation fuel demand is decomposed into changes accruing via gasoline fuel demand and diesel fuel demand (this decomposition is feasible due to the zero substitution possibilities between the two fuel demands).

One of the welfare components in table 4 is the monetary value of the policies’ impact on changes in GHG emissions. These emission changes are also reported separately in physical units (tCO₂e), and decomposed between those occurring in the United States and in the ROW. The latter accounts for the implication of “leakage,” which arises when unilateral efforts to reduce a global externality are thwarted by induced emission elsewhere (Hoel 1991). One of the two main avenues for carbon leakage to occur is via the impacts of policies on terms of trade (Felder and Rutherford 1993). Because the model can trace the impact of the RFS on equilibrium crude oil price, we can account for the leakage effect that arises because the ROW oil consumption responds to changes in crude oil price.¹⁷

Status quo, status quo ante, and laissez faire. Given the calibration strategy described in the foregoing, the values of equilibrium variables for the “2015 mandates” column in table 3 are equal to the 2015 values that were used in calibration, a verification that the intercepts and coefficients of all

demand and supply functions are precisely calibrated. The ethanol blending ratio in the calibration data is 9.88%, indicating that the blend wall issue is not a concern in the benchmark year. The “No RFS” scenario, as noted, presumes that all mandates and biodiesel subsidies are repealed. Comparison of this scenario with the “2015 mandates” case provides some insight as to the overall market impacts of the current RFS. The largest impact is on agricultural prices: relative to the *status quo ante* the RFS increases corn price by 34% and the soybean price by 9%. All this notwithstanding the fact that the oxygenate requirement for ethanol (which turns out to bind) entails the use of 4.1 billion gallons of ethanol in the “No RFS” scenario. Because biodiesel biases demand of soybean products, the RFS increases soybean oil price by 49% whereas soybean meal price actually declines (by 3.6%). Not surprisingly, the RFS impact on crude oil price (and refined products prices) is much smaller: the crude oil price is estimated to decline by 1.4%, the gasoline price to decline by 9.5% (the prices of diesel and of other refined petroleum products instead increase—reduced amount of refined crude oil, along with the Leontief technology, result in a relative scarcity of these refined products). The RFS leads to a modest contraction in domestic crude oil production, and a larger decline in imports of crude oil (which drop by about 6%).

The *laissez faire* scenario, in addition to the repeal of the RFS, also envisions dropping all motor fuel taxes. This is not a scenario with realistic policy prospects, of course, but it is of some interest to gain insights into the working of the model. Interestingly, the production of corn-based ethanol in the *laissez faire* is considerably higher than in the “No RFS” scenario (the 3% oxygenate requirement is not binding in *laissez faire*). Correspondingly, the corn price is also considerably higher in the *laissez faire* relative to the “No RFS” scenario. The reason for this effect has to do with the impact of transportation fuel taxes. Consistent with the institutional setup, we have modeled these motor fuel taxes as levied on a volume basis (Schroeder, 2015). And, under the presumption that consumers care about miles traveled, fuel demand accounts for the different energy content of biofuels. Hence, as noted by Cui et al. (2011), motor fuel taxes are inherently biased against fuels (such as biofuels) that have lower energy content than fossil fuels. Conditional on such motor fuel taxes being levied per unit of volume of blended fuel, a subsidy for ethanol (and biodiesel) would actually be required just to level the playing field (*vis-à-vis* the objectives of a Pigouvian tax).

Turning to the welfare impacts reported in table 4, comparing the 2015 mandates case with the “No RFS” scenario we find that aggregate welfare is improved by biofuel policies, by \$2.6 billion. In the logic of the model, there are two distinct reasons why RFS policies may improve welfare: they can help correct the carbon pollution externality (under the maintained presumption

that biofuels are less polluting than fossil fuels); and, because the United States is a large country, they may lead to favorable changes in the US terms of trade. It is immediately apparent from table 4 that no portion of the welfare gain associated with 2015 mandates (relative to the no RFS scenario) can be ascribed to a reduction in the carbon externality. The increased use of biofuels does reduce carbon emission in the United States (by about 29 million tCO₂e), but this effect is more than offset by increased ROW emissions caused by the RFS-induced decline in the price of crude oil. Leakage, therefore, turns out to imply that US biofuel policies do not contribute to reducing global emissions. It is important to stress that the effects we are quantifying here are distinct from the indirect land use effects emphasized by other critics of US biofuel policies (e.g., Searchinger et al. 2008). Even abstracting from the latter, we find that leakage via terms of trade effects essentially nullifies the potential environmental gains arising from using (marginally) more environmentally friendly fuels.

When comparing the 2015 mandates with the *status quo ante*, it is apparent that the welfare redistribution effects due to the RFS are large (relative to the overall effects). Agriculture is the big winner. Because of the sizeable increase in the prices of corn and soybeans, noted earlier, the RFS is estimated to increase the sector's producer surplus by \$14.1 billion per year. The large increase in land prices that has been observed in recent years (Lence 2014) is certainly consistent with these conclusions. Consumers of gasoline fuel also benefit from the decrease in gasoline price, whereas users of diesel fuels are actually hurt by the RFS (as are the consumers of other refined petroleum products). Overall, therefore, these results suggest that repeal of the RFS would lower domestic welfare, both because of terms of trade effects, and because the resulting excess taxation of biofuels (relative to fossil fuels) would excessively depress biofuel production. It is also of some interest to note that, compared with the no RFS scenario, the *laissez faire* results in higher welfare. This seems counterintuitive, given that the welfare function includes an externality cost, and the *laissez faire* does not have corrective motor fuel taxes. One of the reasons for this outcome is that—given the assumed social cost of carbon—motor fuel taxes are set at a higher level than what would be required to internalize the carbon emission externality.¹⁸

Year 2022 mandates. The second-to-last column in both table 3 and table 4 considers the 2022 RFS scenario, the terms of which were discussed earlier and are illustrated in table 1. The major differences in mandated volumes from 2015 levels are that the implied biodiesel mandate is increased by 84%, whereas the implied corn-ethanol mandate is increased by just 7%. Despite the modest increase in corn ethanol production, the ethanol blending ratio (fraction of ethanol in total

gasoline fuel) exceeds 10%, a consequence of the decline in gasoline fuel demand associated with higher gasoline prices. As noted, ethanol blend ratios in excess of 10% would require some biofuel to be sold in higher-ethanol blends such as E85 suitable for FFVs. This raises an issue of feasibility of the mandate, and one of interpretation of our results. Because the 10.7% blend ratio of this scenario only marginally exceeds the blend wall, it seems quite feasible given current infrastructures.¹⁹

Both corn and soybean prices increase substantially, relative to the *status quo*. The increase in soybean price (10.6%) is larger than the increase in corn price (4.6%), relative to the *status quo*, a consequence of the need to expand biodiesel production to meet the advanced biofuel mandate. This is also reflected in a much higher biodiesel RIN price (again under the assumption of no biodiesel subsidy). The increased use of both biofuels, combined with an overall decline in gasoline fuel consumption, achieves some pollution reduction (unlike the 2015 mandates case). As for welfare measures, however, table 4 shows overall welfare is considerably lower with the 2022 mandates than with 2015 mandates. The increase in crop prices benefits farmers, as the agricultural sector's aggregate producer surplus is highest among the scenarios we have considered. Despite the further improvement in the US terms of trade (in addition to increased prices of agricultural exports we have a decrease in the price of crude oil imports, relative to 2015 mandates), overall welfare declines. This is because these pecuniary effects are offset by the efficiency cost of expanding biofuel production (the supply price of biodiesel is increased by \$0.83 per gallon, and the supply price of ethanol also increases by \$0.05 per gallon). In the end, our model shows that biodiesel produced from vegetable oil turns out to be a costly way to increase biofuel supply. The projected expansion of the cellulosic biofuel mandate also weighs heavily on the welfare impacts of the 2022 mandates scenario. The large excess cost of these biofuels relative to consumer value—captured by the D3 RIN price that we have assumed, based on current market conditions—makes expansion of cellulosic biofuel use particularly onerous.

Optimal mandates. One of the advantages of the structural model that we have developed is that we can compute “optimal” mandates. In this second best scenario, we take as given existing motor fuel taxes and ask what level of mandates would maximize the welfare function (Marshallian surplus net of external damages). The grid search method that we implemented identifies an optimal biodiesel mandate of 1.8 billion gallons, zero mandates for cellulosic biofuel, and an overall renewable fuel mandate of 18.6 billion gallons (implying an effective corn-based ethanol mandate of

approximately 16.8 billion gallons). Thus, the constrained optimal mandates that we find would envision an 18% expansion of the implied corn-based ethanol mandate, relative to the year 2022 scenario, and a drastic reduction of the advanced biofuel mandate (including zero cellulosic biofuel). The corn price would increase, relative to both 2015 mandates and the year 2022 scenario, but the soybean price would decline.

The corn price increase results in higher marginal cost of supplying ethanol, and the ethanol price also increases. Consequently, the ethanol RIN price also increases. Table 3 indicates that the biodiesel RIN price also increases with the optimal mandates, relative to 2015 mandates, despite the fact that soybean oil price is lower. Note, however, that the optimal mandate scenario presumes the elimination of the biodiesel subsidy (\$1 per gallon), so that the RIN price in the optimal mandate case reflects the full extent of the marginal cost of biodiesel production in excess of its consumer valuation (if the \$1 subsidy were preserved, the optimal mandates would entail essentially a zero RIN price for biodiesel).²⁰ These optimal mandates would result in higher emissions than with the projected 2022 mandates. The overall welfare gain associated with such optimal mandates, relative to 2015 mandates is \$0.7 billion, but relative to the projected 2022 scenario the gain amounts to \$5.2 billion.

The ethanol blending ratio with optimal mandates turns out to be 11.6%. Concerning feasibility, as discussed earlier (footnote 19), this blending may be supportable given current infrastructures. But, as highlighted by Anderson (2012), E10 and E85 are best viewed as imperfect substitutes on an energy-equivalent basis. Even if consumers only cared about the cost per mile of fuel, because E85 requires more frequent refilling than E10, and not all gas stations carry E85, there is a convenience cost to using E85. We have chosen not to embed this imperfect substitutability property in our demand specification.²¹ As a result, we cannot offer a rigorous welfare assessment of optimal mandates when E85 consumption needs to be expanded beyond current patterns. Still, the welfare gain that we estimate from optimally rebalancing RFS mandates may be interpreted as the upper bound of the potential payoff of whatever investments may be required to accommodate the blend wall.²²

Sensitivity Analysis

Inevitably, some of the assumed elasticity values or coefficients used to parameterize the model may be perceived as having a degree of arbitrariness. We note at this juncture that the existing econometric evidence can only be of partial help, both because of the limited number of relevant

studies, and because the structure underlying existing econometric estimates may not be entirely consistent with the structure of this article's model. In any event, sensitivity analysis can be helpful to assess the robustness of the results to alternative parameter values. Here we present the results associated with alternative assumptions concerning the ROW elasticity of crude oil supply to the United States, and the ROW elasticities of demand for US agricultural exports. A more comprehensive set of sensitivity analyses is presented in the supplementary appendix online.

In the logic of the model, there are two distinct reasons for RFS policies: to correct the carbon pollution externality (under the presumption that biofuels are less polluting than fossil fuels); and, to exploit the terms of trade. Concerning the first of these objectives, the second best setting of the model needs to account for the fact that existing motor fuel taxes also ameliorate the carbon externality. Furthermore, as noted, insofar as these taxes are levied on a volume basis, they are inherently biased against biofuels (because the latter entail lower pollution effects and have lower energy content). This imbalance can, to a degree, be addressed by RFS mandates because these policy instruments work as a tax on fossil fuel and a subsidy for biofuel (in a revenue neutral fashion, as shown in Lapan and Moschini 2012). And because they tax products (fossil fuels) for which the United States is a net importer, and subsidize domestic use of products (corn and soybean products) for which the United States is a net exporter, RFS mandates can also improve the U.S. terms of trade.

To isolate the contribution of these various elements to the estimated market and welfare effects, table 5 reports counterfactual results for scenarios that postulate the absence of all or part of the terms of trade effects. Specifically, the columns labeled as "no TOT effects" presumes that the ROW excess supply of crude oil, and the ROW excess demand for agricultural products, are infinitely elastic (such that the prices of crude oil, corn, soybean oil and soybean meal are constant at the calibrated values). Under these assumptions, we evaluate both 2022 projected mandates and optimal mandates. Because by assumption there are no terms-of-trade effects here, we find that 2022 projected mandates would entail a large welfare loss (relative to the no RFS scenario) of \$11.3 billion, despite the fact that they considerably decrease the carbon externality (because there is no leakage in this case). Without terms of trade effects we also find that there is no scope for biofuel policies. Note that, even without terms of trade effects, there remains market failure arguments for intervention (carbon externality and the overtaking of biofuels by existing motor fuel taxes). But the assumed technological requirement for ethanol use as an oxygenate, which is binding at the optimal solution, make such considerations irrelevant.

The last four columns of table 5 decompose the importance of terms of trade as arising from the crude oil market or from agricultural markets. When there are no crude oil terms of trade, such that the price of crude oil is fixed at the baseline level, we find that 2022 mandate levels still entail considerable welfare loss relative to the no RFS scenario. Optimal mandates for this case are close to those reported in table 3 and lead to a \$2.1 billion gain in overall welfare (relative to no RFS). If we do allow crude oil price to adjust, and simply postulate that the ROW demands for US agricultural exports are perfectly elastic, then the last two columns in table 5 indicate large welfare losses associated with 2022 mandates, and minor gains arising from optimal policies (a mere \$0.15 billion more than in the no RFS scenario).

The combined evidence of tables 4 and 5 suggests that virtually all of the estimated increase in US aggregate welfare is ultimately due to the positive impacts that the RFS has on the US terms of trade. Mandates result in increased prices of corn and soybeans, and a decreased price of crude oil. Because the United States is a net exporter of corn and soybean products (both before and after the RFS), and a net importer of crude oil, these changed terms of trade are beneficial. Furthermore, it seems that the terms of trade effects arising from exports of agricultural commodities dominate the beneficial effects associated with decreased crude oil price (which are also affected by the leakage effect).

Comparison with Other Studies

Differing methodologies and empirical approaches makes comparison of our results with those of other studies perilous. Concerning market effects of the RFS, though, we note that our estimated agricultural price increases due to the RFS are quite similar to those obtained by Carter, Rausser and Smith (2016). Using a completely different methodology—a structural vector autoregression econometric approach—these authors estimate that the EISA additional 5.5 billion gallons ethanol requirement (relative to those envisioned in the 2005 legislation) caused a 31% long-run increase in corn prices. This is quite consistent with our higher estimate for the 2015 mandate levels (34% corn price increase), but our model traces the effects of a larger mandate level. Our estimated agricultural price increases are smaller than those obtained by Cui et al. (2011), reflecting the implications of a much more elaborate model as well as somewhat more conservative elasticity assumptions. Our model is unique in the existing literature, as noted earlier, as being able to articulate the impact of the RFS on soybean prices, not just corn prices.

Other studies have emphasized that the blend wall can make the RFS more costly. Similar to our study, Meiselman (2016) recognizes the RIN price linkages implied by the hierarchical structure of RFS mandates, but he only considers a closed economy scenario and does not envision supply-side interactions between biodiesel and ethanol production. He finds that increasing the mandate around the blend wall would reduce GHG emission, but this would entail a very high (marginal) social cost (\$800/tCO₂e). Although we do not have a comparable scenario for this estimate, we note that our projected 2022 mandate levels improve on carbon emission, both relative to 2015 levels and to the no RFS scenario, although welfare declines. The latter conclusion, of course, depends on our assumed social cost of carbon ($\gamma = \$20/\text{tCO}_2\text{e}$). To investigate how the welfare result is affected by the assumed social cost of carbon, we computed two break-even levels for the γ parameter. We find that a social cost of carbon of \$110/tCO₂ would make welfare with the 2022 mandates the same as in the “No RFS” scenario, but that it would take a social cost of carbon of \$192/tCO₂ to make welfare with the 2022 mandates the same as with 2015 mandates.

Conclusion

This article analyzes some of the market and welfare impacts of US biofuel support policies under the RFS program. To do so, we have constructed a tractable multi-market model that incorporates biodiesel markets as well as ethanol markets, thereby extending previous work that focused solely on gasoline-ethanol blends. We show how compliance requirements on obligated parties, which are mediated by RIN prices, can be used to identify the relevant zero-profit conditions required to close the model. Within this framework, the model is calibrated to match market data for the 2015 benchmark year. The model can then be solved and simulated to study counterfactual policy scenarios, yielding equilibrium prices, quantities and welfare impacts. A first-order impact of the RFS is to divert large amounts of corn and soybean oil to biofuel production. This reduces the amount of these products available for export, and the RFS-induced biofuels production also marginally lowers the US demand for refined fossil fuels. Given that the United States are a net importer of crude oil and net exporter of corn and soybean products, the favorable terms-of-trade effects that arise because of the RFS are quite important in order to assess the resulting welfare impacts. Having endogenized the relevant agricultural and energy markets, the model that we construct offers an ideal tool to assess the overall consequences, from the point of view of the United States, of current RFS policies and alternative paths that may be considered going forward.

The results that we have presented confirm that the current RFS program considerably benefits the agriculture sector. Compared with the *status quo ante* situation (no RFS), we find that current biofuel policies increase corn and soybean prices by 34% and 9% , respectively, and also lead to a 1.4% decline in crude oil price. The welfare gain to the United States that can be imputed to the RFS, in 2015, is estimated at about \$2.6 billion. Virtually all of these US welfare gains are due to the impact of RFS policies on the terms of trade. Furthermore, the most relevant effects are those associated with the RFS impacts on the price of key US agricultural exports (corn and soybean products). The RFS net impact on carbon emission is nil in the benchmark year, and minimal with the projected 2022 mandate levels. One of the main reasons for this finding is the leakage effects that arise because of increased consumption of fossil fuels in the ROW due to the RFS-induced decline in crude oil price.

There is considerable uncertainty, and policy debate, concerning future implementation of the RFS. The model that we have developed can be used to assess the market and welfare consequences of alternative paths. We find that full implementation of the EISA statutory 2022 mandate levels (except for the widely expected extensive waiver of cellulosic biofuel mandates) would be costly to the United States. This is because biodiesel, as the marginal fuel of choice to meet the advanced biofuel mandate, does not appear to be an efficient enough tool. Alternatively, if we ask what the optimal mandates levels would be in the context of the model, we find that it would be desirable to expand corn-based ethanol production beyond the 15 billion gallon cap envisioned by the EISA legislation (concomitantly, optimal mandates suggest that a reduction of biodiesel production from current levels is also desirable, and no cellulosic biofuel production). As noted, of course, the viability of such an option may need to deal with the blend wall issue. In any event, relative to 2015 mandate levels, these optimal (second best) mandates produce limited welfare gains. This is because, as documented in the analysis we have presented, it is the impact of the RFS on agricultural terms of trade that is most important. For these effects to remain sizeable, the magnitude of US exports cannot be curtailed too much.

In addition to quantifying the overall welfare gains, the model permits a characterization of the re-distribution effects implied by various scenarios. The magnitudes of such effects are quite large, and the documented impacts—agriculture is the big winner—may help to rationalize some of the political economy features of the debate about the future of the RFS. Although our analysis has been consistently articulated in terms of US welfare, our finding that the predominant welfare impacts are rooted in terms of trade effects suggests that this domestic program has clear “beggar-

thy-neighbor” implications. Obligations undertaken within the World Trade Organization (WTO) restrain the ability of the United States to use border policies to shift to other countries some of the costs of its long-standing agricultural support objectives. RFS provisions, while *prima facie* consistent with the national treatment principle of the WTO, are apparently effective at shifting some of their costs onto foreign constituencies. The fact that the latter represent mostly consumers of agricultural products adds weight to the food-versus-fuel debate. Finally, our finding that the RFS has minimal impacts on reducing global carbon emissions suggests that, from an international perspective, the scope of biofuel policies to improve global welfare may be extremely limited.

Table 1. Statutory Mandates, EPA Final Rulings, and 2022 Scenario (billion gallons)

	2015		2016		2017		2022	
	EISA	EPA	EISA	EPA	EISA	EPA	EISA	Projected
Renewable fuel	20.5	16.93	22.25	18.11	24.0	19.28	36.0	20.787
Advanced biofuel	5.5	2.88	7.25	3.61	9.0	4.28	21.0	5.787
Biodiesel	≥ 1.0	1.73	≥ 1.0	1.90	≥ 1.0	2.00	≥ 1.0	... ^a
Cellulosic biofuel	3.0	0.123	4.25	0.230	5.5	0.311	16.0	0.787 ^b
<i>Non-cellulosic advanced biofuel</i>	<i>2.5</i>	<i>2.757</i>	<i>3</i>	<i>3.38</i>	<i>3.5</i>	<i>3.969</i>	<i>5</i>	<i>5</i>
<i>Corn ethanol</i>	<i>15</i>	<i>14.05</i>	<i>15</i>	<i>14.5</i>	<i>15</i>	<i>15</i>	<i>15</i>	<i>15</i>

Source: Schnepf and Yacobucci (2013) and EPA (2016). All quantities are in ethanol-equivalent gallons except for biodiesel, which are in physical volume.

Note: ^a Biodiesel produced as needed (assumed to be the marginal advanced fuel); ^b Linear trend projection based on 2014-2017 EPA rulings ($R^2 = 0.998$).

Table 2. Elasticities

Parameter	Symbol	Value	Source/explanation
Corn acreage own-price supply elasticity	η_{cc}^L	0.36	Estimated. ^d
Corn acreage cross-price supply elasticity	η_{cs}^L	-0.18	Estimated. ^d
Soybean acreage own-price supply elasticity	η_{ss}^L	0.23	Estimated. ^d
Corn yield own-price elasticity	η_{cc}^Y	0.05	Berry and Schlenker (2011)
Soybean yield own-price elasticity	η_{ss}^Y	0.01	Berry and Schlenker (2011)
Domestic demand elasticity of corn	ε_{cc}	-0.20	de Gorter and Just (2009)
Domestic demand elasticity of soybean meal	ε_{mm}	-0.20	Bekkerman et al. (2012) ^a
Domestic demand elasticity of soybean oil	ε_{vv}	-0.20	Bekkerman et al. (2012) ^a
Cross-elasticity of domestic corn demand w.r.t. p_m	ε_{cm}	0.065	Calculated ^{b, d} ($\varepsilon_{mc} = 0.105$)
Cross-elasticity of domestic corn demand w.r.t. p_v	ε_{cv}	0.014	Calculated ^{b, d} ($\varepsilon_{vc} = 0.105$)
Cross-elasticity of domestic meal demand w.r.t. p_v	ε_{mv}	0.014	Calculated ^{b, d} ($\varepsilon_{vm} = 0.065$)
ROW import demand elasticity of corn	$\bar{\varepsilon}_{cc}$	-2.50	Calculated ^d
ROW import demand elasticity of soybean meal	$\bar{\varepsilon}_{mm}$	-1.60	Calculated ^d
ROW import demand elasticity of soybean oil	$\bar{\varepsilon}_{vv}$	-1.30	Calculated ^d
Domestic supply elasticity of crude oil	η_R	0.25	EIA (2014)
ROW export supply elasticity of crude oil	$\bar{\chi}_R$	4.40	Assumed ^d
Domestic demand elasticity of gasoline fuel	ε_{gg}	-0.35	Bento et al. (2009)
Domestic demand elasticity of diesel fuel	ε_{dd}	-0.15	Assumed ^{c, d}
Domestic demand elasticity of other refined petroleum products	ε_{hh}	-0.50	Assumed ^{c, d}

Note: ^a Rounded values. ^b Calculated assuming that all of the Allen-Uzawa elasticities of substitution are the same. ^c Based on Dahl (2012) and Winebrake et al. (2015). ^d See the supplementary appendix online for more details.

Table 3. Market Effects of Alternative Policy Scenarios

	<i>Laissez Faire</i>	No RFS	2015 Mandates	2022 Mandates	Optimal Mandates
Gasoline motor fuel tax (\$/gal.)		0.449	0.449	0.449	0.449
Diesel motor fuel tax (\$/gal.)		0.516	0.516	0.516	0.516
Biodiesel subsidy (\$/gal.)			1.000		
Cellulosic biofuel mandate (billion units)			0.123	0.787	
Advanced biofuel mandate (billion units)			2.880	5.787	1.795
Renewable biofuel mandate (billion units)			16.930	20.787	18.616
Corn price (\$/bu.)	3.08	2.75	3.68	3.85	3.88
Soybean price (\$/bu.)	9.26	9.23	10.10	11.18	9.66
Soybean meal price (\$/ton)	378.42	382.07	368.49	362.09	368.20
Soybean oil price (¢/lb.)	22.20	21.17	31.60	42.44	27.81
Crude oil price (\$/bbl)	49.83	49.10	48.40	48.00	48.36
Gasoline fuel price (\$/GEEG)	2.03	2.35	2.22	2.30	2.15
Diesel fuel price(\$/DEEG)	1.39	1.98	2.23	2.12	2.46
Gasoline price (\$/gal.)	2.03	1.90	1.72	1.74	1.63
Diesel price (\$/gal.)	1.39	1.47	1.67	1.50	1.87
Ethanol price (\$/gal.)	1.43	1.33	1.61	1.66	1.66
Biodiesel (supply) price (\$/gal.)	2.93	2.85	3.65	4.48	3.36
Other refined products' price (\$/KEEG)	1.08	1.17	1.26	1.31	1.27
RIN price for ethanol (\$/unit)			0.49	0.49	0.60
RIN price for biodiesel (\$/unit)			0.73	2.02	1.06
Ethanol quantity (billion gal.) ^a	7.946	4.123	14.140	15.167	16.909
Blending ratio of ethanol (%) ^b	5.457	3.000	9.877	10.692	11.600
Biodiesel quantity (billion gal.) ^a	0.686	0.686	1.779	3.275	1.138
Gasoline fuel quantity (billion GEEGs)	143.265	136.216	139.051	137.349	140.750
Diesel fuel quantity (billion DEEGs)	49.202	47.334	46.548	46.898	45.846
Other refined products (billion KEEGs)	82.097	79.236	76.476	74.887	76.314
Corn production (billion bus.)	13.474	12.959	14.216	14.218	14.643
Soybean production (billion bus.)	4.002	4.082	3.927	3.984	3.835
Corn demand (billion bus.)	8.089	8.231	7.851	7.805	7.752
Corn export (billion bus.)	2.583	2.993	1.833	1.615	1.585
Soybean meal demand (million tons)	47.113	46.540	48.408	49.052	48.609
Soybean meal export (million tons)	54.133	53.236	56.572	58.146	56.643
Soybean oil demand (billion lbs.)	12.801	12.773	12.260	11.467	12.623
Soybean oil for biodiesel (billion lbs.)			8.363	19.803	3.457
Soybean oil export (billion lbs.)	31.096	32.046	22.421	12.425	25.918
Crude oil domestic supply (billion bbl)	3.475	3.462	3.450	3.443	3.449
Crude oil import (billion bbl)	3.284	3.092	2.907	2.800	2.896
Crude oil foreign demand (billion bbl)	23.131	23.201	23.268	23.307	23.272

Note: ^a Quantities (from all sources) blended into US fuel supply. ^b Calculated by using physical units (ratio of gallons of ethanol to gallons of gasoline fuel).

Table 4. Welfare Effects of Alternative Policies (changes relative “No RFS” scenario)

	<i>Laissez Faire</i>	2015 Mandates	2022 Mandates	Optimal Mandates
Social welfare (\$ billion)	2.562	2.647	-1.900	3.344
Pollution effect ^a	-1.866	-0.106	0.422	-0.336
Tax revenue	-86.165	0.516	2.168	2.987
P.S. Agriculture ^b	9.266	14.112	21.783	13.481
P.S. Crude oil supply ^b	2.519	-2.422	-3.814	-2.564
Efficiency cost of cellulosic biofuel ^c		-0.221	-1.417	
C.S. Crop products' demand ^d	-2.652	-8.154	-10.496	-9.223
C.S. Fuel demand ^d	73.851	6.008	0.507	6.495
Gasoline fuel demand	45.000	17.828	7.080	28.688
Diesel fuel demand	28.851	-11.820	-6.573	-22.194
C.S. Other refined products ^d	7.608	-7.086	-11.054	-7.495
GHG emissions (million tCO₂e) ^a	93.28	5.28	-21.09	16.80
Changes in the United States	128.52	-28.73	-74.68	-19.21
Changes in the ROW	-35.24	34.01	53.60	36.01

Note: ^a In the “No RFS” scenario the GHG emission level is 14,684 [2,976 (US) + 11,709 (ROW)] million tCO₂e, the monetary cost of which is \$293.7 billion. ^b P.S. = producer surplus. ^c Computed based on a D3 RIN price of \$1.80. ^d C.S. = consumer surplus.

Table 5. Sensitivity Analysis: Terms-of-Trade (TOT) Effects

	Baseline	No TOT effects		No crude oil TOT		No agricultural TOT	
Policies / Market Effects	2015 Mandates	2022 Mandates	Optimal Mandates	2022 Mandates	Optimal Mandates	2022 Mandates	Optimal Mandates
Gasoline motor fuel tax (\$/gal.)	0.449	0.449	0.449	0.449	0.449	0.449	0.449
Diesel motor fuel tax (\$/gal.)	0.516	0.516	0.516	0.516	0.516	0.516	0.516
Biodiesel subsidy (\$/gal.)	1.000						
Cellulosic biofuel mandate (billion units)	0.123	0.787		0.787		0.787	
Advanced biofuel mandate (billion units)	2.880	5.787	1.117	5.787	1.454	5.787	1.117
Renewable biofuel mandate (billion units)	16.930	20.787	5.159	20.787	16.723	20.787	9.662
Corn price (\$/bu.)	3.68	3.68	3.68	3.85	3.73	3.68	3.68
Soybean price (\$/bu.)	10.10	10.10	10.10	11.18	9.48	10.10	10.10
Soybean meal price (\$/ton)	368.49	368.49	368.49	362.09	370.52	368.49	368.49
Soybean oil price (¢/lb.)	31.60	31.60	31.60	42.44	25.78	31.60	31.60
Crude oil price (\$/bbl)	48.40	48.40	48.40	48.40	48.40	48.03	48.88
Gasoline price (\$/gal.)	1.72	1.76	1.88	1.75	1.65	1.75	1.79
Diesel price (\$/gal.)	1.67	1.50	1.44	1.52	1.84	1.48	1.65
Ethanol price (\$/gal.)	1.61	1.61	1.61	1.66	1.62	1.61	1.61
Biodiesel (supply) price (\$/gal.)	3.65	3.65	3.65	4.48	3.20	3.65	3.65
RIN price for ethanol (\$/unit)	0.49	0.44	0.41	0.49	0.55	0.44	0.46
RIN price for biodiesel (\$/unit)	0.73	1.47		2.00	0.98	1.48	
Ethanol quantity (billion gal.)	14.140	15.167	4.129	15.167	15.357	15.167	8.633
Blending ratio of ethanol (%)	9.877	10.685	3.000	10.703	10.589	10.675	6.140
Biodiesel quantity (billion gal.)	1.779	3.275	0.686	3.275	0.911	3.275	0.686
Corn export (billion bu.)	1.833	1.568	4.628	1.615	1.769	1.568	3.370
Soybean meal export (million tons)	56.572	57.421	47.636	58.146	56.074	57.421	51.657
Soybean oil export (billion lbs.)	22.421	10.982	30.785	12.425	27.788	10.982	30.785
Crude oil domestic supply (billion bbl)	3.450	3.450	3.450	3.450	3.450	3.443	3.458
Crude oil import (billion bbl)	2.907	2.797	3.114	2.786	2.933	2.810	3.033
Welfare Impacts (relative to “No RFS”)							
Social welfare (\$ billion)		-11.268	0.0	-3.725	2.143	-9.522	0.146
Pollution effect		1.549	0.0	1.696	0.361	0.330	-0.191
Tax revenue		2.088	0.0	1.880	2.527	2.364	1.163
P.S. Agriculture		-1.243	0.0	21.307	10.686	-0.797	-1.412
P.S. Crude oil supply		0.0	0.0	0.0	0.0	-3.646	-0.741
Efficiency cost of cellulosic biofuel		-1.417	0.0	-1.417	0.0	-1.417	0.0
C.S. Crop products’ demand		0.0	0.0	-10.490	-7.921	0.0	0.0
C.S. Fuel demand		-0.985	0.0	-4.933	3.120	4.219	3.518
C.S. Other refined products		-11.260	0.0	-11.768	-6.629	-10.576	-2.192
GHG emissions (million tCO ₂ e)		-77.45	0.0	-84.81	-18.04	-16.52	9.55
Changes in the United States		-77.45	0.0	-84.81	-18.04	-67.76	-0.85
Changes in the ROW		0.0	0.0	0.0	0.0	51.24	10.40

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Appendix

Table A1. Technical Coefficients

Parameter	Symbol	Value	Source/explanation
Ethanol production coefficient (gal./bu.)	α_e	2.8	Cui et al. (2011)
Ethanol by-product replacing corn in feed, as fraction of corn used for ethanol	δ_1	0.218	$\delta_1 = 0.307 \times 0.71$
Ethanol by-product replacing soy meal in feed, as fraction of corn used for ethanol	δ_2	0.003	$\delta_2 = (0.307 \times 0.29)(56/2000)$
Biodiesel production coefficient (gal./lb.)	α_b	0.131	EIA ^a
Soybean meal production coefficient (tons/bu.)	α_m	0.024	$\alpha_m = 45.1/1,873$ ^b
Soybean oil production coefficient (lbs./bu.)	α_o	11.425	$\alpha_o = 21,399/1,873$ ^b
Gasoline heat content (mil. BTUs/bbl)	ζ_1	5.06	EIA
Diesel heat content (mil. BTUs/bbl)	ζ_2	5.77	EIA
Ethanol heat content (mil. BTUs/bbl)	ζ_3	3.558	EIA
Biodiesel heat content (mil. BTUs/bbl)	ζ_4	5.359	EIA
Ethanol energy equivalent coefficient (GEEGs/gal.)	ζ_e	0.703	$\zeta_e = \zeta_3 / \zeta_1$
Biodiesel energy equivalent coefficient (DEEGs/gal.)	ζ_b	0.929	$\zeta_b = \zeta_4 / \zeta_2$
Gasoline production coefficient (gal./bbl)	β_g	21.286	$\beta_g = x_g / x_R$
Diesel production coefficient (gal./bbl)	β_d	9.115	$\beta_d = x_d / x_R$
Other refined petroleum products production coefficient (KEEGs/bbl)	β_h	13.96	$\beta_h = (42 \times 1.063 - \beta_g - \beta_d) \times 0.98$ ^c
“Equivalence value” of RIN generation for biodiesel	g	1.5	Schnepf & Yacobucci (2013)
Fraction of cellulosic ethanol in cellulosic biofuel	μ_{ce}	0.02, 0.10	Assumed ^d
Required fraction of ethanol as oxygenate	μ_{oxy}	0.03	Assumed

Note: ^a Corresponds to 7.65 pounds of soybean oil per gallon of biodiesel.

^b Data taken from <https://www.ers.usda.gov/data-products/oil-crops-yearbook/>

^c The coefficient 1.063 accounts for 6.3% average “refinery yield” gains accrued in 2015, whereas 0.98 is the weighted average of kerosene energy equivalence for petroleum products in this category.

^d The benchmark value of $\mu_{ce} = 0.02$ is estimated from EPA’s “RIN generation summary” over 2014-2016. For the 2022 (and optimal mandates) scenarios we set $\mu_{ce} = 0.10$, consistent with data and discussion contained in EPA (2016).

Table A2. GHG Emission Rates (kg CO₂e/gallon) and Social Marginal Damage

Parameter	Symbol	Value	Source/explanation
Gasoline	E_g	11.831	EPA (2010)
Diesel	E_d	13.327	EPA (2010)
Corn-based ethanol	E_e	6.572	$E_g \times 0.79 \times \zeta_e$ (EPA 2010) ^a
Sugarcane ethanol	E_{se}	3.245	$E_g \times 0.39 \times \zeta_e$ (EPA 2010) ^a
Cellulosic biofuel	E_{ce}	3.328	$E_g \times 0.40 \times \zeta_e$ ^a
Biodiesel	E_b	5.332	$E_d \times 0.43 \times \zeta_b$ (EPA 2010) ^a
Other refined petroleum products	E_h	9.410	EIA ^b
Crude oil (kg CO ₂ e/bbl)		504.67	Computed from E_g , E_d and E_h
Marginal emissions damage (\$/tCO ₂)	γ	20.0	Stern (2007) and Cui et al. (2011)

Note: ^a Life-cycle GHG emissions rates per energy unit relative to gasoline and diesel baselines (EPA 2010, Chapter 2.6). ^b Weighted average of CO₂ emissions rates from various other refined products (see text).

Footnotes

¹ To keep the analysis tractable we avoid the structural representation of other vegetable oil industries. Insofar as soybean oil is a close substitute for other vegetable oils that can also serve as feedstock for biodiesel production, this simplification would seem to entail little loss of generality.

² RINs are identifiers assigned to biofuel batches at production. They are “separated” from the physical product when the biofuel is blended with fossil transportation fuel. Such separated RINs can then be used by obligated parties to show compliance. Obligated parties can meet the RIN requirements by buying a sufficient amount of biofuel themselves or, alternatively, by buying separated RINs from other parties (McPhail, Westcott and Lutman, 2011).

³ Although the biodiesel mandate is defined in physical volume, when biodiesel is used to meet the advanced biofuel standard, or the overall renewable fuel standard, each gallon is multiplied by an “equivalence value” (either 1.5 or 1.7) (Schnepf and Yacobucci 2013).

⁴ Lade, Lin Lawell and Smith (2016) also find that biodiesel served as the marginal biofuel for RFS compliance in 2013. Irwin and Good (2016) derive mandate projections to 2022 very similar to ours.

⁵ The supplementary appendix online provides an explicit justification for this assumption based on Beckman, Borchers and Jones (2013). Note that, whereas this simplifies the representation of the relevant equilibrium conditions, we still can account for the impact of changing equilibrium energy prices (across scenarios) in the computation of agricultural producer surplus.

⁶ Sobolevsky, Moschini and Lapan (2005) explain why, given the maintained assumptions, the location of soybean processing is undetermined such that the only meaningful trade flows that can be recovered by competitive equilibrium pertain to the factor content of trade.

⁷ In the RFS regulation, these fuels are denoted as D6, D5, D4 and D3, respectively.

⁸ Most of the current production of cellulosic biofuel takes the form of compressed natural gas and liquefied natural gas derived from biogas (EPA 2016). Note, however, that the full mandate x_{ce}^M is relevant for the purpose of refiners/blenders’ cost of compliance with the RFS, as discussed below.

⁹ The marketing year runs September to August for corn and soybeans, and October to September for soybean meal and soybean oil.

¹⁰ The relative lifecycle GHG emissions rates for corn-ethanol, sugarcane ethanol, and biodiesel—when fuels are measured in energy equivalent units—are 79%, 39% and 43%, respectively, compared to corresponding fossil fuel baselines. For cellulosic biofuel, the EPA requires that

qualifying products provide at least a 60% emission savings relative to fossil fuels, so we conservatively assumed this limit value in calculating the carbon emission coefficient in table A2.

¹¹ These products—aviation gasoline, kerosene-type jet fuel, propane, kerosene and residual fuel oil—account for 52%, by weight, of all other refined petroleum products. Owing to the assumed Leontief technology, the assumed emission rates for refined products can alternatively be expressed per units of crude oil consumption, and this rate is used to compute GHG changes in the ROW.

¹² The US government’s estimate for the 2015 social cost of carbon (in 2007 dollars) ranges from \$11/ton of CO₂ (when using a 5% discount rate) to \$56/ton of CO₂ (when using a 2.5% discount rate), with an additional estimate of \$105/ton of CO₂ to represent higher-than-expected impacts of temperature changes (US Government 2016, p. 4).

¹³ The average annual biodiesel price for 2015 that we computed from USDA data \$2.83/gallon. (National Weekly Ag Energy Round-Up, USDA Ag Marketing Service).

¹⁴ Computation of this price requires simultaneously solving equations (26), (32) and (33), which also yields the blended fuel prices p_{gf} and p_{df} at the calibration point.

¹⁵ The core value for cellulosic biofuel RINs, used to impute the social cost of (exogenous) cellulosic biofuel mandates, is estimated at \$1.80 per unit (from the average of D6 RIN prices, over the relevant period, as reported in “PFL Weekly RIN Recap”).

¹⁶ For this scenario, however, we assume that even without biofuel policies a certain amount of ethanol is used by blenders as a gasoline oxygenate. This is modeled as a technological minimum requirement, which is set at 3% of the blended gasoline fuel. The supplementary appendix online provides the equilibrium conditions for the case when this requirement is binding.

¹⁷ The elasticity of the ROW crude oil demand used to estimate the leakage effect is $\bar{\varepsilon}_R = -0.2$. As detailed in the supplementary appendix online, this is the demand elasticity that is implied by the model’s assumed elasticities for refined petroleum products’ demands. This value was also used to rationalize the ROW crude oil export supply elasticity used in the model.

¹⁸ Given the assumed emission rates and social cost of carbon, the per-gallon Pigouvian taxes needed to correct the externality would be \$0.237 for gasoline, \$0.267 for diesel, \$0.131 for corn-based ethanol, and \$0.106 for biodiesel. Of course, motor fuel taxes can be rationalized in the pursuit of more than just reduction in carbon emissions, such as reducing congestion and other externalities associated with vehicle use (Parry and Small 2005).

¹⁹ In a recent intercept survey carried out in five US states, Liao, Pouliot and Babcock (2016) find that about 50% of FFV motorists use E85. At present, FFVs constitute approximately 8.3% of the US fleet of gasoline-powered cars and light trucks (EIA 2016). Because E85 on average contains 74% ethanol, if half of FFV miles were to be fueled by this blend, the ethanol “saturation point” would be about 12.2%. Liao, Pouliot and Babcock (2016) also find that E85 is sold at a premium relative to E10 (on an energy equivalent basis), so that a higher saturation point could actually be supported if E85 were to be priced more aggressively.

²⁰ Similar considerations also pertain to the reported RIN prices for the year 2022 scenario.

²¹ As consumers are likely heterogeneous with respect to the convenience cost of refueling, an accurate aggregate demand representation of this imperfect substitutability would require considerable information on the distribution of the relevant consumer heterogeneity, making calibration nontrivial. The alternative of representing imperfect substitutability between E10 and E85 by means of CES demand functions, as done by Meiselman (2016), does not appear attractive in this context.

²² A more accurate assessment would consider mandate levels that are optimal given the blend wall, with an explicit representation of the imperfect substitutability between E10 and E85. Alternatively, in the context of our model, we can compute the optimal mandates conditional on a maximum ethanol blend ratio of 10%. Such optimal mandates produce a welfare change of \$3.18 billion (relative to no biofuel policies). Hence, whatever investment that may be required to permit the larger blend ratio of the optimal mandates in table 4 would increase welfare by a mere \$0.17 billion.

Attachment B

Renewable Fuels Association. “Ethanol Consumption Breaks Through the ‘Blend Wall’ in 2016.” April 2017.

ETHANOL CONSUMPTION **BREAKS THROUGH** THE “BLEND WALL” IN 2016



SUMMARY:

ETHANOL CONSUMPTION BREAKS THROUGH THE “BLEND WALL” IN 2016

Recent data from the U.S. Energy Information Administration (EIA) confirm that the so-called “blend wall”—the point at which ethanol makes up 10% of the U.S. gasoline supply—was exceeded nationwide for the first time ever in 2016. The data dispel the myth that 10% is the marketplace “limit” for ethanol content in U.S. gasoline, and demonstrate that the “blend wall” is not a real constraint on ethanol consumption.

Growing consumption of E15 (gasoline blends containing 15% ethanol), mid-level blends (containing 20-50% ethanol) and flex fuels (containing 51-83% ethanol) was responsible for the increase in the average ethanol content of U.S. gasoline in 2016. Based on EIA data and assumptions about the demand for ethanol-free gasoline (E0) from the American Petroleum Institute (API) and U.S. EPA, we estimate that consumption of mid-level blends and flex fuels was no less than 450 million gallons and as much as 1.7 billion gallons in 2016. Volumes at the high end of this range are based on API’s assumption that E0 consumption is approximately 5.3 billion gallons annually. A summary of key findings is provided below:

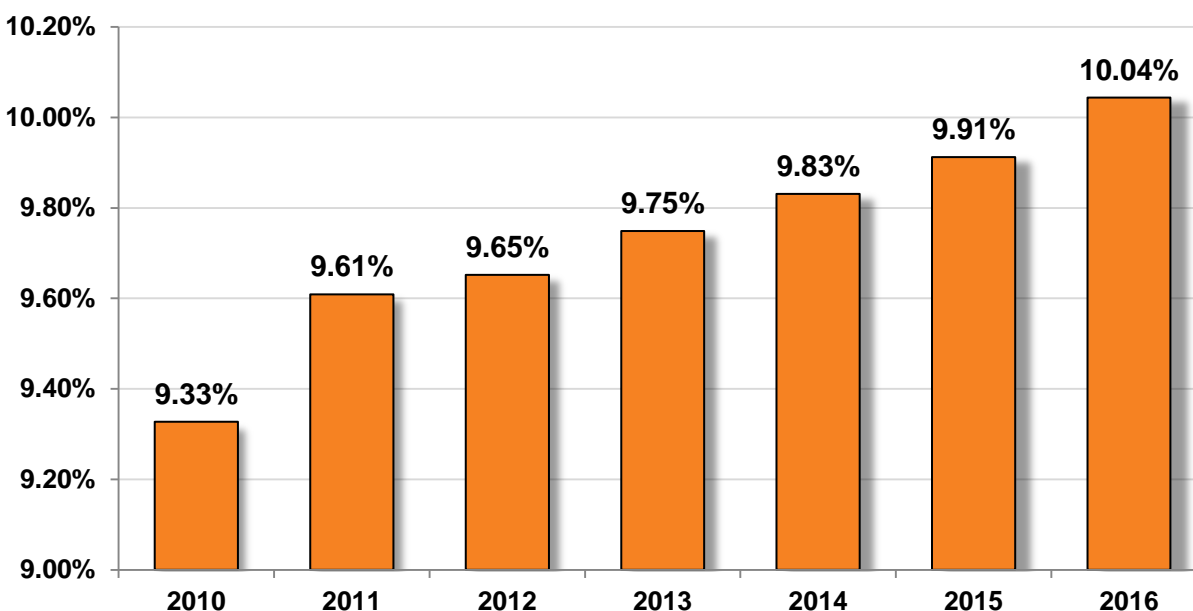
- Finished motor gasoline contained **10.04%** fuel ethanol on average in 2016, meaning nationwide ethanol consumption exceeded the so-called “blend wall” for the first time.
- National average ethanol content was 10.0% or higher in six of the last seven months of 2016, culminating with a record high monthly rate of **10.30%** in December.
- On a weekly basis, the ethanol blend rate surpassed 10.0% in 13 of the 20 weeks between Oct. 8, 2016, and Feb. 24, 2017, hitting a weekly record of **10.41%** in early January 2017.
- These data undermine the assertion by API and others that the gasoline market cannot accommodate more than 9.7% ethanol due to purported infrastructure and vehicle constraints. April 2015 was the last time average ethanol content was *below* 9.7%.
- Using the most conservative assumptions, EIA data imply that **447 million gallons** of mid-level blends and flex fuels (containing 313 million gals. of ethanol) were consumed in 2016.
- However, if API’s assumptions about E0 demand are used, then consumption of mid-level blends and flex fuels was **1.2 to 1.7 billion gallons** (843 mil. to 1.17 bil. gals. of ethanol).
- Logically, as the assumed volume of E0 sales is increased, the amount of ethanol consumed in E10 falls, but the amount of ethanol consumed in E15, mid-level blends, and flex fuels rises significantly.
- The EIA data demonstrate that the supposed “blend wall” is not a real constraint on ethanol consumption in the United States. The data further underscore that statutory Renewable Fuel Standard (RFS) blending obligations in excess of the 10.0% level can be readily satisfied by the marketplace.

ETHANOL CONSUMPTION BREAKS THROUGH THE “BLEND WALL” IN 2016

Gasoline consumed in the United States contained more than 10.0% ethanol on average in 2016, meaning the so-called “blend wall”—the point at which ethanol makes up 10% of the gasoline supply—was exceeded nationwide for the first time ever.

Data from the Energy Information Administration (EIA) show that U.S. fuel ethanol consumption was 14,399,140,000 gallons in 2016, while 143,367,042,000 gallons of finished motor gasoline were supplied to the U.S. market.¹ Thus, finished motor gasoline contained 10.04% fuel ethanol on average (Figure 1). These data demonstrate that the supposed “blend wall” is not a real constraint on ethanol consumption in the United States. Further, the EIA data underscore that statutory Renewable Fuel Standard (RFS) blending obligations in excess of the 10% level can in fact be satisfied by obligated parties.

Figure 1.
Annual U.S. Average Ethanol Content of Finished Gasoline, 2010-2016



Source: U.S. EIA

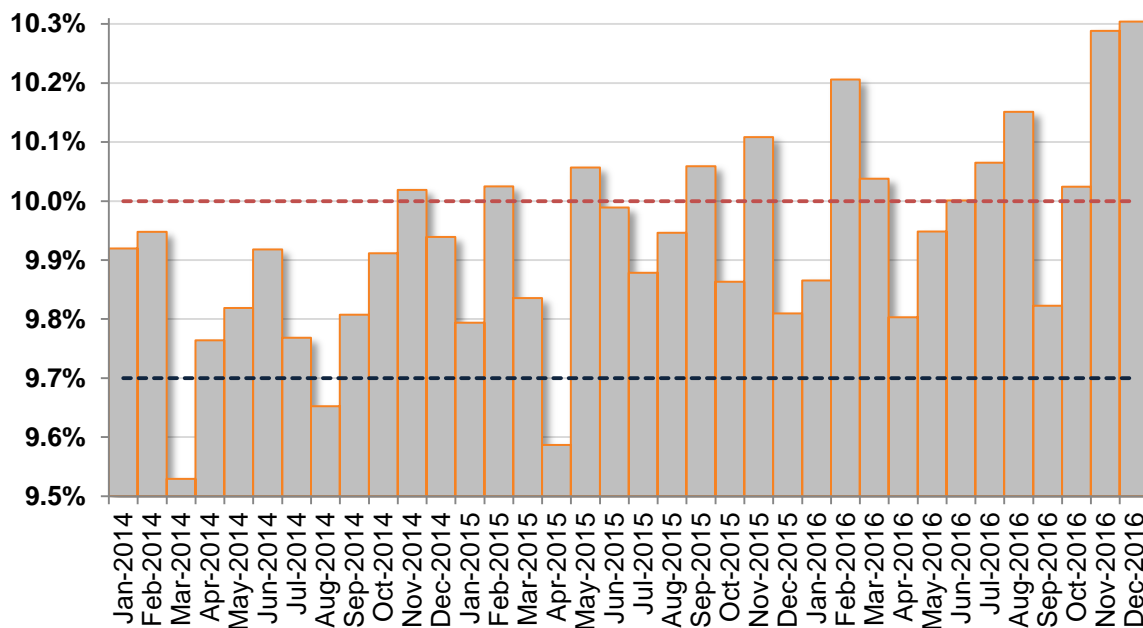
Nearly all of the gasoline consumed in the United States last year contained 10% ethanol by volume (E10). However, a small volume of ethanol-free gasoline (E0) was consumed as well. Thus, the average blend rate of 10.04% implies increased consumption of blends containing 15% ethanol (E15), “mid-level” blends containing 20-50% ethanol (e.g., E20 or E30), and flex fuels containing 51-83% ethanol (often colloquially called “E85”).

¹ U.S. Energy Information Administration (EIA). “Petroleum Supply Monthly: U.S. Product Supplied of Finished Motor Gasoline.” (<https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=p&s=m&f=a>) (According to EIA, “product supplied...represents consumption of petroleum products because it measures the disappearance of these products from primary sources (emphasis added).”); and “Monthly Energy Review: Renewable energy: Table 10.3 Fuel Ethanol Overview.” (<https://www.eia.gov/totalenergy/data/monthly/>)

While half of the 50 states had already surpassed the 10.0% ethanol concentration level in 2015 due to broader use of E15, mid-level blends and ethanol flex fuels², 2016 marks the first time that the national average for ethanol content in gasoline exceeded 10.0%.

On a monthly basis, national average ethanol content trended higher throughout 2016. Ethanol content was 10.0% or higher in six of the last seven months of 2016, culminating with a record high monthly rate of 10.30% in December (Figure 2). Further, weekly EIA data (which tend to underestimate actual ethanol blending and consumption when later compared to EIA monthly data) show the average ethanol blend rate exceeded 10.0% in 13 of the 20 weeks between October 8, 2016, and February 24, 2017. The weekly ethanol blend rate hit a record high of 10.41% in early January. These data from EIA undermine the assertion by the American Petroleum Institute (API) and others that the gasoline market cannot exceed 9.7% denatured fuel ethanol content due to purported infrastructure and vehicle constraints.³ In reality, April 2015 was the last month in which the national average for ethanol content was *below* 9.7%. In the 20 months since, the ethanol content of finished gasoline has averaged 10.01% nationally.

Figure 2.
Monthly U.S. Average Ethanol Content of Finished Gasoline



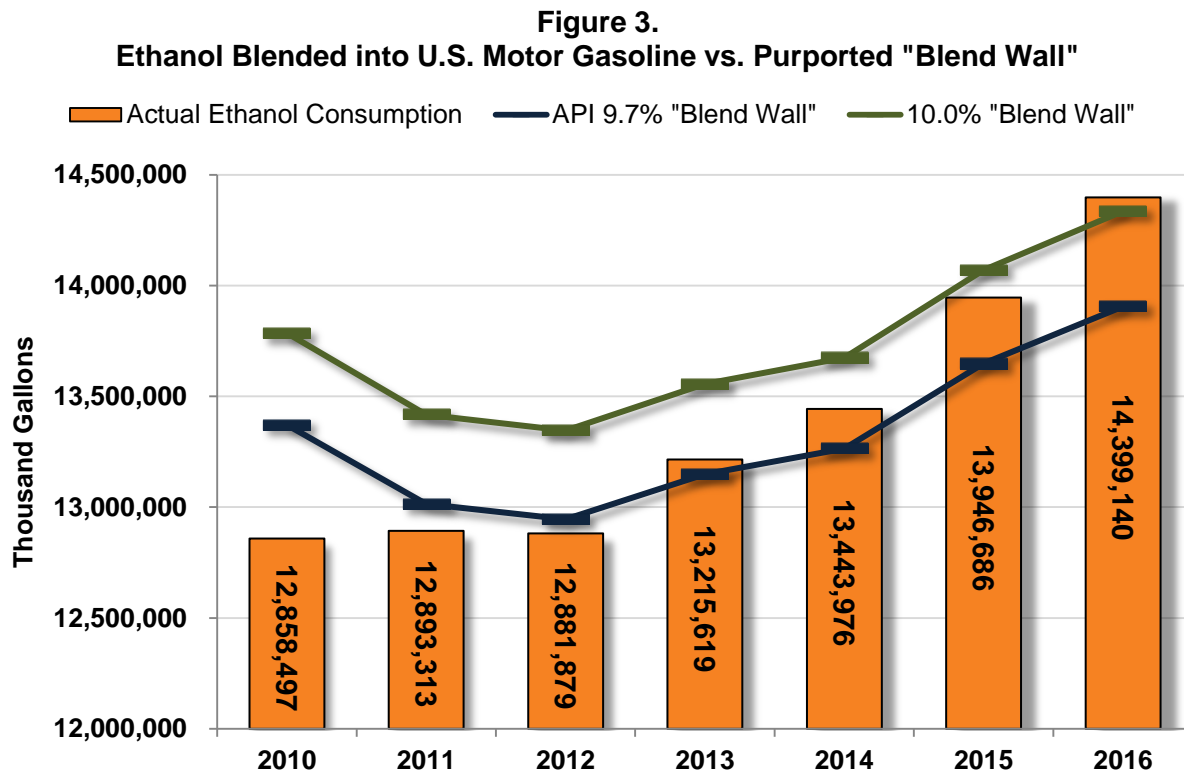
Source: U.S. EIA

The difference between ethanol concentration rates of 9.7% and 10.04% might at first seem trivial. But across billions of gallons of gasoline, the seemingly modest increase in the ethanol blend rate is actually quite significant. For example, if the gasoline market were truly limited to a

² RFA. "DOE Data: Half of United States Broke Through So-Called 'Blend Wall' in 2015." Dec. 13, 2016. (<http://www.ethanolrfa.org/2016/12/doe-data-half-of-united-states-broke-through-so-called-blend-wall-in-2015/>)

³ See, for example, Comment submitted by Frank J. Macchiarola, Group Director, Downstream and Industry Operations, American Petroleum Institute (API). July 11, 2016. (<https://www.regulations.gov/document?D=EPA-HQ-OAR-2016-0004-3512>)

maximum of 9.7% ethanol, total ethanol blending in 2016 would have been nearly 500,000,000 gallons lower. This is roughly equivalent to the annual output of six average-sized fuel ethanol plants. Due to incremental growth in both total gasoline demand and the ethanol blend rate, total U.S. ethanol blending in 2016 was more than 1,500,000,000 gallons higher (12%) than just five years earlier in 2012 (Figure 3).



Source: U.S. EIA

HOW MUCH ETHANOL WAS CONSUMED IN BLENDS ABOVE E10 IN 2016?

While a simple examination of U.S. ethanol and finished gasoline consumption data reveals the average ethanol content across the entire gasoline pool, it does not readily uncover the volume of ethanol consumed in blends other than E10. Some volume of gasoline contained no ethanol at all (E0), while other volumes contained significantly more than the average concentration (e.g., flex fuels like E70 or E85). The EIA data sets do not reveal the volume of E0 supplied to the retail market, nor do they show how much ethanol was specifically consumed in E10 blends versus higher-level blends (e.g., E15 and flex fuels). However, we are able to approximate the volume of ethanol consumed in mid-level blends and flex fuels based on various publicly available estimates of E0 consumption.

By subtracting total fuel ethanol consumption from total finished motor gasoline supplied, we are able to derive the total amount of "unblended" gasoline and gasoline blendstock consumed in 2016, which was 128,967,902,000 gallons. Some of this gasoline volume was indeed consumed at retail as E0, but most of it was blended with 10% ethanol before being distributed to retail

stations and sold to consumers. Based on the EIA data, we know a total of 14,399,140,000 gallons of fuel ethanol were blended with gasoline. Thus, making certain assumptions about E0 retail consumption allows us to estimate how much ethanol was consumed both in E10 blends as well as higher-level ethanol blends.

The amount of assumed E0 consumption significantly affects the implied volume of ethanol consumed in mid-level blends and flex fuels. That is, if it is assumed that a very small volume of E0 is consumed at retail (e.g., 0.5% of total gasoline consumption), then the amount of ethanol consumed in E10 blends will be larger, and the implied volume of ethanol consumed in mid-level blends and flex fuels will be relatively modest. Conversely, if it is assumed that a relatively large volume of E0 is consumed (e.g., 3.5% of total gasoline consumption), then E10 consumption will be lower, but the volume of ethanol consumed in mid-level blends and flex fuels will be much higher.

Estimates of E0 consumption vary widely. The U.S. Environmental Protection Agency's (EPA) most recent estimate for E0 consumption was 700,000,000 gallons in 2015⁴, while the API asserts that E0 consumption in 2015 was 5,300,000,000 gallons.⁵ For the reasons stated by EPA in response to API's comments on the 2014-2016 RFS proposal, we believe EPA's estimate is far more credible than API's estimate.⁶ However, both estimates are used in this analysis as bounds for the range of E0 consumption, and to illustrate the importance of this assumption.

Further, to derive an estimate of the amount of ethanol consumed in mid-level blends and flex fuels, assumptions must be made regarding the actual ethanol content of E10 blends. The API states that E10 blenders "...blend slightly less than 10 percent [ethanol] to address measurement inaccuracies and avoid compliance issues."⁷ API suggests that blenders target 9.7% ethanol for E10 blends, though we believe the actual average ethanol content of E10 is likely closer to 9.9% ethanol. Again, we use both values as bounds for the range of actual ethanol content in E10.

Other Assumptions

Estimating the volume of ethanol consumed in mid-level blends and flex fuels in 2016 requires certain other assumptions to be made. Specifically, the volume of E15 sold and the average ethanol content of mid-level blends and flex fuels (grouped together in this analysis as E20-E85) must be estimated.

E15: Relatively small, but growing, volumes of E15 were consumed in 2016. Based on our knowledge of the number of stations selling E15 in 2016 and typical sales volumes per station, we estimate that a total of approximately 90,000,000 gallons of E15 were sold. Based on

⁴ 81 Fed. Reg. 89776 (Dec. 12, 2016)

⁵ Comment submitted by Frank J. Macchiarola, Group Director, Downstream and Industry Operations, American Petroleum Institute (API). July 11, 2016. (<https://www.regulations.gov/document?D=EPA-HQ-OAR-2016-0004-3512>)

⁶ 80 Fed. Reg. 77462 (Dec. 14, 2015)

⁷ Comment submitted by API and American Fuel & Petrochemical Manufacturers (AFPM). Re: Renewable Fuel Standard Program: Standards for 2014, 2015, and 2016 and Biomass- Based Diesel Volume for 2017. July 27, 2015. https://www.afpm.org/uploadedFiles/Content/Policy_Positions/Agency_Comments/API%20AFPM%20RFS%20Comments%20July%202015.pdf

information provided by blenders and retailers, we further assume the actual average denatured ethanol content of E15 was 14.5%. Because the volume of E15 consumed was relatively small in 2016, varying these assumptions does not significantly change the resultant estimate of the amount of ethanol consumed above the E10 “blend wall.” That is, if the actual amount of ethanol consumed in E15 blends was lower than we estimated here, then actual ethanol consumption in mid-level and flex fuel blends will be marginally higher than we estimated. Conversely, if actual E15 consumption was higher than estimated, then actual consumption of mid-level and flex fuel blends was marginally lower than estimated.

Mid-Level Blends and Flex Fuels: Small volumes of mid-level ethanol blends like E20, E30, and E40 are also being sold commercially, while larger volumes of ethanol flex fuels (defined by ASTM International as blends containing between 51-83% ethanol for use in flex fuel vehicles) are also being sold at more than 3,700 stations nationwide. For the purposes of this analysis, we assume the volume-weighted average denatured ethanol content of E20-E85 blends sold in 2016 was 70%.⁸

Scenarios

To determine the potential volume of ethanol sold in blends other than E10 in 2016, we examined four scenarios where two variables were altered: 1) the actual average ethanol content in E10, and 2) the volume of E0 sold at retail. Using these assumptions, a simple equation was used to solve E20-E85 consumption (average 70% ethanol) based on known EIA values for gasoline blendstock consumption, fuel ethanol consumption, and total finished motor gasoline. That is, the sum of gasoline blendstock and fuel ethanol volumes for E10, E0, E15, and E20-E85 blends under all scenarios must equal the totals from EIA.

Scenario A: E10 actual ethanol content = 9.9% (RFA) E0 consumption = 700 mg (EPA)	Scenario B: E10 actual ethanol content = 9.9% (RFA) E0 consumption = 5,300 mg (API)
Scenario C: E10 actual ethanol content = 9.7% (API) E0 consumption = 700 mg (EPA)	Scenario D: E10 actual ethanol content = 9.7% (API) E0 consumption = 5,300 mg (API)

Results

When the most conservative assumptions are used regarding E0 consumption and the actual ethanol content of E10 (Scenario A), the data suggest nearly 450,000,000 gallons of E20-E85 (with an average ethanol content of 70%) were consumed in 2016. On the other hand, when API’s assumptions are used regarding E0 consumption and E10 ethanol content (Scenario D), the level of E20-E85 consumption needed to solve the equation rises to more than 1,600,000,000 gallons in 2016. This is logical because if E0 consumption is relatively large, as argued by API, then less gasoline blendstock is available to blend with the known volume of fuel ethanol that was consumed, necessitating larger volumes of mid-level blends and flex fuels. The

⁸ This assumption is based on the volume-weighted average ethanol content of mid-level blend (E20, E30, E40, E50) and E85 (70% ethanol October-April, 83% ethanol May-September) sales volumes reported by the Minnesota Department of Commerce for 2016. (<http://mn.gov/commerce-stat/pdfs/e85-fuel-use-2016.pdf>)

actual volume of mid-level blends and flex fuels consumed in 2016 is likely somewhere in between the lowest and highest volumes resulting from these four scenarios.

Scenario A

	Gasoline Blendstock (gals.)	Fuel Ethanol (gals.)	Total Volume (gals.)	% Ethanol
E10	128,056,949,000	14,073,459,000	142,130,408,000	9.90%
E0	700,000,000	-	700,000,000	0.00%
E15	76,953,000	13,047,000	90,000,000	14.50%
E20-E85	134,000,000	312,634,000	446,634,000	70.00%
Total	128,967,902,000	14,399,140,000	143,367,042,000	10.04%

Scenario B

	Gasoline Blendstock (gals.)	Fuel Ethanol (gals.)	Total Volume (gals.)	% Ethanol
E10	123,229,549,000	13,542,927,000	136,772,476,000	9.90%
E0	5,300,000,000	-	5,300,000,000	0.00%
E15	76,953,000	13,047,000	90,000,000	14.50%
E20-E85	361,400,000	843,165,000	1,204,565,000	70.00%
	128,967,902,000	14,399,140,000	143,367,042,000	10.04%

Scenario C

	Gasoline Blendstock (gals.)	Fuel Ethanol (gals.)	Total Volume (gals.)	% Ethanol
E10	127,913,149,000	13,737,872,000	141,651,021,000	9.70%
E0	700,000,000	-	700,000,000	0.00%
E15	76,953,000	13,047,000	90,000,000	14.50%
E20-E85	277,800,000	648,220,000	926,020,000	70.00%
Total	128,967,902,000	14,399,140,000	143,367,042,000	10.04%

Scenario D

	Gasoline Blendstock (gals.)	Fuel Ethanol (gals.)	Total Volume (gals.)	% Ethanol
E10	123,091,249,000	13,220,000,000	136,311,249,000	9.70%
E0	5,300,000,000	-	5,300,000,000	0.00%
E15	76,953,000	13,047,000	90,000,000	14.50%
E20-E85	499,700,000	1,166,092,000	1,665,792,000	70.00%
Total	128,967,902,000	14,399,140,000	143,367,042,000	10.04%

CONCLUSION

Recent data from EIA confirm that the so-called “blend wall” has been exceeded nationwide for the first time ever. The data dispel the myth that 10% is the marketplace “limit” for ethanol content in U.S. gasoline, and demonstrate that the “blend wall” is not a real constraint to future ethanol consumption. Based on known volumes of finished gasoline consumption and fuel ethanol consumption, and assumed volumes of E0 and E15 consumption, we were able to consumption of mid-level blends and flex fuels in 2016. When the most conservative assumptions are used, the data suggest nearly 450 million gallons of E20-E85 (with an average ethanol content of 70%) were consumed in 2016. On the other hand, when API’s assumptions are used, the level of E20-E85 consumption rises to more than 1.6 billion gallons in 2016. Regardless of the E0 assumptions used, the EIA data underscore that statutory Renewable Fuel Standard blending obligations in excess of the 10% level can be readily accommodated by the marketplace.