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Penelope L. Diebel

The United States Congress set out to increase the blending of biofuels by updating and implementing the Renewable Fuel Standard (RFS2) in 2007. The new mandate required that a combination of 36 billion gallons of ethanol, biodiesel, and cellulosic biofuel be blended annually, by 2022. To offset the cost of compliance with the mandate, Congress authorized the U.S. EPA to implement a renewable energy credit scheme for each type of biofuel produced. The credit, called a Renewable Identification Number (RIN), is generated for each gallon of biofuel produced and can be traded with other blenders who find it more expensive to blend biofuel.

Few studies have focused directly on the RIN market. Subsequently, there is a dearth of understanding about how the RIN program actually effects the production of blended fuels under the RFS2. This research aims to extend the available research by quantifying the effect that RINs have on the ethanol and biodiesel markets, using blending margins as a predictor for RIN prices. The biofuel supply chain is also considered for this analysis insofar as geography plays an important role in the costs associated with procuring biofuel to comply with the RFS2 mandate. To measure the effect that RINs have on the production of blended fuel, this analysis assumes that blenders face a trade-off between physically moving biofuel to combine with conventional fuel, and purchasing a RIN.

The analysis presented in this study provides a useful view of how blenders perceive the trade-off between blending biofuel and purchasing RINs in the immediate run. By understanding how blending margins effect RIN prices and in turn, how blenders respond to those prices, the hope is that this study can extend the understanding of the effectiveness of the current RIN program, relative to the goals set forth under the RFS2. This, in turn, should set the foundation for more sophisticated models in later research.

RINs and Biofuel Mandates: Comparing Ethanol and Biodiesel Markets

by
Joel H. Ainsworth

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APPROVED:

Major Professor, representing Applied Economics

Head of the Department of Applied Economics

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. Introduction

In 2007, the United States Congress updated the Renewable Fuel Standard (RFS2) program to increase the blending of various renewable fuels used for transportation. The updated requirements are enforced through a blending mandate, which will require approximately 36 billion gallons of renewable fuel to be blended annually, by 2022.

In order to reduce the financial burden and increase the efficiency of reaching the mandated blending goal by 2022, the U.S. Environmental Protection Agency (EPA) implemented a renewable credit market. The credit, called a Renewable Identification Number (RIN), can be traded with other blenders, or held as an option. Market complexities and favorable blending conditions have previously limited interest in exploring the RIN's effect on biofuel production, but recent price volatility in the ethanol market has begun piquing the interest of researchers across several disciplines.

There is a wealth of research that explores domestic and international biofuels markets under different policy regimes, however, few studies have focused on the RIN market. The few researchers who have investigated RINs have concentrated on RIN price formation and volatility to understand the welfare effects of different policy scenarios under the RFS2. What still appears to be lacking in the current research is a cogent discussion about how RINs can effect aggregate blended fuel production.

This analysis seeks to identify and compare how RINs affect the production of blended fuel up to the RFS2 mandate, in the ethanol and biodiesel markets under RFS2. To the knowledge of this researcher, only two previous studies have considered how RINs effect biofuel production by attempting to understand how agents interact with each other in the supply chain. Both studies have focused their analyses on the more ethanol market. Yet research from Thompson, et al. (2008) suggests that RINs can have a more significant effect on production in markets, such as biodiesel, where the RFS2 mandate is binding. A binding mandate means that blenders must comply with the mandate by blending above their optimal levels.

This analysis will extend the previous literature and provide a more holistic discussion on how RINs can effect aggregate biofuel blending. To understand how RINs can affect the blending of biofuels, we must consider the drivers of RIN prices and thereafter how agents in the biofuels market will respond to different prices. Geography is in important component to understanding how agents will respond to price changes in that blenders incur cost associated with physically transporting biofuel from producers. The changing price of procuring biofuel can have significant spillover effects along the supply chain as blenders decide how best to meet their blending mandates. This analysis will integrate the drivers of RIN prices and the supply chain in a simplified model to describe the effect that RINs have on blenders as they attempt to meet their mandate requirement in the ethanol and biodiesel markets.

1.1. The Renewable Fuel Standard

This section presents the background information on the Renewable Fuel Standard (RFS2) currently being enforced by the U.S. Environmental Protection Agency. Since the absence of the RFS2 would eliminate the need for a RIN market, a brief history about its creation is relevant to providing the context needed to understand the RIN market. Later sections provide an overview of the RIN lifespan and a brief discussion of the underlying economics. Finally, in the last section I introduce a qualitative overview of the biofuels supply chain, with an emphasis on the production facilities and the infrastructure used to move ethanol and biodiesel to blending facilities.

Background of the Renewable Fuel Standard

The RFS is the latest attempt in a series of federal legislation to increase fuel efficiency and promote alternative biofuel adoption across the United States. Though fuel conservation and renewable energy policies have a long history in the United States, early legislation was directed at the creation of fuel reserves during times of war (Duffield and Collins, 2006). Initial attempts at peacetime federal energy conservation initiatives and alternative energy adoption occurred during the 1970's after a turbulent time in the global energy supply and increasing oil prices.

The promotion of biofuels by the federal government can be traced back to the Energy Tax Act of 1978, which gave corn ethanol a $0.40 per gallon exemption from the motor vehicle excise tax for fuel blends that contained at least 10 percent ethanol (National Research Council, 2011). As anxieties about the global oil supply and national security grew, further legislation through the 1980's - 2000's introduced a series of tax credits and blending requirements to promote the adoption of biofuels, with biodiesel receiving its first tax credit under the American Jobs Creation Act of 2004 (Duffield and Collins, 2006).

While national security continued to play a prominent role in the promotion of biofuels, environmental policies also helped bolster demand. In an attempt to reduce damages from toxic air conditions, The Clean Air Act Amendments (CAAA) of 1990 required that fuel additives (containing alcohol or ether) be used in gasoline in locations where carbon monoxide levels exceeded federal air quality standards in the winter (McPhail, Westcott, and Lutman, 2011). While ether was initially the preferred additive compared to ethanol due to its lower price, studies later showed contamination issues to groundwater supplies, resulting in a ban across 25 states. With the EPA regulations for winter fuel additives still in place under the CAAA, ethanol became a primary tool for blenders to meet their requirements (Novack and Henderson, 2007).

Rural development through the growth of agricultural markets remained an underlying theme throughout the implementation of various federal biofuels initiatives. Congress attempted to incentivize biofuels production throughout the 1980's and 1990's with varying success. As the demand for ethanol continued to grow to meet blending requirements, the 2002 farm bill became first legislation by Congress to directly address the goal of rural development through biofuels policies (National Research Council, 2011). The Farm Security and Rural Investment

Act of 2002 supported programs dedicated to the education and procurement of bio-based products and included new programs dedicated to bioenergy (Johnson, 2008).

The initial Renewable Fuel Standard (RFS) was formally established under the Energy Policy Act of 2005, truly representing a convergence in national security, environmental and rural development policies using a single mandate. In addition to aligning incentives for biofuels production, the RFS also represented a shift in policy about how increased biofuels adoption would be achieved. As opposed to earlier blending requirements incentivized by tax credits, the RFS mandated a minimum number of gallons that would be blended into the U.S. gasoline market. The program initially required that 4 billion gallons of renewable fuel be blended into U.S. fuel in 2006 and increased to 7.5 billion gallons by 2012.

Current Structure of the Renewable Fuel Standard

In 2007, the RFS mandate was reexamined and expanded under the Energy Independence and Security Act (EISA), creating new categories for applicable biofuels while dramatically increasing the amount of fuel required to be blended into the U.S. fuel supply to 36 billion gallons by 2022 (McPhail, Westcott, and Lutman, 2011). In addition, the EISA requires that the EPA apply lifecycle analysis to new biofuels ensuring each new fuel source emits lower levels of greenhouse gases relative to traditional petroleum fuels (US EPA, 2014).

Under the existing guidelines for the second iteration of the Renewable Fuel Standard (RFS2), a renewable fuel is defined as any fuel produced using a biomass product that can be used to offset a given quantity of fossil fuel for transportation. Within this broader context of renewable fuels, the RFS2 further refines the definition of biofuels by distinguishing between conventional and advanced biofuels. Conventional biofuels refers to any cornstarch ethanol. Advanced biofuels, on the other hand, contain further subcategories, including cellulosic and biomass-based diesel. Each classification of biofuel has its own requirements for offsetting Greenhouse Gas (GHG) emissions relative to the baseline established under the EISA. The table below lists the biofuels categories as defined by the RFS, along with the required GHG offsets.

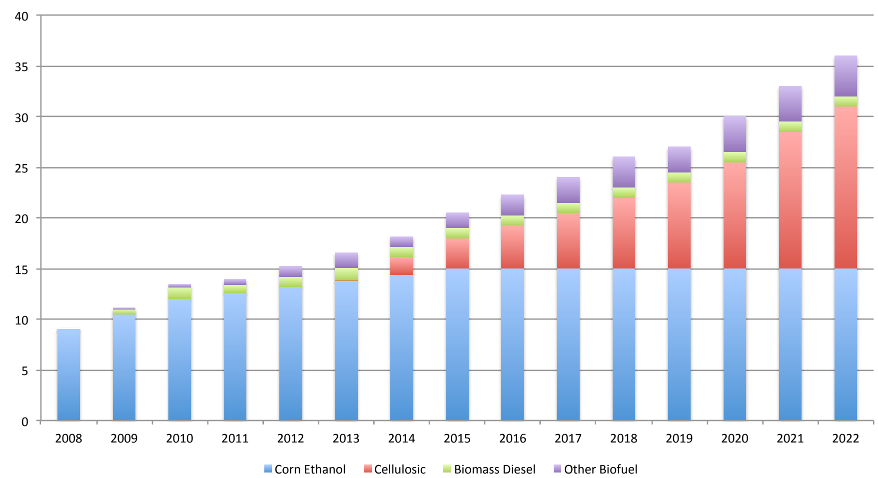
Table 1. Biofuel Categories and GHG Offsets Under the RFS2

Biofuel	Definition	Minimum GHG Reduction
Conventional Biofuel		
Corn Ethanol	Renewable fuel that is ethanol derived from corn starch	20 percent
Advanced Biofuel		
Cellulosic Biofuel	Renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass	60 percent
Biomass-Based Biofuel	A diesel fuel substitute produced from nonpetroleum renewable biomass, including animal byproducts, vegetable oil, and grease	50 percent
Other Advanced Biofuel	Any other renewable fuel than ethanol from corn starch, that is derived from renewable biomass	50 percent

Source: EISA, 2007 and U.S. EPA, 2014

This "nesting" within the mandate further complicates the RFS2 by requiring each category and sub-category to meet different Renewable Volume Obligations (RVO). As the mandated volume of renewable fuel increases to 36 billion gallons through 2022, the relative fuel makeup of the total mandate changes overtime. Starting in 2015, ethanol is capped at 15 billion gallons. Additionally by the year 2020, the EISA mandates that advanced biofuels account for half of the total renewable volumes. The chart below illustrates the RFS2 fuel volumes by category through the year 2020.

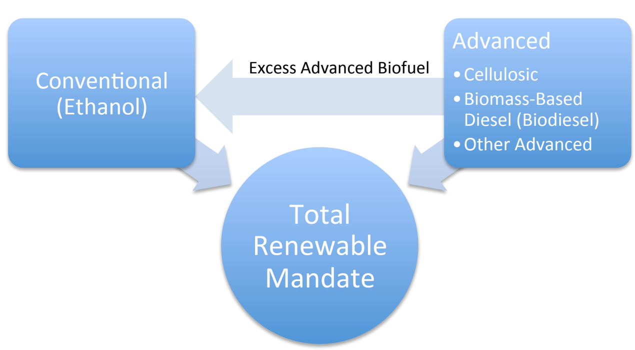
Figure 1. Renewable Fuel Standard Volumes by fuel category (in billions of gallons)



Source: EISA, 2007

Because of the separate mandates for fuel volumes, the nested subcategories create a hierarchy within the RFS2. As an example, by 2015 the RFS2 mandates that 1 billion gallons of renewable fuel come from biodiesel, while 3 billion gallons come from cellulosic biofuels. The RFS2 also specifies that an additional 1.5 billion gallons of “other” advanced biofuels be blended into the U.S. fuel supply that year. This portion of the advanced biofuels mandate can be met with either cellulosic, or biodiesel, along with any feedstock approved by the EPA that meets the minimum requirements of a 50 percent reduction in GHG emission. Additionally, any advanced biofuels generated in excess of the required mandate can be used to count toward the total mandate by offsetting conventional biofuels (i.e. ethanol).

Figure 2. Hierarchy of Biofuels Within the RFS2



While the RFS2 sets blending mandates at the national level, the EPA enforces compliance through obligated parties using the aforementioned RVOs. Under the RFS2, an obligated party includes any firm in the continuous United States, and Hawaii, that produces or imports diesel fuel and gasoline. The RVO formula can be calculated broadly, using the following formula:

$$RVO_{b,t} = \; RFStd_{b,t} * (GV_t + DV_t) + D_{b,t-1} \quad (1)$$

Where:

$RVO_{b,t}$ = The Renewable Volume Obligation for biofuel (*b*) for an obligated party in calendar year *t* (in gallons).

$RFStd_{b,t}$ = The standard determined by the U.S. EPA for biofuel (*b*) in calendar year *t* (in percent).

GV_t = The non-renewable gasoline volume, produced in or imported into the 48 contiguous states or Hawaii by an obligated party in calendar year *t* (in gallons).

DV_t = The non-renewable diesel volume, produced in or imported into the 48 contiguous states or Hawaii by an obligated party in calendar year *t* (in gallons).

$D_{b,t-1}$ = Deficit carryover from the previous year for biofuel (b) (in gallons).

Source: EISA, 2007 and EPA, 2014

To ensure compliance with the RFS2, an obligated party collects renewable energy credits for each gallon of biofuel they blend that meets the annual RVO set by the EPA. The same hierarchy described in the RFS2 also applies to each obligated party. In other words, each obligated party must meet their share of all four RVOs including: total renewable, advanced, biodiesel, and cellulosic biofuels to ensure compliance to the EPA in a given year.

An important note when considering an obligated party's obligation under RFS2 is that physical gallons of renewable fuels are actually measured by energy content relative to that of ethanol. This equivalence value (EV) is then translated into the number of gallons used to show compliance with the blending mandate.

Table 2. Equivalence Values

Fuel Type	Equivalence
Ethanol	1.0
Biodiesel (alkyl esters)	1.5
Renewable diesel	1.7
Butanol	1.3

Within the context of the hierarchy established under RFS2, the EV can be important for a blender attempting to meet their mandate. If a blender is using biodiesel to meet the biomass-based biodiesel requirement, each gallon of renewable fuel counts as 1 gallon. However, if that gallon is instead applied to the "other" advanced biofuels requirement, or to offset ethanol the EV will be 1.5 or 1.7 gallons.

1.2. Introduction to Renewable Identification Numbers

The renewable energy credits that each obligated party collects to demonstrate compliance with the RFS is given a 38-digit number known as a Renewable Identification Number (RIN). Each RIN contains information relevant to tracking the fuel and ensuring compliance with the RFS mandate is met. Within the 38-digit code includes the year of production, type of fuel, EV, and the firm that produced the fuel, along with other important information.

RIN = K YYYY CCCC FFFFF BBBBB RR D SSSSSSSS EEEEEEEE

K = Identifies if RIN is assigned or unassigned to fuel
YYYY = Year of production/importation
CCCC = Company ID
FFFFF = Facility or Plant ID
BBBBB = Producer batch number
RR = Equivalence Value (based on energy content)
D = Renewable Fuel Category
SSSSSSSS = Block starting number
EEEEEEEE = Block ending number

Category D, the fuel category corresponds with each type of conventional or advanced biofuel required under the RFS2 mandate. As previously mentioned in the discussion about nesting within the RFS2 hierarchy, biodiesel and cellulosic can fall into several categories to meet the blending requirements. Table 3 below illustrates the different RIN categories under RFS2.

Table 3. RIN Identifier and Categories

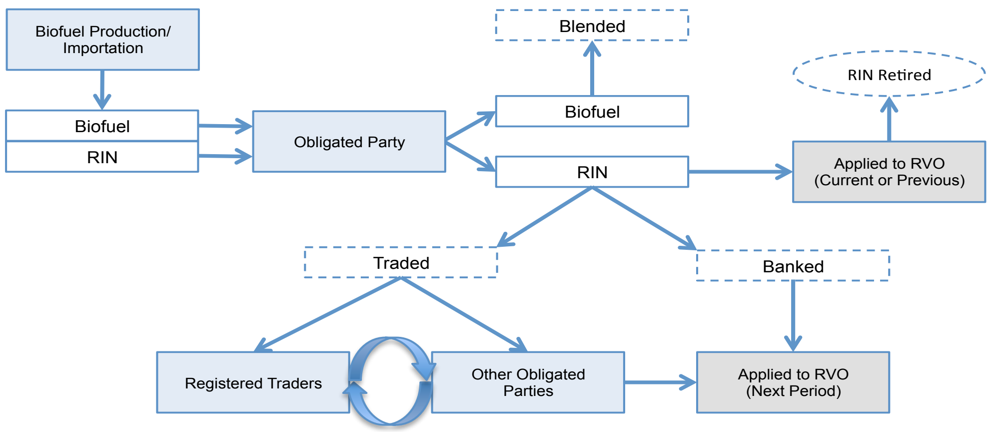
RIN Identifier	RFS2 Category
3	Cellulosic Biofuel
4	Biomass-Based Diesel
5	Advanced Biofuel
6	Conventional Biofuel (Ethanol)
7	Cellulosic Diesel

Each RIN is assigned to a qualifying gallon of biofuel at the time of production, or importation to the U.S. and remains attached until the fuel is blended. The firm that produces or imports the renewable fuel owns the RIN, but must report all production and transaction activities to the EPA Moderated Transaction System (EMTS). Once the RIN is produced, the owner has an option to sell, or hold the corresponding renewable fuel based on market demand.

To keep the supply of renewable fuel available to refiners however, a RIN is valid only for two years: the year of production and the following year.

Once the producer sells the fuel to a refiner, who actually meets the required blending mandates, the refiner also has several options on how to use the RIN. In order to meet the blending mandate a refiner could detach the RIN and blend the corresponding biofuel, then apply that gallon to their RVO. After the RIN is detached (blended), it is retired from further use. Aside from blending immediately, the refiner has several other options to use the RIN.

Figure 3. Lifecycle of a Renewable Identification Number



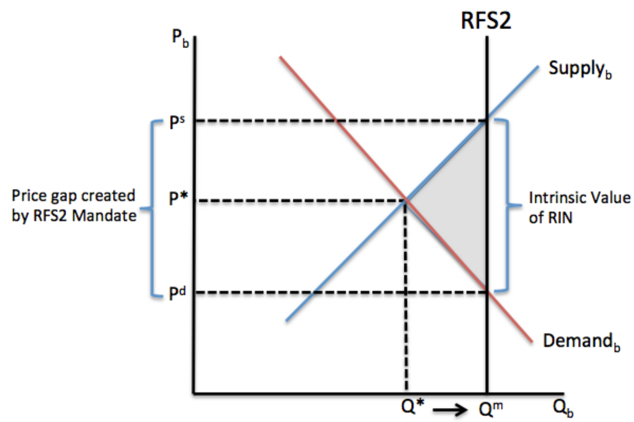
Source: Adapted from Paulson, 2012

RINs were established in part to reduce the costs of complying with the RFS2 mandate and to help cover producer's costs to blend the required amounts of biofuel (Babcock, 2009). Because of that effort, the EPA established a market where anyone registered with the EPA could purchase or sell RINs creating a type of "environmental currency."

RINs have two components associated with price formation within the renewable credit market, time and intrinsic value. The time value associated with RINs allows the credit to be treated as an "option" that can be bought, sold, or held over a two year span. As previously mentioned, a RIN is valid for only two years, after which the value of that credit falls to zero.

To reduce costs associated with meeting the blending requirements, blenders can trade excess RINs with another obligated party, or a RIN trader. Those refiners who are unable to meet their RVO during a particular year may find it less expensive to purchase RINs from a trader, or other obligated party than try to blend up to their mandated requirements. Additionally, if the blender foresees an increase in RIN price, or difficulty meeting their blending mandate in the following period, they can also bank and carry over 20 percent of their RINs into the following year.

Figure 4. RIN Market with a Binding Mandate



Source: Adapted from Thompson, Meyer, and Westhoff, 2009

The "intrinsic" or core value of a RIN is the price gap between supply and demand in the biofuels market. The RIN price essentially captures the costs associated with meeting the RFS2 mandate. If the prices of RINs increase, the market incentivizes firms to minimize costs in production or find ways to increase the value of biofuels (Babcock and Pouliot, 2013). The graph above illustrates that a RIN only has value in the market because of the binding RFS2 mandate. If the mandate is not binding (where the equilibrium price is higher than the mandate) then the price of RINs should fall to zero as there would be no demand for RINs

1.3. Biofuel Supply Chain

This section introduces an overview of the biofuels supply chain with an emphasis on the production facilities. Additionally, I explain the infrastructure used to move ethanol and biodiesel to blending facilities. Each section represents a particular category of fuel used in the later analysis. Cellulosic biofuel is excluded from this overview, as it is not included in the analysis.

Petroleum Refiners

Petroleum is a naturally occurring hydrocarbon derived from organic materials found in sedimentary rock. The high-energy content and widespread functionality make petroleum useful for a variety of refined products. It is the most common energy source consumed in the United States accounting for 36 percent of energy use in 2012. The two primary biofuels consumed for transportation, ethanol and biodiesel, are also considered petroleum products as gasoline and diesel are the foundation for the biofuel blends.

In 2013, there were an average of 139 petroleum refineries operating across the United States with an average production of 17.8 B/CD[1]. The EIA separates the country into Petroleum Administration Defense Districts (PADD) in order to facility regional analysis of petroleum supplies. Much of the refining capacity is located in the coastal areas of the United States.

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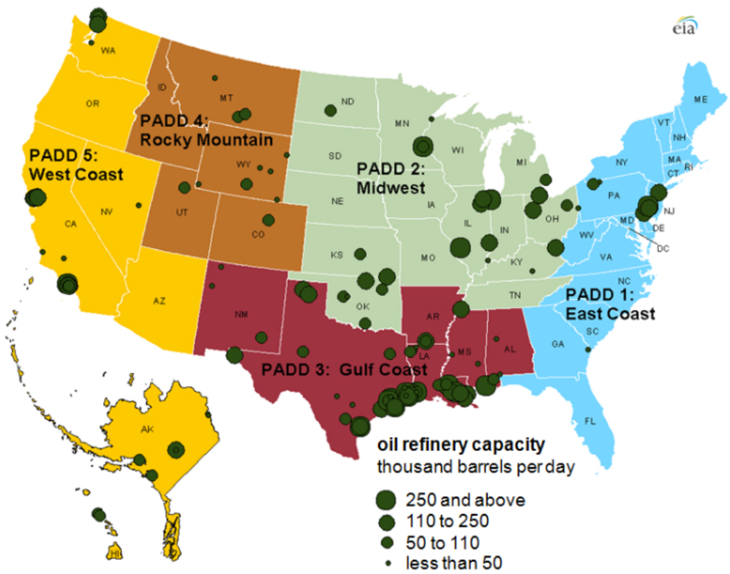
[1] Barrels per Calendar Year

PADD 3, which consists of the Gulf Coast states account for the majority of refineries in the United States with operating capacity concentrated in Texas and Louisiana. The western states in PADD V account for the second largest share of operating capacity with almost all of the refinery activity located in California and Washington. The Midwest states located in PADD 2 had fewer refineries overall, but tended to have larger facilities with strong regional connections to ethanol production centers (Du and Hayes, 2008).

Figure 5. Operable Refinery Locations and Capacity Volumes



Source: Energy Information Administration, 2014

Operating capacity varies widely across the United States, with an average production capacity of 127,000 B/CD. The smallest refinery, located in in Ely, NV produced approximately 2000 B/CD in 2013. Conversely, the largest facility in Baytown, TX maintained a production capacity of 560,500 B/CD.

The distribution infrastructure for petroleum refineries relies on a complex supply chain of pipelines, rail, barge, and road transport. Imports and exports, along with global crude oil prices and capital costs all play a significant role in understanding refinery-operating capacity. Much of the refiner's decisions about operating capacity lay outside the scope of this paper and will simply be taken as given by the EIA.

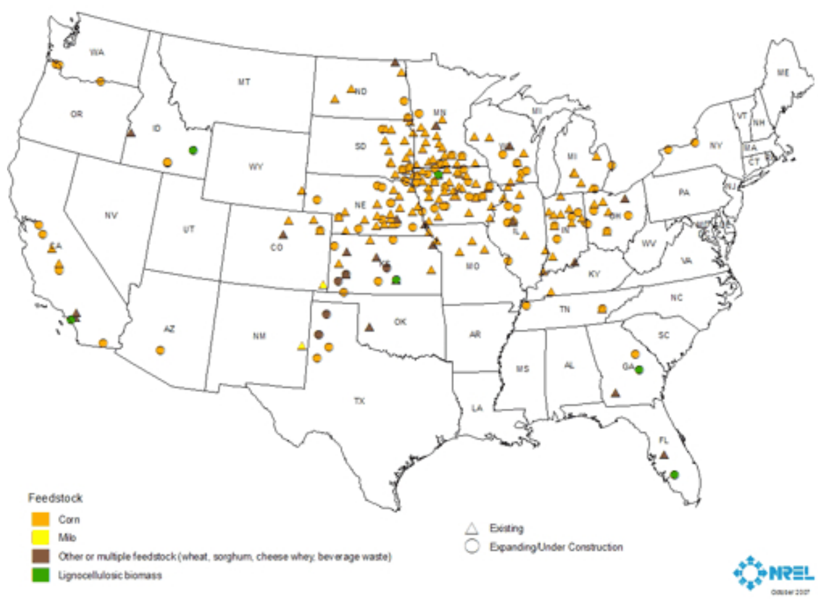
Ethanol Producers

Ethanol fuel is an ethyl or "grain" alcohol made from distilling the sugars found in many grains such as sorghum, and barley, but is primarily derived from corn in the United States. The most common blends for ethanol are E10 and E15, which represent a 10 percent blend, or 15 percent blend respectively, of ethanol with gasoline. The E10 blend still accounts for the majority of ethanol blends given manufacturing recommendations and infrastructure constraints (US EIA, 2014).

Like petroleum, ethanol can be transported through a multitude of distribution points. Rail, however, tends to be the dominant method of transporting ethanol in the United States, accounting for 70 percent of ethanol distribution (Dinneen, 2014). Given the large distances between ethanol producers and refiners, the unit costs of rail tend to be lower relative to truck transport.

On a per unit cost basis, shipping ethanol via pipeline or barge may have lower unit costs, but also have infrastructure limitations, or effects to the quality of fuel. For the domestic fuel market, tank barge represents a small portion of the domestic market since few ethanol producers are located near river terminals (USDA, 2007). Pipelines are typically considered the most efficient mode of transportation, but remain a difficult option for ethanol due to corrosion and water absorption (Hughes, 2011).

Figure 6. U.S. Ethanol Production Facilities by Type



Source: National Research Energy Laboratory

The map above illustrates, the majority of ethanol plants are concentrated in the Midwestern United States near corn production. The availability of feedstock and other ethanol inputs have driven the concentration of ethanol plants in the Midwestern United States (Lambert, Wilcox, English, and Stewart, 2008). The are currently 190 ethanol producers operating in the United States, with a total annual operating capacity of 13.9 billion gallons. The production capacity of ethanol plants ranges from of 0.4 million gallons per year of ethanol, up to 420 million gallons per year. Iowa, Nebraska, and Illinois are home to both the highest concentration of ethanol plants and plants with the largest nameplate capacity.

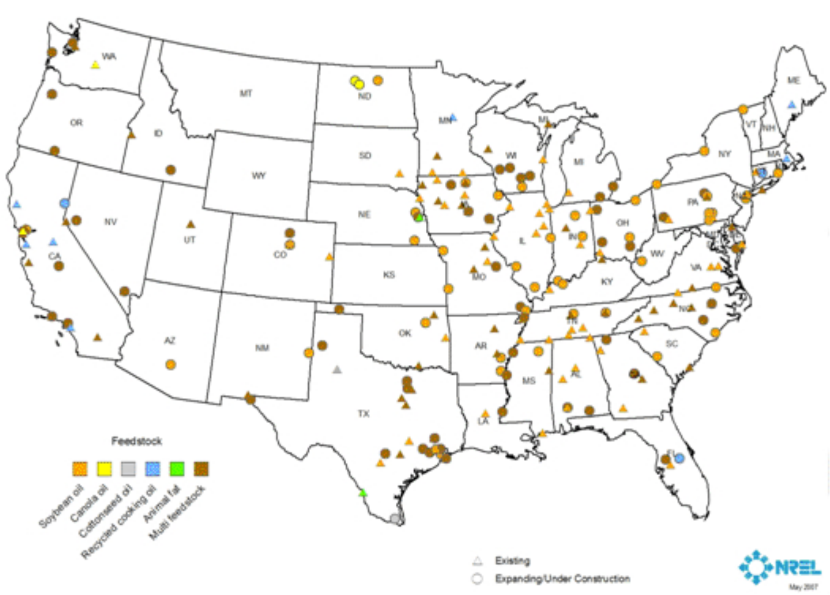
While ethanol plants are concentrated in the Midwest, refineries and gasoline demand are predominately located along the coastal areas of the Unites States. This separation between ethanol supply and demand suggests that supply chain and transportation costs may have an important role in how refineries choose to meet their RFS2 blending mandate. Access to cheaper fuels can reduce relative the costs associated with blending biofuels compared to purchasing RINs to meet the refinery's RVO.

Biodiesel Producers

Biodiesel is a renewable fuel derived from a variety of feedstock inputs, typically manufactured vegetable oils, with soy being the most common. Biodiesel can also be produced using animal fats, and grease. Before biodiesel can be blended, it must first go through a process called transesterification; this process uses a catalyst isolate the glycerin and bonding it with an alcohol. Biodiesel has a similar labeling structure to ethanol. Pure biodiesel is labeled B100, but are commonly blended at 20 percent (B20) with petroleum diesel fuel.

Biodiesel can be transported across a variety of infrastructure with rail also the most common method of transporting biodiesel at distances greater than 300 miles. Truck is the second-most common for of transporting biodiesel at distances less than 50 miles. While the unit-cost of moving biodiesel by truck may be higher than rail, it also offers greater flexibility to move the product at shorter distances. Pipelines are currently being explored for moving biodiesel, but most biodiesel producers are not located near existing pipelines, and are prohibited from being used in petroleum pipelines. Additionally, pipelines that ship diesel also tend to move jet fuel, where trace amounts of biodiesel are not permitted (US EIA, 2012).

Figure 7. U.S. Biodiesel Production Facilities by Type



Source: National Research Energy Laboratory, 2007

In 2013, there were an average of 134 biodiesel plants operating in the United States, which produced approximately 2.5 billion gallons of biofuel. The operating capacity for active biodiesel plants ranged from 250,000 to 180 million gallons, which is substantially smaller than the majority of ethanol producers. The location of biodiesel plants is more diffuse than ethanol plants. Biodiesel producers in the eastern United States tend to be clustered around soybean production, while in Texas and along the western United States biodiesel producers appear to be located near petroleum refineries. Interestingly, in 2013 *Ethanol Producer Magazine* reported that an ethanol plant in Illinois would be co-located with a biodiesel facility to integrate operations and reduce transportation costs.

1.4. Structure of the Research

This analysis seeks to identify if RINs have a different effect on blending ethanol and biodiesel within their nested mandates, rather than treating the RFS2 mandate as a single market. Accounting for these differences will allow for a comparative analysis between the ethanol and biodiesel markets and a more comprehensive understanding of the RINs effect on aggregate production. The microeconomics of the biofuel supply chain is not well developed, but this analysis attempts to further previous work by using a more complete model for empirical analysis. I measure changes on biofuel production by focusing on transportation costs associated with moving fuel to refineries for blending.

The analysis begins by conceptually tying together the underlying microeconomics of the EPA's renewable energy credit market and biofuel supply chain. I then lay out the theoretical foundation based on previous work from McPhail (2010) and Wang, et al. (2013). Using the groundwork laid by previous researchers, I then specify the model using previous research from Figer (2011), which make the transportation costs explicit for this analysis.

There are several limitations in available data for this analysis, but I use available market and open-source data, along with estimated parameters from previous studies to measure the change in blender response in ethanol and biodiesel markets. All the variables used, along with their description and sources are provided in Section 3.3 of this paper.

2. Literature Review

This section lays out the most recent and relevant research regarding the RIN market and the biofuel supply chain under the RFS2. While considerable research has been conducted on U.S. and global biofuels markets, academic literature on understanding the RIN market's effect on blended fuel production under the RFS2 is quite limited. There is especially a dearth of specific research on how agents in the RIN market interact with each other through the supply chain.

2.1. RINs and Social Welfare

The economic intuition underlying the biofuels mandate derives from de Gorter and Just, (2009) who illustrated the underpinnings of how mandates can affect the market. Given the uncertainty on social welfare from a blending mandate, they also compared the changes to social welfare when implemented alongside tax credits for biofuels. Their general finding is that tax credits alone may create significant losses in social welfare alone (they estimate $29 billion by 2022), but those impacts may be reversed if implemented along side a blending mandate. Additionally, if only one policy instrument can be implemented, they suggest that the mandate will result in a smaller deadweight loss when compared to the tax credits.

An article written by Babcock (2009) lays out the fundamental understanding of the RINs market and trade-offs that blenders face under RFS2. He points out that the RIN market plays a fundamental role in reducing the cost of compliance to reach the RFS2 goals by ensuring biofuel prices remain high enough to cover the costs of production up to the RFS2, due to the artificial demand created by the regulation. Babcock also points out that in a competitive market with a binding mandate, blenders should only choose to purchase RINS when the price of the credit is more favorable than purchasing biofuel. Firms that find it more efficient to blend will generate excess RINs introduced into the market. In terms of the supply chain, it is likely that blenders clustered around centers where feedstock and producers are located nearby will find it cheaper to blend.

2.2. RINs and Price Formation

McPhail (2010) conducted an analysis, which looks at price formation and factors that affect price levels in the RIN market. She starts by modeling a blender's optimal use of biofuel and RIN investment under the RFS2. McPhail then uses stochastic methods to allow shocks to different agents under various scenarios in the RIN market. Her findings suggest a high degree of volatility in RIN prices due to high variability in feedstock and oil prices, along with uncertainties in regulation. This creates a challenge for blenders who will be required to blend at levels above their optimal amount to meet the RFS2 mandate and will rely on RIN prices as a gauge for minimizing their costs of compliance.

Thompson, Wyatt, and Westhoff (2008, 2009a) have also provided significant contributions to the understanding of RIN prices in relation to their core value. Their FAPRI-MU simulation model has been used extensively to measure RIN prices in the medium term over a range of supply shocks and policy uncertainties. Some of the interesting results from their analysis are that the nested mandates for each type of biofuel tend to be more binding than other policy instruments, or even the overall RFS2 mandate itself. This suggests a strong rationale for segmenting the market by each type of biofuel for future analysis.

2.3. RINs and the Supply Chain

While most of the limited research into the RIN mechanism has focused on welfare changes from policy implementation, little work has been done to tie the RFS2 to the supply chain. The first known assessment of how a RIN market may directly affect the biofuel supply chain was by Figer (2011) who measured how ethanol was transported at different blending margins. While that research was instrumental in forming the objectives of this paper, the analysis lacked a complete microeconomic framework to tie together RINs and market agents. Additionally, that research considered only the aggregate effect of RINs on the ethanol market, while not including the sub-mandates for different biofuels under RFS2.

The first known attempt of theoretically integrating the RIN market and supply chain comes from Wang, et al. (2013). Those researchers constructed a theoretical framework under perfectly competitive and monopolistic scenarios to anticipate farmer, producer, and blender behavior along the complete supply chain. One of their interesting conclusions is that a rigid mandate on blenders under a monopolistic scenario may actually decrease biofuel production. In response, they introduce a unit-RIN penalty scheme, which allows blenders to pay a fine to the EPA rather than blend biofuels at a higher market price. Under the monopoly scenario, they suggest that the option to pay the penalty, rather than the higher price for biofuels prevents the producer from setting the price above the market value.

3. Methods and Data

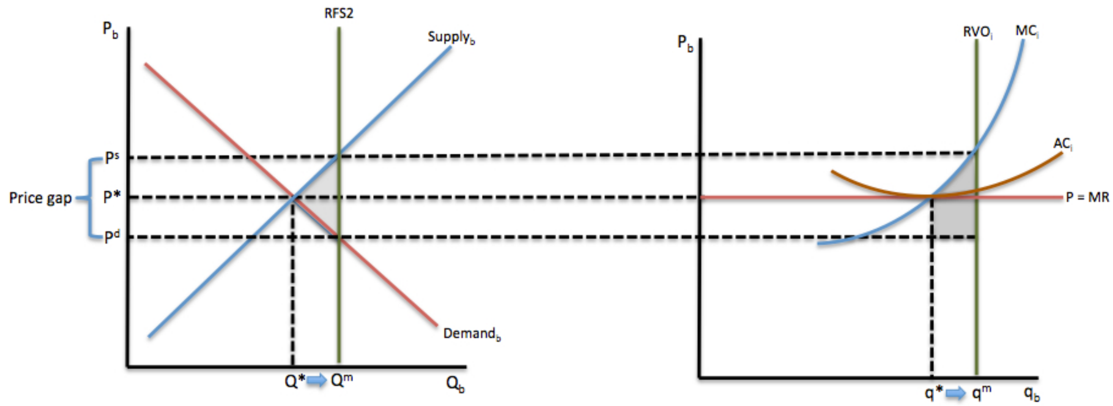
In this chapter, I present the framework used to conduct this analysis. The cost savings from the RIN market takes into account several important factors for blenders along the supply chain. Estimates of transportation costs, blending quantities, producer-refiner matching, and RIN prices all play a significant role in the output from the model.

3.1. Theoretical Model

Microeconomic theory suggests that in under equilibrium conditions in a competitive market, firms will maximize profit and minimize costs. In this analysis, I assume that each obligated party (blender) is a price-taker in a competitive market. In the short run, each blender will operate within their current marginal cost function and capacity constraints. Therefore, given a new quantity mandate under the RFS2, each blender will choose to minimize the costs associated with meeting their RVO. While the total amount of fuel blended will vary for each blender based on capacity and market conditions, the proportion of each biofuel required for blending is homogenous across all blenders in the market. The graphs below illustrate how we can map the RFS2 mandate to a given blender's RVO.

Figure 8. Mapping the RFS2 Mandate to the Blender's RVO

Blended Fuel Market Under RFS2 ***Blender's RVO Under RFS2***



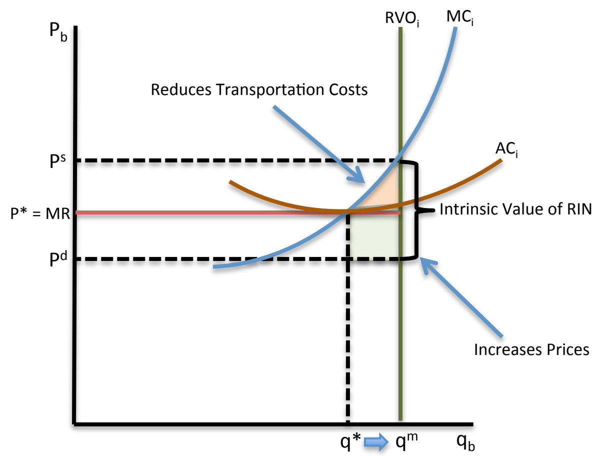
In this static model, the quantity required to be produced by a given blender shifts from q* to q^m under their new RVO required by the mandate. While the *total* amount blended will vary across blenders based on capacity, the *proportion* of biofuel will remain similar under the mandate. A binding mandate will theoretically have two effects on the blender. With additional fuels being mandated into the market, the enforced renewable fuel obligation (RVO) drives up the marginal costs for the blender and the cost of supplying blended fuel into the market. Simultaneously, the retail price that blended fuel can be sold in the market decreases due the mandated excess supply. The shaded grey areas represent the theoretical deadweight loss in the market and for the producer under a binding mandate.

The gap created by the blender's RVO represents firm's cost of compliance under RFS2. This in turn, suggests the intuitive solution that the horizontal sum of each blender's cost of compliance will equal the cost of compliance for the RFS2 mandate. This presents an opportunity to tie in the supply chain with the RIN market. Under the RFS2, it is clear that blenders will need to physically move and blend greater amounts of blended fuel to meet their individual RVO. As discussed earlier, the mandate creates inefficiencies by forcing blenders to purchase greater than optimal amounts of biofuel, while selling that fuel at a lower retail price.

The introduction of a RIN market is designed to reduce the cost of compliance under the RFS2. RINs can do this in several ways. First, RINs helps keep the price of feedstock high enough for biofuel producers and blenders to stay in business up to the RFS2. Under a binding mandate, the demand for specific biofuels is assured by imposing the requirement to blend. The RIN market is highly correlated with feedstock prices and therefore acts as feedback loop by which prices are high enough to ensure supply (Babcock 2009). This represents any point that lays above p^d in the graphic of the binding mandate above.

Secondly, RINs reduce the cost of compliance associated with physically shipping fuel to meet a blender's RVO. But a blender will only be willing to purchase RIN if that price is higher than their marginal cost to produce biofuel. Under a tradable RIN market, a blender will only choose to blend up to the point where the marginal cost of blending is equal to the price of a RIN. The graph below illustrates the intrinsic value of a RIN from a blender's perspective.

Figure 9. Intrinsic Value of a RIN for Blender



Blenders now face a trade-off in meeting q^m by choosing whether to blend and incur the net cost of shipping an additional gallon of biofuel, or offsetting that gallon by purchasing a RIN. The blender can minimize their costs by purchasing RINs at a lower cost rather than incurring the cost of physically moving fuel. In other words, if purchasing a RIN is cheaper than physically shipping fuel at any point up to the blender's RVO, then the *total distance* a blender is required to move fuel, is reduced relative to a "no RIN" alternative, where blenders would bear the full cost of meeting the mandate.

Blender's Cost-Minimization Problem

As mentioned earlier, the value of RINs derives from both time and intrinsic components. I use previous work by McPhail (2010) and Wang et al. (2013) to lay out the structure and constraints associated with this general model. For this analysis, I will isolate the intrinsic and time components of a RIN to develop a static model to illustrate how a blender will choose to blend, or buy RINs in a single period. Equation 1 below presents a simplified cost-minimization model for a generic blender with an RVO of q_i operating in period t.

Within this model, I assume that all prices and mandated quantities of blended fuel are exogenous to the blender. Using analysis from Rubin (1996) and McPhail (2010), the minimum cost $(\mathrm{C_{it}})$ for the mandated quantity under RFS2 $(\boldsymbol{q_{it}^{m}})$ is the amount is required to blend under RFS2 and $(\boldsymbol{q_{it}})$ is the optimal blending quantity when the mandate is not present. The cost function is continuous and twice differentiable such that $c' > 0$ and $c'' < 0$. Following research from (Wang et al., 2013), the blender also accounts for net revenues when choosing between purchasing an additional gallon of fuel or a RIN. The net revenue $(\boldsymbol{p_{it}^{k}})$ for the blender is the difference between the wholesale and retail costs of biofuel j in the current period. The variable $(\boldsymbol{y_{it}^{rin}})$ represents a single RIN for biofuel j purchased, or sold by the blender.

The optimal decision for a blender can then be shown as:

$$\min_{\{q_{it}, y_{it}^{rin}\}} c_{it}(q_{it}^{m}) + p_{it}^{k} q_{it}^{m} + p_{it}^{rin} y_{it}^{rin} \quad (2)$$

$s.t.$

$$S_{it} = q_{it}^{m} - y_{it}^{rin} - q_{it} + S_{it-1} = 0$$

$$q_{it}^{m} \geq 0$$

The first constraint limits blenders from carrying forward any RINs from the previous period (S_{it}) by requiring them to use (buy or sell) all of their available RINs in the current period. The second constraint invokes the RFS2 mandate by requiring that the RVO for the blender in period *t* is binding. We can therefore solve for the first order conditions with respect to the voluntary blending level $(\boldsymbol{q_{it}})$, which yields the following equations:

$$c_{it}'(q_{it}^{m}) + p_{it}^{k} = p_{it}^{rin} \quad (3)$$

$$y_{it}^{rin} = q_{it}^{m} - q_{it} + S_{it-1} \quad (4)$$

Equation (3) suggests that each blender will equate the cost and net revenue of blending an additional gallon of biofuel above their optimal level, along with the additional net revenue to the price of a RIN. The bottom equation (4) says that if RINs from the previous period are already used, the blender will choose the quantity of RINs needed based on the quantity required to meet their RVO in the current period.

Cost-Minimization Problem for all Blenders

We can apply the conditions above to all blenders in the market as the vertical sum of each blender's RVO by accounting for both fuel that is physically blended and RINs purchased, or sold in the current period. Equation (5) below represents the aggregate market under the RFS2.

$$\min_{\{q_{it}^{m}, y_{it}^{rin}\}} \sum_{n=1}^{N} C_{it}(q_{it}^{m}) + p_{it}^{k} q_{it}^{m} + p_{it}^{rin} y_{it}^{rin} \quad (5)$$

$s.t.$

$$\sum q_{it}^{m} + q_{it} + y_{it}^{rin} \geq Q_{t}^{m}, \mathrm{i} \in \mathrm{I}$$

$$Q_{t}^{m} \geq 0$$

The first constraint says that the aggregate number of blended fuel and RINs in the market in the current period should be equal to the total mandate under RFS2. The second constraint ensures that the mandate is binding to all blenders by required blending levels above the voluntary blending levels of the market. At this point, we can tie the model closer together with the supply chain by introducing parameters explicit to transporting biofuel between producers and blenders

3.2. Specified Model

In this section, I elaborate on the model developed in Equation 2 and Equation 5, by including transportation and distance parameters. This allows for an explicit description of how blenders will minimize the costs of complying with the RFS2 by either purchasing a RIN, or physically shipping biofuel. This model follows work by Figer (2011) and Wang et al. (2013) who were instrumental in first considering the role of the supply chain in the RIN market. The notation for the specified model below generally follows that of the previously discussed equations, but I will discuss differences and new variables below.

$$\min_{\{q_i^m, y_i^j\}} \sum_{n=1}^{N} C_i[q_i^m(\beta + \alpha d_{i,j}) + p^k q_i^m] + \sum_{n=1}^{N} p^{rin} y_i^{rin} \quad (6)$$

The cost function, rather than being a generalized function, now includes variables for the blending margin **(β)**, transportation cost **(α)**, and distance matrix **(d_{ij})**. The subscript (*i,j*) represents the identified distance traveled between a blender and producer. Additionally, as we've identified that this model is static, representing a single period in which a RIN may be traded in the market with no carryover, the *t* subscript is no longer present. Also, note that the subscripts for the price variables are excluded. This is because I assume that all blenders face the same prices for a given biofuel in the market.

The Role of Blending Margins

Blending margins are the difference in purchasing price for biofuel, or conventional gasoline and play an important role in shaping the compliance costs associated with blending biofuel. In aggregate, the margins can also illustrative of the cost of compliance by measuring how binding the RFS2 mandate is for a specific biofuel requirement. When the blending margin is zero, there is no difference in price, which allows conventional fuel and biofuel to act as perfect substitutes. On the other hand, a large spread between the wholesale prices for a biofuel and its conventional equivalent will change a blender's responsiveness to meeting their RVO, due to the increased opportunity cost of forgoing one fuel for another.

A positive blending margin represents a blender's ability to purchase a particular biofuel at a lower price than its conventional equivalent. Conversely, a negative blending margin suggests that blenders must purchase biofuel at a higher price than its conventional equivalent, which drives up the cost of compliance. For the blender, this may have significant impacts on their short-run variable costs and therefore the steepness of their marginal cost curve.

The strength of correlation between the margin and its corresponding RIN measures the degree to which that sub-mandate is binding for that particular biofuel. In markets with generally negative blending margins, the RIN acts as an "option" to be held or traded with other blenders to drive down compliance costs with the mandate. As mentioned earlier, blenders that are able to produce additional biofuels more cheaply due to lower procurement costs will also be more likely to derive additional revenue by trading RINs with other blenders that have higher marginal costs of compliance. Given the volatility in global fuel prices, the allocation of RINs should still yield an efficient outcome, even if the blending margin is strongly negative.

3.3. Data Sources and Description

This section provides a summary of the variables used for the calculations and parameters in the model. Table 4 provides a definition and observational information for all the information used in this analysis. A discussion of any further data manipulations and limitations will be discussed in Section 3.4

Table 4. Descriptive Information for Data Used in the RIN Model

Variable	Definition	Observation	Source
Price Data			
Gasoline	Monthly Average Wholesale (Rack) for Unblended Conventional Gasoline	Omaha, Nebraska F.O.B., 2007 - 2013	State of Nebraska, Department of Energy Statistics
Ethanol	Monthly Average Wholesale (Rack) for Ethanol	Omaha, Nebraska F.O.B., 2007 - 2013	State of Nebraska, Department of Energy Statistics
E-10 Ethanol	Monthly Average Retail for 10 Percent Blended Ethanol	National Aggregate, 2007 - 2013	U.S. Energy Information Administration
USLD Prices	Monthly Average Spot for Ultra-Low Sulfur Diesel	New York Harbor, 2007 - 2013	U.S. Energy Information Administration
B-100 Biodiesel	Monthly Average Wholesale (Rack) for High-Level Blend Biodiesel	IL, IN, and OH F.O.B., 2007 - 2013	U.S. Department of Agriculture - AMS
B-20 Biodiesel	Monthly Average Retail for 20 Percent Blended Biodiesel	National Aggregate, 2007 - 2013	U.S. Department of Agriculture - AMS
Other Data			
RFS2 Mandates	Annual Blending Mandate set by EPA for a given year, final ruling	Constant, 2013	U.S. Environmental Protection Agency - RFS
Transportation Costs	Cost of moving a gallon of biofuel 1 mile by rail	Annual Average, 2013	U.S. Department of Agriculture - AMS
Refinery Capacity	Operating Capacity for an Individual Refinery	Refining District Aggregate, 2013	U.S. Energy Information Administration
Producer Capacity	Operating Capacity for an Individual Biofuel Producer	Refining District Aggregate, 2013	State of Nebraska, Department of Energy Statistics

3.4. Variables and Methodology

In the following section, I discuss the methodology used to calculate the compliance costs for this analysis. Each sub-section below, defines a variable identified by the specified model, which is described in Section 3.2. Additional information and summary tables about the variables below are provided in the Appendix.

RVO Estimates $(\boldsymbol{q_i^m})$

The U.S. EIA surveys and provides public data on the location and operable capacity of refineries in the United States twice each year. Unfortunately, the EIA estimates of operable capacity are not the same as "working" capacity. To overcome this hurdle, this analysis assumes that 70 percent[2] of a refiner's operable capacity is used for transportation fuel. The percentage of ethanol and diesel required by the EPA to be blended for 2013 is based on the remaining capacity for each refiner.

This analysis uses the final rules for the 2013 RFS2 volume requirements, which required a total of 16.55 billion gallons of total renewable fuel. In the 2013 mandate, ethanol accounts for 6.99 percent of the total volume and biodiesel accounted for 1.13 percent. The mandate for cellulosic and other advanced biofuel blends are not included in this analysis and the volumes are therefore excluded from the production estimates.

Distance Matrix ($\boldsymbol{d_{i,j}}$)

Creating the distance matrices for this analysis presented some unique problems due to the difficult nature of determining how blenders and producers would choose to interact along the supply chain. As the map in Figure 5 above shows, blenders are congregated close to each other across the United States. To accommodate this geographical clustering of blenders, the dataset is divided into strata using PADD sub-regions called refining districts.

Within each refining district, a random sample of each sub-population, weighted by population, was pulled for each stratum. Having previously geocoded the data, I located the closest five producers for each blender in the sample population using Euclidian distance. Each distance was then measured against Google Earth for accuracy. The parings were generated for both the ethanol and biodiesel markets.

The distance information gathered for each blender in a refining district was combined into an average distance for the five closest producers. The average distance of producer-refiner parings were then applied to each refiner and multiplied by that refiner's RVO to estimate the procurement costs for each blender. Those costs are then aggregated to estimate the costs and savings for each refining district.

2 Recent estimate obtained at: http://www.whitehouse.gov/sites/default/files/docs/finaltrucksreport.pdf

Transportation Costs ($\boldsymbol{\alpha}$)

This study primarily uses a single estimate of $0.008 derived from the USDA Agriculture Marketing Service to calculate per gallon-mile estimates in the study. Additionally, a low and a high estimate were obtained from other sources for comparison. Though this estimate certainly does not capture all the variation in transportation costs across the supply chain, few cost estimates of transporting biofuels are available.

Additionally, both ethanol and biodiesel are predominately transported by rail either due to lower costs, or other constraints along the supply chain. This analysis uses this single value to estimate the per-unit cost of shipping from both biodiesel and ethanol producers to the blenders. The physical distances between the producers and blenders will therefore account for the variance in transportation costs.

Net Revenues ($\boldsymbol{p^k}$)

Incorporating net revenues into this equation brings an additional complexity to the model due to factors that can affect market prices, including domestic consumption, relative U.S. market strength, and regulatory changes. No prior research was identified that attempted to predict revenues due primarily to short-run changes in blending margins. To simply this analysis, historical data were used to identify correlations between blending margins and retail fuel prices.

The economic justification for this methodology is that while the competition between biofuel and conventional fuels drive the short-run direction of the blending margins, retail prices in the broader energy market should act as a feedback loop for agents who supply biofuel feedstock to the market. Agents upstream in the wholesale market should then respond to retail prices by attempting to maximize their own profits. This should, in effect, change the net revenue for blenders downstream in the supply chain.

Blending Margins ($\boldsymbol{\beta}$)

Blending margins for ethanol and biodiesel are typically estimated by take the difference between wholesale prices for conventional fuels and its biofuel equivalent (P_{con}-P_{bio}). To make the comparison to RINs the margin is normally multiplied by negative one. In this study, I reverse the equation (P_{bio}-P_{con}) to negate the need of multiplying the results by a negative value. The result is that discussions about positive a negative margins has an opposite meaning than when we are not discussing RINs.

To perform the empirical part of this research, I use monthly estimates that are publically available on government websites. The aggregation does reduce the robustness of price activity in the wholesale markets compared to daily prices, but more detailed price data are provided by third party services at a cost and could not be obtained for this study. Despite the loss of detail, the blending margins still provide the necessary data to look at their relationship to RINs.

<u>*RIN Prices*</u> ($\boldsymbol{p^r}$)

Predicted RIN prices in this analysis are based on regression output from Guidice. His analysis laid out the tools needed to understand how blending economics affect RIN prices for both the biodiesel and ethanol markets. Additionally, his research covers a discussion of blending margins through the study period used in this analysis.

His analysis revealed strong statistical relationships between D-4 (biodiesel) RINs and the blending margin. Specifically, a $1.00 increase in in the blending margin correlates with a larger $1.179 increase in D-4 RIN prices. The large price increase can be attributed to a highly negative historical blending margin, suggesting a binding mandate during enforcement of RFS2.

Predicting D-6 (ethanol) RINs is more problematic, given the low correlation between RIN prices and blending margins. This is not a surprising result, given the largely positive blending margin while the RFS2 mandate has been in place, suggesting the policy has not been particularly binding on ethanol. Guidice's analysis reveals that a $1.00 increase in the blending margin yields an increase in $0.181 in D-6 RIN prices.

<u>*RIN Quantities*</u> ($\boldsymbol{y_i^r}$)

The available quantity of RINs in the market is dictated by the RFS2 mandate set by the EPA for a given year and market conditions that affect the favorability of producing biofuels during that period. In this analysis, no carryover of RINs is permitted in order to eliminate the time component of RINs. This forces the blender to trade between purchasing a RIN and blending fuel.

The quantity of available RINs is dictated by how many gallons are being blended. For every gallon not blended, a RIN will be available for purchase. Regardless of how the prices change in the model, the summation of gallons blended and available RINs will always equal the RFS2 mandate set by the EPA.

4. Results and Discussion

In this chapter, I discuss the results of the model and their importance to the RFS2 mandates and RIN market. In the first section, I demonstrate how cost savings between the rigid and relaxed mandate scenarios are captured in this analysis. After comparing the two scenarios at a single blending margin, I describe the model results about blender behavior under different blending margins. Then I discuss the limitations of this analysis, along with implications and opportunities for future research.

4.1. Results

The initial computational results from the model are illustrated in Table 5 below. Two scenarios are used to illustrate the effect that RINs can have on the biofuels market. The rigid mandate scenario assumes a binding mandate where blenders are unable to trade RINs. In this situation, blenders are responsible for bearing the full cost of complying with the mandate. The relaxed mandate introduces the RIN market into the system providing greater flexibility with how blenders meet their RVO.

In the scenario below, RINs are introduced at a price where the blending margin is equal to zero. At this point blenders are indifferent to purchasing the wholesale conventional fuel and biofuel since the prices are identical. When the wholesale costs are netted out of the equation by limiting the blending margin to zero, the entire cost savings derives from forgoing the cost of transporting the biofuel. As seen in Table 5, the cost of shipping biofuel is an important component to consider, especially compared to the rigid mandate, where blenders must pay the full cost of compliance. When RINs are introduced into the biofuels market by relaxing the mandate, the savings in sourcing costs has the potential to be substantial by reducing the costs of compliance.

Table 5. Comparison of Rigid and Relaxed Mandates, in Millions (Blending Margin = 0)

Scenario	Blending Margin	Average Blending Cost ($/gal)	Biofuel Blended (gal/MM)	Blender's Cost ($/MM)	Potential Savings ($/MM)
Rigid Mandate	-	1.84	14,649	26,998	-
Relaxed Mandate	0	0.30	3,184	4,336	22,662

The estimated program savings of $22.6 billion dollars is the result of blenders reducing their aggregate sourcing distance by 7,053.2 billion mile-gallons. While significant, it is important to realize that these savings represent a snapshot of potential aggregate savings at a given blending margin. The savings are distributed differently across the ethanol and biodiesel markets due to differences in producer geography and RIN prices. In the following section, I will extend the analysis between the rigid and relaxed mandates by discussing the ethanol and biodiesel markets.

Segmenting The Market

By parsing the results above into their respective markets, we can begin to observe substantial differences between the ethanol and biodiesel markets. In contrast to the scenario above where the RIN market was introduced at a blending margin of zero, looking at the markets individually requires that we take into account their respective historical margins.

As mentioned earlier, ethanol has traditionally been cheaper than the conventional blendstock (CBOB), with a historical average blending margin of -$0.20. Conversely, B-100 has historically maintained a strongly positive margin relative to ultralow sulfur diesel (USLD) with an average differential of $0.59. Table 6 below compares the costs and savings between the rigid and relaxed market scenarios by introducing RINs into the system at prices based on the mean historical margin for their respective markets.

Table 6. Comparison of Scenarios For Biofuel and Ethanol Markets, in Millions (Blending Margin = Average)

Market	Mandate	RIN Price ($/gal)	Average Blending Cost ($ gal/mi)	Biofuel Blended (gal/MM)	Blender's Cost ($/MM)	Potential Savings ($/MM)
Ethanol	Rigid Mandate	-	1.57	12,610	19,783	-
	Relaxed Mandate	0.21	0.08	3,440	994	18,788
Biodiesel	Rigid Mandate	-	1.13	2,040	2,312	-
	Relaxed Mandate	0.50	0.90	1,087	1,832	479

As expected, the ethanol market accounts for the overwhelming majority of costs associated with the blending mandate due to its market share. In the rigid market, the average cost of blending ethanol is higher than biodiesel despite the negative blending margin and lower market prices compared to B-100. This is generally due to the longer distances blenders must travel to procure ethanol to meet their RVO in the absence of a RIN market.

Before the introduction of RINs into the system, the average distance blenders must transport ethanol to meet their RVO is 297 miles. After the introduction of RINS at the median blending margin, the average distance to procure ethanol drops to average distance of 87 miles. The decrease in transport costs also significantly decreases the average blending cost of ethanol, from $1.57 per gallon to $0.08, since blenders are not required to move further outward into the supply chain to source their ethanol.

In contrast to the ethanol market, the average sourcing distance for biodiesel is calculated to be approximately 119 miles prior to the introduction of RINs, and drops to an average of 79 miles afterward. This turns out to be a savings of 157 gallon-miles. Despite the lower average distances needed to transport biodiesel from producers to blenders, the average cost of blending biodiesel remains around $0.90 per gallon.

Geography is an important component to consider when considering how RINs reduce the cost of compliance in producing biofuels for their respective markets. Table 7 compares two refining districts that are comparable in their refining capacity for ethanol and biodiesel. The results illustrate there is indeed, a clear advantage of being closer to the point of production, especially in the ethanol market.

While both refining districts, blenders in the Indiana-Illinois-Kentucky district are at a clear advantage at meeting their RVO with lower compliance costs. In fact, the introduction of RINs at the mean blending margin offers no immediate benefit to blenders in the Indiana-Illinois-Kentucky district. At the mean blending margin the aggregate profit for producers in this region is still $387 million. This suggests that for blenders in this region, the ethanol mandate isn’t particularly binding, given their ability to produce at their RVO and still make a profit.

Table 7. Comparison of Scenarios in Selected Refining Districts, in Millions (Blending Margin = Average)

Refining District	Ethanol			Biodiesel		
	Rigid Mandate (gal/MM)	Relaxed Mandate (gal/MM)	Potential Savings ($/MM)	Rigid Mandate (gal/MM)	Relaxed Mandate (gal/MM)	Potential Savings ($/MM)
Indiana-Illinois-Kentucky	1,823.8	1,823.8	0.0	295.0	118.0	32.6
West Coast	1,648.1	329.6	2,361.9	266.6	160.0	26.1

In contrast to blenders in the Midwest, those located in the West Coast refining district experience an aggregate potential savings of $2.36 billion, equivalent to approximately 452 billion gallon-miles at the mean blending margin. Allowing for tradable RINs offers reduces the cost of compliance significantly for blenders in the West Cost district looking for opportunities to minimize their costs.

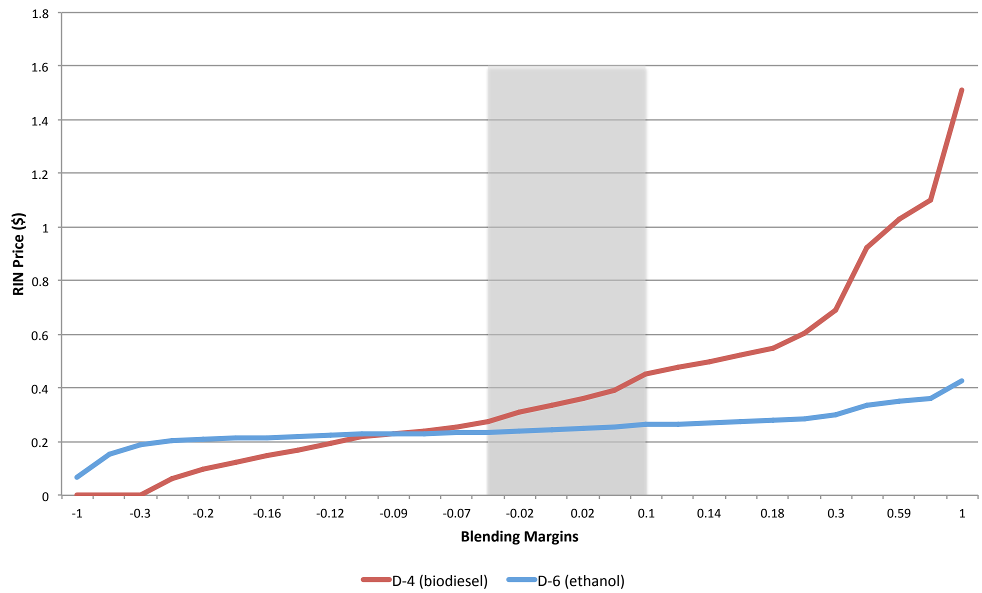
The story reverses somewhat when discussing the biodiesel market. The potential savings from a RIN market is higher for the Midwest blenders than those in the West Cost region. Blenders in the Indiana-Illinois-Kentucky district reduce the physical transport of biodiesel by approximately 60 percent and instead, opt to purchase RINs to meet their remaining RVO, yielding a potential savings of $36.1 million. In contrast, blenders in the West Coast Region who tend to be closer to biodiesel producers will exercise their geographical advantage by choosing to physically blend more biodiesel than blenders in the Illinois-Kentucky district after RINs are allowed to be traded.

Changing The Blending Margins

Introducing RINs into the biofuels market using a single blending margin illustrates the role that RINs have in reducing compliance costs associated with the blending mandate. But using a single metric does not capture how the RIN prices change and blenders respond to price changes. Including a range of historical blending margins is important to help us understand how binding the mandate is on particular biofuels and therefore, how RINs can actually effect the aggregate production of blended fuels.

While the historical blending margins for ethanol and biodiesel are on opposing sides of the scale, it can still be useful to combine them on a single metric to illustrate the effect that fluctuating blending margins can have on RIN prices and the costs associated with meeting the sub-mandate for that particular type of biofuel. Figure 10 compares RIN prices along the historical blending margins for ethanol and biodiesel. The shaded area denotes the regions where the blending margins for both RINs overlap. The historical blending margin actually increases up to 1.7, however, that the blending margins for biodiesel have almost it is not necessary to carry the blending margins out to their extremes to see the disparate relationship between D-4 and D-6 RINs and the corresponding blending margins when the margins are strongly positive.

Figure 10. Comparison of D-4 and D-6 RINs Across Blending Margins



The blending margins in Figure 10 range from -$1.00 to $1.00. The change in RIN prices is substantially different between the two RINs. The D-4 ethanol RINs range from $0.07 to $0.43 in the chart above. The D-4 biodiesel RINs see a rapid growth, even at the negative and low ends of the blending margins, ranging from $0.00 (since RIN prices cannot be negative) to $1.51. The rapid increase in D-4 prices is particularly indicative of the binding nature of the sub-mandate for that market.

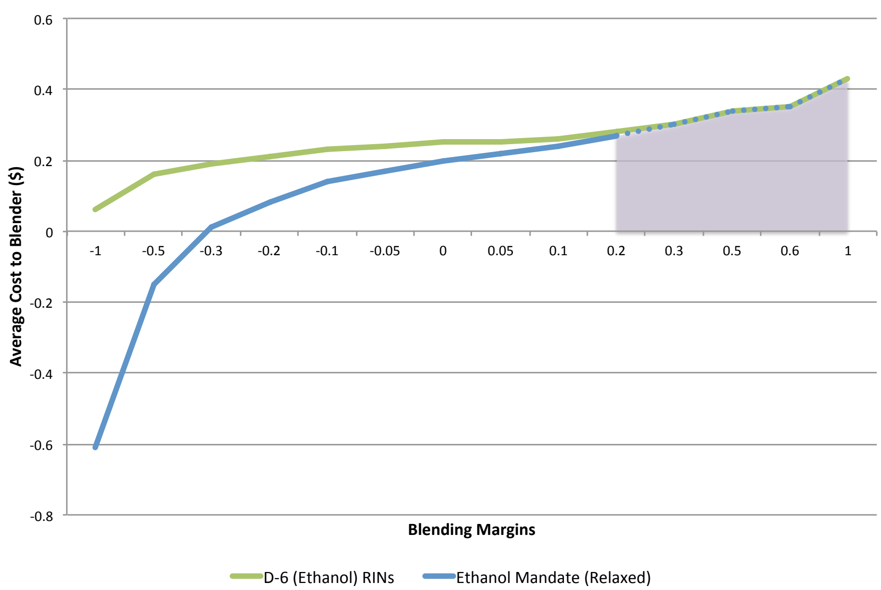
Another way of looking a how RINs can drive the market, is comparing the average blending costs under the relaxed mandate to the RIN price. RINs should only drive the price of blending biofuel when the economics of procuring biofuel are not favorable to the blender. When the blending margin for a market is strongly negative, the availability of RINs should not have a large effect on the quantity of biofuel blended and the market should absorb the majority of biofuel. The sub-mandate for that biofuel will therefore, will not be binding.

As the margins turn strongly positive, however, the cost of blending increases. The availability of RINs becomes more important to blenders as they attempt to meet their RVO by shifting away from blending and toward the RIN market. With a strongly positive blending margin, the mandate becomes binding as blenders are forced to meet RVOs above their optimal blending levels. As the price for biofuels becomes larger than their conventional equivalent, blenders will seek out RINs in quantities that will allow them to meet their RVO while minimizing their total compliance costs.

Figure 11 and Figure 12 illustrates how different blending margins affect how RINs influence their respective markets. Notice that as the margins turns strongly positive, the average cost of blending and the RIN price converge as RINs begins to have a stronger influence on the cost of blending. This is because as physically blending fuel becomes more important, blenders will choose to sell or purchase RINs. Without frictions in the market that prevent trading, the cost of blending should not be greater than the price of RINs. At any average price where transporting biofuel is higher than the RIN price, the blender should choose to purchase a RIN following from the principle of cost-minimization.

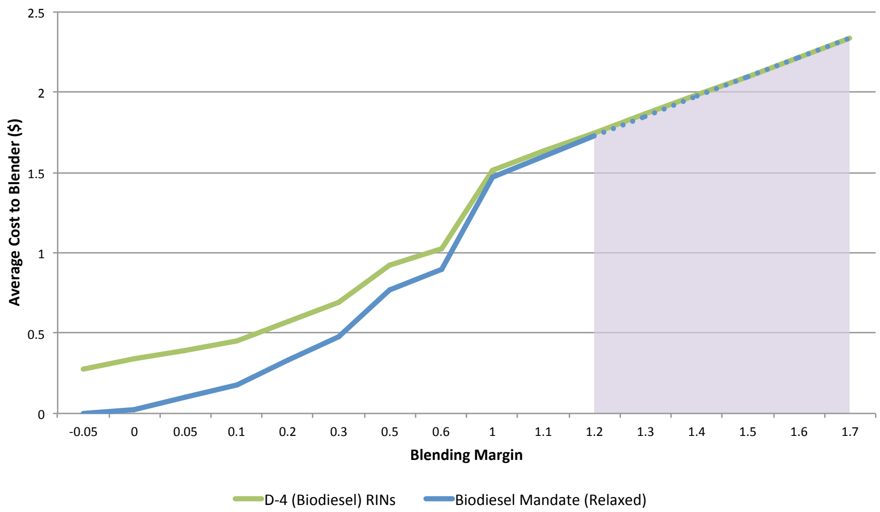
For the ethanol market, the mandate appears to become strongly binding around $0.20, which is where the average blending cost and the D-6 RIN price converge. In this dataset, however, the historical average blending margin for ethanol has been closer to -$0.20, adding more validation to earlier discussions about the non-binding nature of the ethanol market.

Figure 11. D-6 (Ethanol) RINs and Average Costs at Different Blending Margins



As opposed to the ethanol market, the biodiesel market has historically had a strongly positive blending margin. In Figure 12 below, the average blending cost and the D-4 RIN price converges around $1.20, but clearly begins to merge at smaller blending margins. The average blending margin for biodiesel is $0.59 and is frequently above $1.00. Given how closely aligned the D-4 RIN price and average blending costs are in the blending region where biodiesel is frequently purchased, the binding effect of the RFS2 sub-mandate is more obvious.

Figure 12. D-4 (Biodiesel) RINs and Average Costs at Different Blending Margins



We can now extend the discussion of how RINs affect biofuel production in the broader market, to understanding the regional effect than RINs can have on blenders. Table 8 and Table 9 help illustrate the regional effects RINs have on ethanol and biodiesel blenders at different blending margins. The tables below list the 5 regions that benefit the most from tradable RINs at high-end, average, low-end of their respective historical blending margins.

The results in Table 8 confirm that blenders located along the coastal areas in the United States generally tend to benefit the most from the RIN program. This result is not entirely surprising given the higher average costs associated with moving ethanol from the Midwest to the refinery to be blended. Regardless of which end of the blending margin is discussed, there is no change in which region benefits from tradable RINs.

Table 8. Regions that Benefit Most from D-6 (Ethanol) RINs, in Millions

Blending Margin = Low		Blending Margin = Median		Blending Margin = High	
Refining District	Savings ($/MM)	Refining District	Savings ($/MM)	Refining District	Savings ($/MM)
Texas Gulf Coast	4,297.6	Texas Gulf Coast	8,755.9	Texas Gulf Coast	16,008.1
Louisiana Gulf Coast	1,629.7	Louisiana Gulf Coast	4,536.1	Louisiana Gulf Coast	9,668.0
West Coast	847.2	West Coast	2,361.9	West Coast	5,664.7
Texas Inland	502.0	Texas Inland	1,213.6	Indiana-Illinois-Kentucky	3,091.4
East Coast	253.6	East Coast	1,068.5	East Coast	2,642.7

The D-4 RINs appear to have quite a different regional effect compared to their ethanol counterparts. The Rocky Mountain and Louisiana Gulf Coast districts benefit the most from RINs. This mainly appears to by due to their higher average costs to source biodiesel. The average procurement distance for the Rocky Mountain and Louisiana Gulf Coast Districts are 364 miles and 136 miles respectively, while the average distance for the biodiesel market overall is 119 miles.

Table 9. Regions that Benefit Most from D-4 (Biodiesel) RINs, in Millions

Blending Margin = Low		Blending Margin = Median		Blending Margin = High	
Refining District	Savings ($/MM)	Refining District	Savings ($/MM)	Refining District	Savings ($/MM)
Rocky Mountain	142.7	Rocky Mountain	171.9	Louisiana Gulf Coast	317.5
Louisiana Gulf Coast	33.0	Louisiana Gulf Coast	127.4	Rocky Mountain	212.9
New Mexico	15.8	Oklahoma-Kansas-Missouri	46.8	Texas Gulf Coast	201.0
Oklahoma-Kansas-Missouri	12.1	Texas Inland	35.8	Indiana-Illinois-Kentucky	165.0
Texas Inland	6.5	Indiana-Illinois-Kentucky	32.6	West Coast	120.4

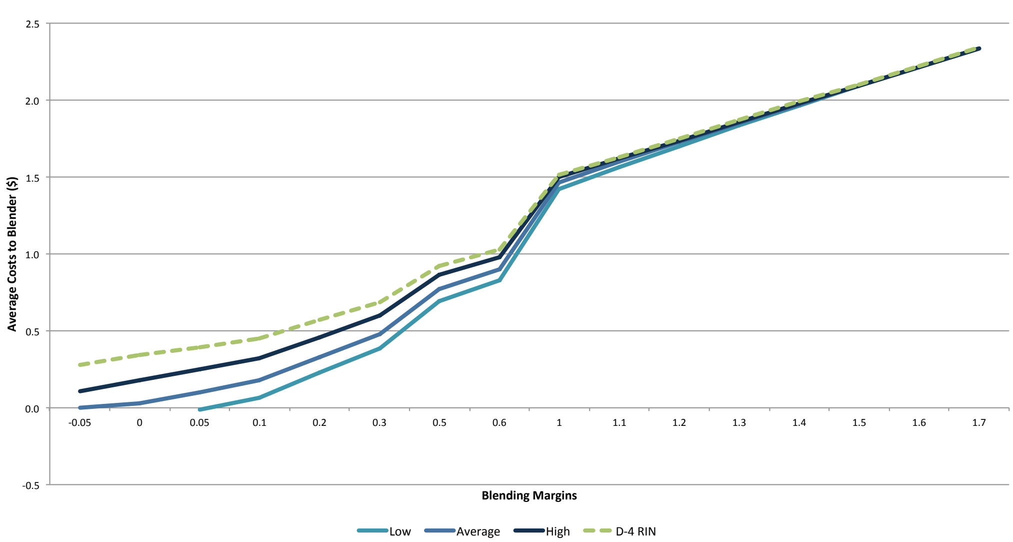
It is also interesting to note how regions benefit differently at various blending margins. At the low end of the blending margin, the majority of regions who benefit from RINs are those with higher average procurement costs. At the other extreme, average costs are high for all agents, but more savings are derived in regions with greater refining capacities. This is because blenders with larger refining capacities are purchasing greater total numbers of RINs resulting in larger aggregate savings.

Transportation Costs

Although the focus of this study is how RINs affect the aggregate production of biofuel under the RFS2, we are exploring the RIN mechanism through the supply chain. Therefore, this discussion would not be complete without some discussion of transportation costs. This is an important component since the cost of physically moving biofuel is embedded in the intrinsic value of a RIN and affects a blender's variable costs.

Intuitively, the cost of transporting biofuel should play a more significant role in the blenders cost function when the economics of blending make it more favorable for them physically blend biofuel. As blending margins turn decrease and producing biofuel becomes cheaper than its conventional equivalent, the incentive to blend increases.

Figure 13. Transportation Costs at Different Blending Margins for Biodiesel



On the other hand, as margins turn strongly positive, the average costs should still converge around the RIN price as the demand for physical biofuel decreases and the demand for RINs increases. This does not suggest that transportation cost become less important at higher blending margins; blenders must still meet their RVO. Rather the convergence of costs and RIN prices suggests that RINs help drive the market by creating a ceiling on costs as blending gets more expensive.

4.2. Discussion

For agents in the ethanol market, blending economics clearly favors blenders located close to the source of production in the Midwest. At the same time, blending margins appear to have little influence over RIN prices themselves, suggesting that D-6 RINs has an ambiguous effect on ethanol blending. This is illustrated in the model by the fact that the D-6 RIN prices do not change much despite pushing the ethanol blending margins to their extremes. Additionally, the low historical RIN prices relative to ethanol suggest that the mandate has not been particularly binding. As confirmed by Guidice (2013), the weak D-6 RIN relationship to blending margins suggests that other factors besides RINs are driving the production of ethanol blends.

The effect of D-4 biodiesel RINs on B-20 blending is more pronounced relative to the ethanol market. The D-4 RINs track closely both with blending margins and blenders' average costs of production. Since D-4 RIN trading often occurs within ranges where the gap between blending margins and RIN prices are small, there is a strong argument to be made that the RFS2 mandate is strongly binding in this market. The convergence of average costs and D-4 RIN prices on the positive end of the biodiesel blending margin also suggest that the presence of D-4 RINs are fundamental to the production of B-20 biodiesel by driving down compliance costs when fuel prices shift upward.

While RINs do appear to influence their respective markets differently with respect to how much they influence the production of blended fuel, results from the model suggest that RINs remain important to reducing compliance costs in both markets. This is because while RINs can be traded with minimal transaction costs, their influence still resides within the geographical confines of the biofuel supply chain. All else being equal, RINs in the ethanol markets appear to be used to offset transportation costs for blenders along the coast with high procurement costs. Meanwhile, D-4 RINs appear to be used more to account for the higher trading prices for B-100 and USLD by ensuring a substitute for blending biodiesel when prices become too high.

This model pushes the results to their logical extremes by eliminating the time component of RINs and forcing blenders to use every available gallon of biofuel over the qualifying period. But even with the time component of the RIN excluded from the model, we are still able to see how RINs act as a signaling tool for blenders deciding how to meet a particular RVO in the most cost-effective way.

It is important to note that this model is meant to be descriptive of how RINs interact with the ethanol and biodiesel markets, it is not designed to be a predictive a model. Rather, the results from this model represent a "snapshot" of the RIN market in a single period under a given RFS2 mandate; normally a year.

In reality, biofuel, and conventional fuel prices fluctuate daily with many factors that may effect the price changes. While it is likely that blenders would certainly take into account their average or marginal costs when considering whether to blend or purchase a RIN, those decisions will be made within the context of other considerations about current and future market conditions. The hope is that this model can serve as an extension of the current literature on RINs, while providing a foundation for more sophisticated models that can achieve a more holistic view of how RINs incentivize blended fuel production.

4.3. Limitations

Data was a significant limitation in this study. Most data used for this analysis were taken from public websites, which offered only monthly averages for price data. RIN prices are not tested directly in this model since RIN prices are often tracked by private entities that charge for access to their data. This required that I use estimates from other studies for this analysis. While the available data was sufficient for quantifying some of the model's assumptions about the biodiesel market, not all assumptions could be tested. For instance, one assumption illustrated in Figure 8 suggests that RINs play a role in keeping prices high enough to be profitable up to the RFS2 mandate. This has been shown to be accurate in other studies (see Babcock, 2009), but unfortunately not able to be verified here.

Another limitation is the assumption of homogeneity of prices across all refining districts and PADDs. There is considerable variation in both biofuel and conventional fuel prices in the retail and wholesale sectors. It is unlikely that blenders in all refining districts would be facing the same blending margin at any given time, especially in the biodiesel market where the distribution of producers is more geographically dispersed. Since this study is only able to capture a only a glimpse of the ethanol and biodiesel markets at any given blending margin, the story of how RINs affect production is a more static and less robust depiction of how the actual market operates.

Finally, this study only attempted to quantify the intrinsic value of RINs. This helps the reader to understand how RIN prices develop and how obligated parties may consider their total costs in the immediate run, however, it doesn't tell a complete story. Blenders are allowed to carry-over up to 20 percent of RINs from a previous period to comply with the RFS2 mandate in the current period. The time component of RINs allows the credit to act as an option to hedge against future risk. This introduces a more complex and richer time horizon than could be analyzed in this study, to describe how RINs affect the production of blended fuel.

4.4. Future Research

The RFS2 is a relatively new program and the RIN market remains ripe for future research opportunities. While this study quantified and compared the RIN market's effect on ethanol and biodiesel production, future studies might take this a step further to determine how the RIN markets interact with each other. The hierarchy of requirements created within the RFS2 mandate affords blenders the opportunity to supplement advanced biofuels to meet their conventional requirement. An exploration into how RINs interact together to drive how each sub-mandate is met at various prices could yield useful policy implications for measuring the effectiveness of the current program.

Additionally, understanding the biofuel supply chain remains a relatively unexplored, but important component to RINs affect the aggregate production of biofuel and blended fuels. This analysis minimized the cost of meeting the blending mandate by selecting the five closest producers to purchase biofuels. More realistically, the production of feedstock and biofuels that travel downstream for refining derives from a combination of market factors such as location, price competitiveness, and contracts to reduce exposure to price volatility and policy changes. This relationship between the agents that interact along the supply chain needs to be explored further to truly understand how RINs may, or may not directly affect production.

5. Conclusions

The U.S. Congress created the RFS2 program to increase the blending of various types of biofuel with national security, energy independence, and rural development as concurrent goals. Several biofuels directed for increased production under the mandate previously had little, or no market exposure. To minimize the financial burden of blenders meeting these blending goals, Congress authorized the EPA to implement the RIN, which could be used in lieu of physically blending fuel to meet the RFS2 mandate.

This research sought out to better understand how RINs influence the production of blended fuels under the RFS2 mandate by looking at the two largest markets, ethanol and biodiesel. The geographical differences between the two markets highlight the need for at least a basic understanding of the biofuel supply chain when attempting to segment the market, as this study has done. Two previous studies have discussed the influence of RINs and the supply chain on biofuels, but not the effect on individual markets.

This analysis shows that RINs influence their respective markets in different ways, both in aggregate and regionally. While ethanol capacity appears to be large enough to meet or exceed the RFS2 mandate, long distances for moving ethanol to be blended leaves room for RINs to reduce compliance costs by ensuring ethanol is moved to its geographically optimal location. Meanwhile, RINs in the biodiesel market plays a fundamental role in ensuring the minimum production of B-20 can be produced to meet the RFS2 mandate.

RINs will continue to be a key policy mechanism for achieving the goals of the RFS2 mandate in an efficient way by reducing compliance costs and acting as a positive incentive for obligated parties to blend biofuel. Understanding how RINs influence production cannot be examined simply by looking at market prices. RINs operate within an extremely dynamic and complex system of the biofuels supply chain. Future research that is able to integrate the two systems will provide valuable policy tools for understanding not only the effectiveness of the RFS2 program, but also its interaction with tangential sections of the economy such as food production and the retail energy market.

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Appendix

Appendix A. Description of the Excel Model

The following section explains the tools used to calculate the costs and savings associated with the RFS2 and the RIN market. Microsoft Excel was the primary tool I used to build the model. The Excel workbook brings together all the data and calculations discussed in Sections 3.3 and 3.4 to measure the costs associated with blending ethanol and biodiesel. The result is essentially an input-output model that can provide results based on applying several different inputs from available historical data. It's worth noting that this model is not meant to be predictive of the ethanol and biodiesel markets, but simply descriptive of blender behavior.

The example in Figure below illustrates the calculations and results for a single refining district, with a blending margin of -0.02. The red arrow points to the different inputs that can be changed to determine how costs will change and blenders will choose to react and different prices. Changing the blending margin and fuel type, will affect the RIN price and net revenue that a blender can receive for an additional gallon of biofuel. Manipulating the region changes the average distance based on calculations for a given refining district, as measured in the distance matrix. Finally, the "transport" input allows the user to test the sensitivity of a region to different transportation costs.

The way to interpret the results from this model are to compare the "Cost to the Blender" column, which represents the "rigid mandate" cost to the "Program Cost" column that calculates the "relaxed mandate" cost. Notice that in the example below, the results are the same. With an ethanol blending margin of -0.02 the blender's costs are -53.5 million dollars. While the output isn't immediately intuitive, what it suggests is that the blender's revenues outweigh the costs and there is no reason to purchase RINs.

Figure A.1. Manipulating the Model Inputs

Inputs

Fuel Type	ethanol
R. District	Minnesota-Wisconsin-North & South Dakota
Blending Margin	-0.02
Transport $ Estimate	medium

	Blending Market							RIN Market			Blend vs Buy		
Quintile	Quantity (per quintile)	Blending Margin	Average Distance (mi)	Rate (per mi/gal)	Net Revenue ($)	Cost to Blender ($)	Average Cost to blend ($)	RIN Quantity (gal)	RIN Price ($)	RIN Cost to Blender ($)	Gallons Blended (gal)	RIN Purchased (gal)	Program Cost
1	97,156,929	-0.02	51.87	0.009	0.66	-22,170,593	-0.228	97,156,929	0.24	23,500,901	97,156,929	0	-22,170,593
2	97,156,929	-0.02	62.36	0.009	0.66	-13,250,134	-0.136	97,156,929	0.24	23,500,901	97,156,929	0	-13,250,134
3	97,156,929	-0.02	64.75	0.009	0.66	-11,222,223	-0.116	97,156,929	0.24	23,500,901	97,156,929	0	-11,222,223
4	97,156,929	-0.02	68.35	0.009	0.66	-8,156,289	-0.084	97,156,929	0.24	23,500,901	97,156,929	0	-8,156,289
5	97,156,929	-0.02	79.47	0.009	0.66	1,295,767	0.013	97,156,929	0.24	23,500,901	97,156,929	0	1,295,767
Total	485,784,644					-53,503,472				117,504,504	485,784,644	0	-53,503,472

Rigid Mandate ($)	Relaxed Mandate ($)	Savings ($)
-53,503,472	-53,503,472	0

As a brief example to demonstrate how a blender's behavior might change, let's adjust the blending margin for ethanol in the above refining district, while holding everything else constant. By changing the blending margin from a negative blending margin of -0.02 to a positive margin of 0.12, we would expect that ethanol is relatively less attractive to the blender as it is now more costly than CBOB. If the next gallon of ethanol is more expensive than CBOB, we should expect the blender to purchase a RIN, rather than incur the transportation costs associated with shipping ethanol. In fact, this behavior does appear to be represented in the model.

In Figure below, we see that while the amount of blended fuel required for that refining district remains unchanged, the price of blending has increased significantly. In this scenario, the blender's costs are now $78.7 million, much higher than the previous example. However, the blender is able to minimize their compliance costs by choosing to purchase RINs, rather than physically moving biofuel at the far end of their supply chain. In this case, the blender will only choose to blend from producers up to their fourth zone, which for this district is up to 68.35 miles, as estimated in the distance matrix.

Figure A.2. Demonstrating the Blender's Trade-Off for Blending or Buying Biofuel

Inputs	
Fuel Type	ethanol
R. District	Minnesota-Wisconsin-North & South Dakota
Blending Margin	0.12
Transport $ Estimate	medium

			Blending Market					RIN Market			Blend vs Buy		
Quintile	Quantity (per quintile)	Blending Margin	Average Distance (mi)	Rate (per mi/gal)	Net Revenue ($)	Cost to Blender ($)	Average Cost to blend ($)	RIN Quantity (gal)	RIN Price ($)	RIN Cost to Blender ($)	Gallons Blended (gal)	RIN Purchased (gal)	Program Cost
1	97,156,929	0.12	51.87	0.009	0.53	4,276,389	0.044	97,156,929	0.27	25,958,777	97,156,929	0	4,276,389
2	97,156,929	0.12	62.36	0.009	0.53	13,196,848	0.136	97,156,929	0.27	25,958,777	97,156,929	0	13,196,848
3	97,156,929	0.12	64.75	0.009	0.53	15,224,759	0.157	97,156,929	0.27	25,958,777	97,156,929	0	15,224,759
4	97,156,929	0.12	68.35	0.009	0.53	18,290,693	0.188	97,156,929	0.27	25,958,777	97,156,929	0	18,290,693
5	97,156,929	0.12	79.47	0.009	0.53	27,742,749	0.286	97,156,929	0.27	25,958,777	0	97,156,929	25,958,777
Total	485,784,644					78,731,438				129,793,884	388,627,715	97,156,929	76,947,466

Rigid Mandate ($)	Relaxed Mandate ($)	Savings ($)
78,731,438	76,947,466	1,783,973

How does the blender decide when to shift from blending to buying RINs? Recall that in equations 4 and 5 I suggest that when minimizing costs, a blender will equate the marginal cost of an additional gallon of biofuel to the price of a RIN. Given the "lumpiness" associated with the geography of producers along the supply chain, the marginal costs are difficult to measure without econometric techniques and additional information about blender and producer pairing. Instead, this model assumes that a blender weighs the average cost for a gallon of biofuel against the price of a RIN. This is determined by simply taking the ratio of the total blending costs and quantity of fuel in a given quintile. As the blender moves outward along their supply chain, the average cost to blend will increase.

Figure A.3 Equating the Blending Cost of Biofuel to the Cost of a RIN

Inputs	
Fuel Type	ethanol
R. District	Minnesota-Wisconsin-North & South Dakota
Blending Margin	0.12
Transport $ Estimate	medium

			Blending Market					RIN Market			Blend vs Buy		
Quintile	Quantity (per quintile)	Blending Margin	Average Distance (mi)	Rate (per mi/gal)	Net Revenue ($)	Cost to Blender ($)	Average Cost to blend ($)	RIN Quantity (gal)	RIN Price ($)	RIN Cost to Blender ($)	Gallons Blended (gal)	RIN Purchased (gal)	Program Cost
1	97,156,929	0.12	51.87	0.009	0.53	4,276,389	0.044	97,156,929	0.27	25,958,777	97,156,929	0	4,276,389
2	97,156,929	0.12	62.36	0.009	0.53	13,196,848	0.136	97,156,929	0.27	25,958,777	97,156,929	0	13,196,848
3	97,156,929	0.12	64.75	0.009	0.53	15,224,759	0.157	97,156,929	0.27	25,958,777	97,156,929	0	15,224,759
4	97,156,929	0.12	68.35	0.009	0.53	18,290,693	0.188	97,156,929	0.27	25,958,777	97,156,929	0	18,290,693
5	97,156,929	0.12	79.47	0.009	0.53	27,742,749	0.286	97,156,929	0.27	25,958,777	0	97,156,929	25,958,777
Total	485,784,644					78,731,438				129,793,884	388,627,715	97,156,929	76,947,466

Rigid Mandate ($)	Relaxed Mandate ($)	Savings ($)
78,731,438	76,947,466	1,783,973

Any point along the supply chain where the average blending cost of procuring biofuel is higher than the RIN price, the blender will shift to purchasing RINs. While the model suffers from a limitation of forcing the quantity of fuel for that quintile into a single category, future iterations of the model could make the calculations more robust.

To calculate the results presented in Chapter 4, the output for each refining district is aggregated by fuel type, at a given blending margin and transportation cost. By then manipulating the blending margin for ethanol and biodiesel, the model reveals how sensitive blenders in a given region are to changing prices in the wholesale market. Additionally, segmenting the market by fuel type allows the user to see how the biodiesel market, while smaller, can still have significant price impacts on a blender given the binding nature of the sub-mandate.

Appendix B. Distance Matrix

The following table is a summary table that shows the calculated distances for each refining district. Theses distances are separated into quintiles, representing the five closest producers for each refinery selected in the random sample used in the calculations. These estimates were then applied to all refineries in that district to create the aggregate cost of transporting biofuels to that district.

Table A.1. Summary of Distance Matrix by Refining District

	Ethanol (average miles by quintile)					Biodiesel (average miles by quintile)				
Refining District	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
Appalachian No. 1	70.4	151.7	163.4	179.9	183.8	34.0	107.8	162.6	173.3	186.6
East Coast	59.4	242.2	278.0	354.4	430.7	0.0	59.8	70.3	94.9	124.2
Indiana-Illinois-Kentucky	46.5	78.1	107.9	115.8	120.3	66.0	97.8	114.9	128.6	141.3
Minnesota-Wisconsin-North & South Dakota	51.9	62.4	64.7	68.4	79.5	38.5	66.2	90.6	123.9	141.4
Oklahoma-Kansas-Missouri	36.9	81.5	93.8	103.2	131.4	128.6	152.0	173.1	173.1	174.4
Louisiana Gulf Coast	150.2	336.7	361.5	424.5	467.5	72.1	122.3	140.0	164.8	184.5
North Louisiana-Arkansas	178.1	345.8	398.0	419.1	444.5	76.2	92.3	102.6	131.3	142.7
New Mexico	320.3	361.7	361.7	400.7	409.5	229.6	260.5	272.7	275.1	286.9
Texas Gulf Coast	207.8	440.1	481.1	481.1	514.8	67.0	84.2	88.2	93.9	99.4
Texas Inland	284.4	418.9	447.3	456.9	459.1	138.6	150.2	153.2	156.6	188.8
Rocky Mountain	179.1	309.1	337.1	362.1	385.3	195.3	310.5	401.3	448.0	468.0
West Coast	93.7	181.4	288.9	349.1	550.9	56.9	70.8	89.0	124.5	145.9

Appendix C. Refinery Capacity

This table summarizes the number of operating refineries by district in 2013, along with their total operating capacity in millions of gallons. In this analysis, the amount of fuel obligated for blending under the RFS2 requirement was assumed to be 70 percent of the operating capacity for the individual refiner. Each refinery's RVO was then calculated by multiplying the percentage of biofuel mandated by the EPA in 2013.

Table A.2. Summary of Refining Capacity by Refining District

Refining Districts	Annual Operating Capacity (Mmgy)	Operating Refineries in District
PADD 1	**430.2**	**9.0**
Appalachian No. 1	35.9	3.0
East Coast	394.3	6.0
PADD 2	**1,428.5**	**25.0**
Indiana-Illinois-Kentucky	888.0	14.0
Minnesota-Wisconsin-North and South Dakota	236.5	4.0
Oklahoma-Kansas-Missouri	304.0	7.0
PADD 3	**3,248.5**	**50.0**
Louisiana Gulf Coast	1,200.6	16.0
New Mexico	47.7	2.0
North Louisiana-Arkansas	58.4	8.0
Texas Gulf Coast	1,696.7	16.0
Texas Inland	245.1	8.0
PADD 4	**229.8**	**17.0**
Rocky Mountain	229.8	17.0
PADD 5	**802.5**	**20.0**
West Coast	802.5	20.0
Grand Total	**6,139.4**	**121.0**

Appendix D. Producer Capacity

This appendix presents the producer information used in this analysis. The locations of each producer were geocoded and used to create producer-blender pairs for the distance matrix. The operating capacities were used to ensure that the amount of biofuel transported from any single producer was not larger than their operating capacity.

Table A.3. Summary of Producer Capacity by Refining District

Refining Districts	Ethanol Producers		Biodiesel Producers	
	Annual Operating Capacity (MMgy)	**Operating Firms in District**	**Annual Operating Capacity (MMgy)**	**Operating Firms in District**
PADD 1	**374.4**	**5**	**254.7**	**34**
Appalachian No. 1	0.0	0	17.9	5
East Coast	374.4	5	236.8	29
PADD 2	**12,273.0**	**166**	**1,305.1**	**52**
Indiana-Illinois-Kentucky	6,624.4	75	749.5	27
Minnesota-Wisconsin-North and South Dakota	3,162.1	53	188.4	10
Oklahoma-Kansas-Missouri	2,486.5	38	367.2	15
PADD 3	**231.5**	**4**	**680.0**	**24**
Louisiana Gulf Coast	1.5	1	243.7	10
New Mexico	25.0	1	1.5	1
Texas Gulf Coast	205.0	2	434.8	13
PADD 4	**186.5**	**7**	**27.2**	**2**
Rocky Mountain	186.5	7	27.2	2
PADD 5	**219.0**	**6**	**244.0**	**22**
West Coast	219.0	6	244.0	22
Grand Total	**13,284.4**	**188**	**2,511.0**	**134**

Appendix E. Comparison of Savings by Refining District

This section provides the remaining information from Table 6. The table illustrates the potential savings by enforcing a binding mandate and introducing RINs into the market at the mean blending margin for the ethanol (-0.2) and biodiesel (0.59) markets. Table A.4 is organized by sorting the ethanol market by least to most potential savings for each refining district. As discussed in Chapter 4, the largest producers of ethanol are clustered in the Midwest and don't realize the same benefit from RINs, relative to blenders on the coast, due to their large production capacity and low sourcing costs. Note that RINs and wholesale fuel are traded daily and have vigorous price activity. These results are potential annual savings, based on a single blending margin.

Table A.4. Savings from RINs for Each Refining District

Refining District	Ethanol			Biodiesel		
	Rigid Mandate (gal/MM)	Relaxed Mandate (gal/MM)	Potential Savings ($/MM)	Rigid Mandate (gal/MM)	Relaxed Mandate (gal/MM)	Potential Savings ($/MM)
Indiana-Illinois-Kentucky	1,823.8	1,823.8	0.0	295.0	118.0	32.6
Minnesota-Wisconsin-North & South Dakota	485.8	485.8	0.0	78.6	47.1	7.0
Oklahoma-Kansas-Missouri	624.5	624.5	0.0	101.0	0.0	46.8
Appalachian No. 1	73.7	14.7	14.4	11.9	2.4	4.2
New Mexico	98.0	0.0	196.2	15.8	0.0	21.9
North Louisiana-Arkansas	119.9	0.0	225.8	19.4	11.6	2.0
Rocky Mountain	471.9	0.0	713.0	76.3	0.0	171.9
East Coast	809.8	162.0	1,045.7	131.0	104.8	3.9
Texas Inland	503.5	0.0	1,195.8	81.4	0.0	35.8
West Coast	1,648.1	329.6	2,315.4	266.6	160.0	26.1
Louisiana Gulf Coast	2,466.0	0.0	4,449.1	398.9	79.8	127.4
Texas Gulf Coast	3,484.8	0.0	8,633.0	563.7	563.7	0.0
Market Total	**12,609.6**	**3,440.3**	**18,788.3**	**2,039.6**	**1,087.3**	**479.5**

Appendix F. Potential Savings at Different Blending Margins

This Appendix provides additional detail for the results in Section 4.1. Each table illustrates the aggregate savings for the biodiesel and ethanol markets at different blending margins. The results for each table are calculated by using the historical range for blending margins in that market. The cost savings is determined by calculating the relative costs of the Relaxed Mandate scenario (with RINs) to the cost of the Rigid Mandate (no RINs).

Table A.5. Ethanol Blending Costs and Savings at Different Blending Margins

Blending Margin	Rigid Mandate Cost ($/MM)	Relaxed Mandate Cost ($/MM)	Average Blending Cost –Rigid ($ gal/mi)	Average Blending Cost-Relaxed ($ gal/mi)	Fuel Blended -Relaxed Mandate (MM/gal)	Gallon-Miles saved (gal/B)
0.2	40,834.1	3,538.6	3.2	0.3	124.9	3,743.5
0.1	38,382.4	3,215.8	3.0	0.3	748.8	3,711.9
0.05	37,156.5	3,025.4	2.9	0.2	943.1	3,699.6
0	35,930.6	2,819.1	2.8	0.2	1,055.0	3,691.9
-0.05	34,704.8	2,584.1	2.8	0.2	1,641.8	3,645.5
-0.1	33,478.9	2,325.4	2.7	0.2	1,641.8	3,645.5
-0.2	31,027.2	1,740.8	2.5	0.1	2,221.2	3,590.0
-0.3	28,575.4	1,044.2	2.3	0.1	3,315.4	3,464.5
-0.5	23,671.9	-612.1	1.9	0.0	3,933.5	3,374.0
-1	11,413.2	-5,642.4	0.9	-0.4	5,137.4	3,138.2

Table A.6. Biodiesel Blending Costs and Savings at Different Blending Margins

Blending Margin	Rigid Mandate Cost ($/MM)	Relaxed Mandate Cost ($/MM)	Average Blending Cost – Rigid ($ gal/mi)	Average Blending Cost- Relaxed ($ gal/mi)	Fuel Blended - Relaxed Mandate (MM/gal)	Gallon-Miles saved (gal/B)
1.7	6,077.5	4,758.5	3.0	2.3	44.3	242.1
1.5	5,399.0	4,273.4	2.6	2.1	44.3	242.1
1.3	4,720.5	3,779.1	2.3	1.9	311.3	225.0
1.1	4,042.0	3,257.3	2.0	1.6	474.4	213.3
1.0	3,702.7	2,993.6	1.8	1.5	587.2	203.9
0.5	2,006.4	1,568.4	1.0	0.8	1,089.7	156.7
0.05	479.7	210.2	0.2	0.1	1,406.8	117.6
0	310.1	55.7	0.2	0.0	1,423.1	115.4
-0.05	140.5	-101.8	0.1	0.0	1,577.6	93.6