THE LEGISLATIVE, ECONOMIC, AND ETHICAL EFFECTS OF BIOFUEL MANDATES
The Unintended Consequences

ABSTRACT
This Paper reexamines biofuel mandates in the United States of America and Brazil, and expands upon the unintended consequences. We analyze the quantitative impacts of biofuel production on agricultural production, the relative energy efficiency of biofuel, the impacts of biofuel mandates on land usage and international trade, and the Renewable Identification Numbers program set forth by the EPA Renewable Fuel Standard. We determine that the unintended consequences of biofuel mandates far outweigh their benefits.

Michael Millman (Economics and Computer Science), Kyle Zheng (Economics), Kyle Nitiss (Economics)
Prepared for Professors R. Stephen Berry and George S. Tolley
Introduction

The Energy Policy Act was signed into law by President George W. Bush on July 29, 2005. The Act was meant to usher in much-needed changes in the energy industry, combating growing problems and effectively altering U.S. energy policy by introducing a new set of standards, tax incentives, and loan guarantees. Within the Energy Policy Act of 2005 was the Renewable Fuel Standard (RFS)—the first mandate of its kind—requiring transportation fuel in the United States to contain a minimum volume of renewable fuels. The main motivation of this Paper is the RFS, as the policies that it sets are what require the production and use of biofuels in the United States.

The benefits of the Renewable Fuel Standard are clear. The mandate continues to be a large contributor to American energy independence, as it is in effect, increasing the volume of fuel available to consumers. Additionally, the mandate has brought the United States to the forefront of ethanol production, of which it is now the world’s largest exporter. The world continues to ask for greener alternatives to the consumption of fossil fuels, and through the Renewable Fuel Standard, the United States was able to provide an answer—billions of dollars in subsidies and research in biofuel production. The Expanded Renewable Fuel Standard requires that 36 billion gallons of renewable fuels be blended by 2022¹.

However, many question the true motives of the RFS. Many of the policies instituted as a result of the Renewable Fuel Standard can be described as purely political—agricultural special interest groups benefited immensely from the passage of the bill, as products such as corn, soybean, and sugar cane were suddenly in much higher demand in order to satisfy volume

¹ Schnepf and Yacobucci. RFS: Overview and Issues, 1.
requirements. These special interest groups rest predominately within the heartland of the United States, and serve as important constituents of the Republican Party.

Apart from the political motives of the RFS, the costs of such a mandate have largely gone unchecked. The immense Washington lobbying presence of the biofuels market, and the fact that the program is government-sponsored, have cut down on negative feedback. In reviewing the literature, we only came across two substantive papers that argue our claim—that biofuel mandates cost more for society than their benefits. In October of 2010, Randy Schnepf and Brent Yacobucci of the Congressional Research Service published *Renewable Fuel Standard (RFS): Overview and Issues*. The paper highlighted the effects and progress of the initiative over the first five years of its deployment, and proceeded to discuss potential sustainability issues with it moving forward. The paper discussed supply issues of corn ethanol, as well as the more low-level infrastructural and distributional issues associated with ethanol. Schnepf and Yacobucci concluded that, although increased biofuel production can achieve energy security and environmental goals, this may come at the cost of the objectives of other policy initiatives. More concretely, they specifically mentioned “rapid expansion of biofuels production may have unintended and undesirable consequences for agricultural commodity costs, fossil energy use, and environmental degradation.”

Also in 2010, Harry de Gorter and David R. Just published *The Social Costs and Benefits of Biofuels*, which analyzed the efficacy of alternative biofuel policies using a cost-benefit analysis. In this paper, they determine that ethanol policies increase the inefficiency of farm subsidies, effectively creating a zero-sum game in the agricultural industry. Furthermore, they

---

2 *Ibid.*, 29
argue that sustainability standards are ineffective and should be re-designed. In their research, they cite several older papers that argue ethanol policies fail such a cost-benefit analysis (Taylor and Van Doren 2007, Metcalf 2008, Hahn and Cecot 2009). They also cite the 2008 Searchinger et al. paper, which argues that ethanol policies actually create higher greenhouse gas emission due to indirect land use changes.¹

In this Paper, we argue that some of the previous literature may be incorrect, particularly pertaining to biofuel mandates’ effects on the prices of agricultural products. However, it is important to note that none of the previous research highlights in aggregate, the many facets of negative externalities caused by biofuel mandates such as the Renewable Fuel Standard. We seek to develop an argument based off the quantitative and qualitative impacts of biofuel production on agricultural prices, the relative energy efficiency of biofuel, the impacts of mandates on unintentional land use changes and international trade, and a deep examination of the Renewable Identification Numbers trading system, and conclude that the costs of biofuel mandates are far greater than their intended benefits.

**Impact of Biofuels on Agricultural Prices**

Biofuel mandates, particularly in the United States, were created in order to subsidize the farming communities that produce the agricultural input necessary for production. The extent to

¹ This is also a subject of this Paper.
which this relationship holds in practice has been the subject of many papers, employing econometric time-series analysis to test this hypothesis. In 2012, the American Journal of Agricultural Economics published *The Impact of Biofuels on Commodity Food Prices: Assessment of Findings*. In this paper, Zilberman et al. compile and analyze the previous literature that has investigated the relationship between biofuel prices and agricultural prices.\(^5\) Serra et al. (2011) used auto-regression to identify the relationships between ethanol, corn, and gasoline prices from 1990-2008, finding a significant positive correlation between these data. A similar—but multivariate—auto-regression analysis was performed by Zhang et al. (2009), who found that changes in ethanol prices have short-term effects on agricultural commodity prices. In all cases, a positive relationship was discovered between ethanol prices and corn prices.

However, the previous research largely concerns itself with price action, and not necessarily with the fundamental drivers of the prices themselves. Instead of analyzing the effects of ethanol prices on agricultural prices, we will consider the effects of ethanol *production* on agricultural prices. In this portion of the paper, we will focus on the relationship between corn and ethanol, as ethanol is the most prevalent form of biofuel in the United States; its primary feedstock is corn. As we are only analyzing the effects of biofuel mandates on corn, it is not appropriate to include the prices—or production—of gasoline and other blendstocks. The data for this analysis spans June 2010 to November 2015, and comes from Quandl—an open source financial database—and the Department of Energy (DOE) weekly petroleum status reports.

The granularity of the data immediately poses a problem for time-series analysis. *Cash*\(^6\) corn prices—as reported by Quandl—are settled daily, whereas ethanol production figures from

---

\(^5\) Hochman et al. *Impact of Biofuels on Commodity Food Prices*, 3.

\(^6\) *Cash* here refers to the spot price of corn, as opposed to the *basis diff*, measured by the difference between spot and the front-month futures contract.
the DOE are posted weekly. Additionally, these production figures are reported on Fridays, and correspond to the “DOE week” measured from the previous Saturday to the corresponding Friday. Further complicating the data are holidays, when cash corn prices are not reported as the Chicago Mercantile Exchange (CME)—the clearing house for corn-based derivatives—is closed. In order to rectify these problems, it was necessary to calculate an average “DOE week” price for corn settlement, which then corresponds to the production of ethanol for that week. This process was performed in Excel, using the following VBA script:

```vba
Sub align_DOE()
    ' Declare variables
    Dim x As Double, y As Double
    Dim sum As Double
    Dim counter As Integer
    Dim DOE_DATE As Double

    ' Begin at x==2, y==2
    x = 2
    y = 2
    Do While Range("D" & x).Value <> ""
        DOE_DATE = Range("D" & x).Value
        sum = 0
        counter = 0
        ' Loop for as long as the closure dates fall within the DOE range
        Do While Range("A" & y).Value > DOE_DATE - 7
            sum = sum + Range("B" & y).Value
            counter = counter + 1
            y = y + 1
        Loop
        ' Put the averages in this cell
        Range("G" & x).Value = sum / counter
    Loop
    x = x + 1
End Sub
```

7 Here, a counter is kept to ensure that holidays and weekends are excluded from the total count when averaging.
After running the VBA script above, we have two vectors $\vec{X}$ and $\vec{Y}$, where $X$ represents the weekly ethanol production figures reported by the DOE, and $Y$ represents the average weekly price of cash corn with respect to the DOE week. We graph the properly-aligned series in Figure 1 below:

![Graph of Ethanol Production and Corn Prices](image)

**Figure 1:** This represents the ethanol production and cash corn price figures, properly aligned and cleaned using VBA.

From the graph, it is not immediately apparent that the two variables exhibit any type of relationship. However, there is clearly a period of interest in the data—between the middle of 2012 and the middle of 2013—when corn prices and ethanol production diverged significantly. Moreover, the divergence occurs simultaneously. In the span of about one month, cash corn prices rise approximately 47.8%, whereas ethanol production in the same period of time falls approximately 13%. In order to identify possible causes for this phenomena, we researched potential events in mid-2012 that could have resulted in such an event.

Research reveals that the summer of 2012 produced some of the most severe drought conditions across the Midwestern United States in decades. Severe drought in corn-producing
regions significantly lowered corn crop yields. As a result, corn futures prices increased 35%\(^8\) from June 18\(^{th}\) to August 29\(^{th}\), and implied volatility of corn front-month options increased 14.3 percentage points, indicative of a large presence of speculative trading. Increased capital and higher prices in the corn markets have tremendous effects on the price of ethanol, as demonstrated in the Zhang and Serra papers. The largest feedstock of ethanol in the United States is corn, and the American biofuel markets did not have the capacity to substitute production with sugarcane or soybean. As a result, it is fair to hypothesize that ethanol prices would also increase, but in this case, this price increase was not enough to counteract the lost profits due to increased corn prices.

In order to verify this analysis, it is necessary to consider the *crush spread*, which is the spread between corn prices and ethanol prices. The spread is calculated as \(\frac{p(\text{corn})}{2.8} - p(\text{ethanol})\)^9, and is used to represent the relative profitability of ethanol production. We graph the crush spread, as well as the price of corn futures, in *Figure 2*:

---

\(^8\) [http://www.eia.gov/todayinenergy/detail.cfm?id=7790](http://www.eia.gov/todayinenergy/detail.cfm?id=7790)

\(^9\) We divide the price of corn by 2.8 in order to derive the per-gallon price of corn, as ethanol is quoted per gallon.
As we can see, the crush spread falls significantly during the main drought period, indicating a significant loss of profitability for ethanol production. Equivalently in Figure 1, this corresponds to the time period during which ethanol production fell 13%. This brief qualitative analysis proves that ethanol producers decided to cut losses due to high corn prices, and cut production in order to save profits. This period of time will also affect the price of Renewable Identification Numbers (RINs) in early 2013, which we will discuss in later sections of this paper.

In order to capture a more long-term trend, we decided to run a simple, ordinary least squares (OLS) regression analysis on the price of cash corn, with respect to ethanol production. However, Figure 1 demonstrates that ethanol production exhibits seasonal characteristics—particularly after 2012—contributing to its oscillating series. Furthermore, corn prices tend to exhibit a random walk. Neither of these characteristics are acceptable given the constraints of OLS. To confirm this, we first graphed the auto-correlation function (ACF) of both times series in R. As we can see from Figure 3, both data sets exhibit auto-correlation and cross-covariance, prohibiting OLS without appropriate transformation:
To confirm this quantitatively, we ran an Augmented Dickey-Fuller test (ADF) on both data series using the R command `adf.test()`. The results below contain p-values > 0.05, indicating that we cannot reject the null hypothesis—the time series are non-stationary.

```r
> adf.test(prod)
Augmented Dickey-Fuller Test
data:  prod
Dickey-Fuller = -2.5291, Lag order = 6, p-value = 0.3532
alternative hypothesis: stationary

> adf.test(prices)
Augmented Dickey-Fuller Test
data:  prices
Dickey-Fuller = -2.9868, Lag order = 6, p-value = 0.1603
alternative hypothesis: stationary
```

In order to derive OLS estimators, we will need to transform the data appropriately. M.B. Priestley discusses common methods of handling non-stationary data in his paper, *Non-Linear and Non-Stationary Time Series Analysis* (1988). One very simple method we can apply to our data is the method of differences, in which, for a series $X$ of $n$ observations, $X = x_0, x_1, \ldots x_n$, and a corresponding difference series $Y$ of $n-1$ observations, we have $y_t = x_{t+1} - x_t$. We apply this method to both the cash corn prices and ethanol production figures, and obtain Figure 4:
We observe a slight lag at the beginning of the series, but this tapers off in the rest of the series, indicating our data is now stationary. To confirm this, we again run an ADF test on the differenced data series, and obtain p-values < 0.01.\(^\text{10}\)

With stationary series, our data now conforms to the assumptions of OLS regression. In R, we estimate the intercept and regression coefficient, and obtain the following results:

```r
> reg <- lm(actual_diff_price~actual_diff_prod)
> summary(reg)

Call: lm(formula = actual_diff_price ~ actual_diff_prod)

Residuals:
     Min      1Q  Median       3Q      Max
-0.8610 -0.1061  0.0048  0.1069  0.9351

Coefficients:               Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.001756   0.012763   0.14   0.89
actual_diff_prod      -0.000207   0.000676  -0.31   0.76

Residual standard error: 0.214 on 280 degrees of freedom
Multiple R-squared: 0.000336,   Adjusted R-squared: -0.00323
F-statistic: 0.0942 on 1 and 280 DF,  p-value: 0.759
```

We see that the regression coefficient is \(-0.000207\), indicating that for every 10,000 barrel increase in ethanol production, there will be a corresponding $0.01 fall in the price of corn. However, with a p-value of 0.759, this result is far from statistically significant, and thus we fail to reject the null hypothesis—ethanol production does not have an effect on the price of corn.

In order to solidify this argument, it is necessary to check the lag periods of weekly changes in corn prices with respect to weekly changes in ethanol production. It is possible that changes in the price of corn exhibit a lagged effect, such that a shock in the supply of ethanol

\(^{10}\) The code here is omitted to eliminate redundancy.
would cause a significant change in the price of corn several weeks later. In order to verify this is not the case, we run the command `lag2.plot()` command in R to obtain the graph in Figure 5:

```r
> lag2.plot(actual_diff_price, actual_diff_prod, 8)
```

Figure 5: The lagged correlation plot displays scatter plots with 8 lag periods. Corresponding correlations are in the upper-right corner of each graph.

The correlation representing the first lag period—0.11—is noticeably stronger than the other lag periods, suggesting a more significant change in the price of corn one week after an ethanol production change. However, results of similar OLS regression analysis prove that this relationship is also statistically insignificant. Once again, we fail to reject the null hypothesis.

In conclusion, treating the data was necessary in order to ensure the series aligned properly, and conformed to the assumptions of OLS regression. The method of differences effectively eliminated seasonality and auto-correlation in the series, allowing for proper analysis. However, the data does not suggest the presence of a quantifiable relationship between the price
of cash corn, and the ethanol production. Regardless of these results, a qualitative analysis of corn prices and ethanol production yielded troubling information—the drastic fall in ethanol production in 2012 and 2013 was primarily caused by a severe drought, driving up the price of corn substantially. In this instance, biofuel production sustained marked impacts of a crisis beyond control of the United States EPA mandates—drought. This study represents one weakness of the U.S. biofuel mandate, and merits further consideration for policy changes.

**Trends in Agricultural Production**

Over the past fifteen years, ethanol production has boomed in the United States, tripling between 2000 and 2007 and rising steadily thereafter. Between 2000 and 2014, ethanol production grew from 1,622 million barrels to 14,340 million barrels, an increase of 884%.\(^{11}\) In this section of the paper, the effect of this precipitous growth in ethanol production on U.S. agriculture will be examined. In particular, as corn is the primary - and nearly exclusive - feedstock for ethanol, we will examine the effect of rising ethanol production on the total yield of production (in USD) of the top five U.S. cash crops (corn, soybeans, hay, wheat, and cotton). In addition, we will also examine the energy inputs required for each of these cash crops in service of determining whether the rise in ethanol production has affected the structure of crop production, and consequently, whether a change in crop structure has significantly altered the energy requirements for crop cultivation in the U.S.

In 2000, before the steep rise in ethanol production, corn comprised 28% of the total field crop yield. Soybeans were the second leading crop at 19%, followed by hay, wheat, and cotton, at 18%, 9%, and 6%, respectively.\(^{12}\) By 2014, corn’s share of the total field crop production had

---

\(^{11}\) Renewable Fuels Association. *Industry Statistics.*

\(^{12}\) USDA/NASS Database.
grown to 35%. Soybeans also increased in terms of share of total field crop yield to 27%, while hay, wheat, and cotton fell to 13%, 8%, and 3% respectively.

![U.S. Crop Production, 2000-2014](image)

**Figure 1:** Area chart of Top 5 U.S. Cash Crop Production

As illustrated in Figure 1, the increase in corn’s share of total field crop yield coincided with the sharp increase in ethanol production. In 2011, corn’s share rose to 44%, accounting for nearly half of total crop production in the U.S., and an increase in share of 12% from ten years earlier. Another noteworthy trend illustrated in Figure 1 is that U.S. crop production as a whole more than doubled between 2000 and 2014.

The total yield from corn rose between 2000 and 2014, growing faster than the rate at which total field crop production grew and also faster than any other of the five major cash
crops. Given this growth, the next question the paper will concern itself with is what, if any, discernible role did the rise in ethanol production have on the increase in corn production.

![Figure 2: U.S. Use of Corn by Billions of Bushels](image)

![Figure 3: U.S. Production of Corn($) and Ethanol (mil. gallons)](image)

In Figure 2, it is evident that corn use for feed and export remained basically constant over the period of observation, but corn use for ethanol rose dramatically. In 1990-1991, corn use for ethanol was around half of what was used for export; by 2010-2011, more corn was being used for ethanol production than was used for feedstock - a roughly fivefold increase in usage. Clearly, growing ethanol production has played a role in the increasing production of corn. The effect seems not to be as simple as ‘more ethanol = more corn’. The downside of using total yield from production is that it encapsulates both the total amount of corn produced as well as the price of corn. A more rigorous treatment of the relationship between corn prices and ethanol production can be found elsewhere in the paper, but here we will take a slightly different approach. To separate out the effect of corn prices on total yield of production from corn, we examined the relationship between bushels of corn produced and ethanol production:

13 USDA, Economic Research Service. Feed Grains Database
While production of bushels of corn does increase over the period of observation, the trend is far less distinct than what was observed in total yield of production. Here we see growth by a factor of less than 1.5, whereas there was growth by a factor of nearly 3 in total yield of production. This points to the relationship between corn production and ethanol production not being as strong as earlier analysis may have suggested.

Another method for ascertaining the trend of corn production is to use area planted over time.
Again, we see a familiar trend, with the area planted with corn increasing distinctly in the mid-2000’s - the same point at which ethanol production spiked. Additionally, we see other cash crop being planted over less area, as wheat and cotton show downward trends, though only cotton’s downward trend seems to originate in the same window of time during which ethanol production increased. Interestingly, soybeans - another crop that is used to produce ethanol, though in far less volume than corn - increases in area planted over roughly the same period as corn.

**Cultivation Energy Requirements**

The next focus will be whether the apparent shift in the crop production has a substantial impact on the energy requirement for crop cultivation in the U.S. Based on various studies on the subject, we settled on estimates for each cash crop we analyzed, each estimate generally representing an average of published energy requirements. Energy requirements include inputs

---

required to plant, enrich, protect, and harvest plants, but do not include after-the-fact inputs such as transportation or, for corn and soybeans, energy inputs required for ethanol conversion.

Figure 6 offers a potential reason for cotton’s declining production: it is remarkably energy-intensive as compared with the other cash crops, requiring more than three times more energy than wheat, which is requires the next most energy to cultivate. Granted, a ton of cotton is worth roughly ten times more than a ton of wheat (as of 11/2015), but at such high relative energy requirements, economies of scale are likely more difficult to achieve. Also of consequence, corn requires only roughly 1.55 GJ per ton of corn produced, second-lowest only to hay. This bodes well if corn continues to be produced at an increasing rate.

Energy efficiency is an important consideration in evaluating the viability of cash crops, but it is not the sole consideration. In particular, with regards to corn, while our estimate includes the energy required to fertilize the corn fields, it cannot fully capture the environmental footprint
these fertilizers leave. Corn, specifically, requires a large amount of nitrogen in the soil to flourish - indeed it is the most nitrogen-intensive crop grown in the U.S. The immense amount of nitrogen used in corn cultivation has several drawbacks, the most grave of which are nitrogen-contaminated runoff water polluting rivers and oceans, and the release of nitrous oxides which are potent greenhouse gases. These consequences will only grow worse as corn production - and therefore nitrogen-fertilizer use increases - and will continue to do so unless containment of these fertilizer byproducts improves dramatically.

**Brazil as a Case Study**

Brazil is the world’s second largest producer of ethanol, and produces most of its ethanol from sugarcane. Its levels of ethanol production are exceeded only by the United States, and together, the two nations produced 83% of the entire world’s ethanol in 2014. Figure 1, taken from the Alternative Fuels Data Center (AFDC) shows the global production volume of ethanol and the shares of production for each of the world’s major producers.

![Figure 1: Global Ethanol Production by Volume and Share of Production](image)

---

15 DOE, Alternative Fuels Data Center. Maps and Data.
While Brazil is one of the largest economies in the world, there are reasons for its high share of global ethanol production that explain why it produces so much more than countries with larger economies, such as China and several countries in Europe.

To better understand these reasons, we will first examine the ethanol production process in order to glean insights as to why Brazil is positioned so well to produce such large volumes of ethanol. Because Brazil produces its ethanol from sugarcane, we will focus on this specific production process. We will also examine the wider Brazilian economy to see why ethanol production levels are so high, and investigate the history of energy policy in Brazil. In doing so, we hope to learn the effects of biofuel and energy mandates on the Brazilian economy, to see their benefits and consequences.

Sugarcane ethanol is regarded as the most successful alternative fuel to date. Figure 2 demonstrates the main steps required for producing ethanol from sugarcane.

![Simplified Process Flow Diagram of Fuel Ethanol Production](image)

*Figure 2 – Simplified process flow diagram of fuel ethanol production (JOSHI and PANDEY, 1999).*
The end product from this process, fuel ethanol, is nearly identical to the ethanol produced when other feedstock, such as corn or wheat. A major advantage that sugarcane has over other feedstock is that it yields nine times more energy than it consumes during the process. This energy balance is over four times better than ethanol produced from wheat or sugarbeet, and nearly seven times that of corn ethanol. Brazilian sugarcane ethanol is also the most productive feedstock, as it produces 7,500 liters of fuel per hectare, compared to the 5,500 liters per hectare of European sugarbeet and 3,800 liters per hectare of U.S. corn.

The advantages of using sugarcane as a feedstock for ethanol contribute to Brazil’s ability to produce so much ethanol, but there are other reasons for its high levels of productions.

---

16 SCI ELO, Proceedings.
17 SugarCane.org, Producing Food and Fuel.
18 Ibid., Preserving Biodiversity.
While its economy is not quite as strong as several countries in Europe and Asia, Brazil’s land mass allows it to farm more feedstock than countries in Europe or Asia. Yet Brazil only extensively utilizes two regions of its entire country for sugarcane farming. Figure 3 shows the portion of Brazil that contributes to the ethanol production industry. In addition to the relatively small amount of land required for sugarcane ethanol production, this process is also environmentally friendly in the way that it does not impose on the rainforests in Brazil, which are a major topic of concern for environmentalists.

We can also point to Brazil’s relatively strong economy that allows it to support the infrastructure required to operate a large-scale ethanol industry. Relative to larger countries that could feasibly farm as much as Brazil, such as other countries in South America, Brazil has a more capable economy that allows it to farm and produce more than such countries. It has a GDP of 2346.12 billion USD\(^\text{19}\), compared to the country with the second highest GDP in Latin America, Argentina, which has a GDP of 540.20 billion USD. In addition to its relatively large size and economy, biofuel mandates that emphasize sugarcane production are major reasons for Brazil’s booming biofuel production.

In the 1930s, Brazil began to blend ethanol and gasoline to provide as a source of fuel. By the 1970s, 80% of oil was imported, and 98% of public and industrial transportation relied on oil and oil derivatives for energy.\(^\text{20}\) As a result, the country was drastically affected by the oil crisis in the 1970, so the Brazilian government decided to adjust the country’s energy strategy to increase the emphasis on biofuels, and subsequently increase its energy supply.\(^\text{21}\) There were several incentives for the implementation of this program. At the pricing level, ethanol prices

\(^{19}\) Trading Economics. Brazil GDP.

\(^{20}\) Giacomazzi. A Brief History of Brazilian Proalcool Programme

were lower than gasoline prices, and taxes are lower for vehicles moved by ethanol. Additionally, the program would help producers by one, insuring that they would be paid for their product, and two, through government aid in financing their production to increase production capacities. The program would also allow the country to internally maintain its strategic reserves so that it could respond to future shocks.

In 1975, the ProAlcool program was implemented, with the goal of slowing down energy consumption by producing ethanol from biomasses, such as sugarcane, cassava, and sorghum, to substitute for gasoline. In phase one of the program, anhydrous alcohol was mixed with gasoline to have a mixture of up to 20% alcohol. To achieve this, the country embarked to increase alcohol production from 600,000 liters/year to 3B liters/year. They accomplished this by subsidizing the expansion of and investment in the sugarcane mills and distilleries. The government viewed this energy strategy as more flexible and adaptive to changes in crop and energy prices. If the price of sugarcane was low, then alcohol could be produced, and if the price of alcohol was low, then sugarcane could be sold as a crop.

Phase two of the ProAlcool program began in 1980, as the government continued to provide economic incentives for increasing the capacities and productivity of the sugarcane mills and distilleries. Additionally, researchers began to use plants that were more productive for producing alcohols, at the loss of the flexibility of being used to produce sugar. Figure 4 below shows how ethanol production has increased over time since the start of the ProAlcool program.
The ProAlcoòl program encouraged innovation in ethanol production processes, as it offered financing for research and development of more efficient processes. As a result, Brazil was able to increase the amount of sugarcane ethanol produced per hectare. Figure 5 demonstrates this increase in productivity as a result of government financing and innovation of technology. As the graph demonstrates, the yield of ethanol per hectare increased by 3.77% annually from 1975 to 2003, which is one of the major explanations for the increase in ethanol production in Brazil. This also explains how the country can utilize so little of its land to produce so much ethanol.

On the consumption side, automobile factories were incentivized to produce cars that could only use alcohol as a fuel. By 1984, 94% of passenger cars could only run on ethanol. The country’s reliance on oil in the 1970s made them vulnerable to the oil crisis of that decade, just as the country’s overreliance on ethanol would in the 1980s.

---

22 Azanha and Dias de Moraes. Reflections on Brazil’s Ethanol Industry, 139.
Ethanol production began to stagnate in the 1980s for several reasons at both the domestic and international levels. Within Brazil, sugarcane farmers paid low prices for ethanol, so there were weaker incentives for them to produce as much. The government became less confident in the program, and Petrobras, a major figure in the oil industry with great influence over the Brazilian economy, was opposed to the consequences they faced as a result of the ProAlcool program. Increases in domestic oil production also contributed to the falling levels of ethanol production. At the international level, ethanol imports were becoming cheaper, making domestic ethanol production less profitable. Lower levels of ethanol production, combined with the increase in ethanol-reliant cars, led to a disparity between ethanol supply and demand. This ultimately resulted in reduced confidence in the ProAlcool program; this combined with the falling oil prices around the world during the 1980s resulted in a shift towards cars that ran on gasoline.

---

23 Goldemberg, Brazil's Biofuel Industry, 5.
To better understand the energy landscape in Brazil with respect to ethanol, we will examine the automobile industry over time, and see how it was affected by Brazilian biofuel mandates. We previously discussed the introduction of E100 vehicles, which ran on 100% ethanol fuel, and saw how its production levels were vastly increased as a result of the ProAlcool program. Figure 6 demonstrates the landscape of the automobile industry in the years following the ProAlcool program.

![Figure 6: Production of Ethanol-Reliant Automobiles in Brazil](image)

Production of these vehicles vastly decreased as a result of stagnating ethanol production during the 1980s. Figure 7 is a continuation of Figure 6, extending to 1999, and thus shows the decline in sales of E100 vehicles. By the end of the 1990s, the ethanol supply, along with its price, stabilized, which encouraged the resurgence of E100 vehicles, as the economic incentives established in the ProAlcool program were still applicable.

---

Global concern over climate change as a result of the use of oil and natural gas promoted the use of alternative fuels, such as ethanol. As a cheap, energy efficient, alternative fuel, sugarcane ethanol increased in popularity, and as a result, E100 vehicles increased in popularity as well. Figure 8 shows the increase in E100 vehicle sales following the turn of the century.

In 2003, the Brazilian automobile industry introduced a type of car that would drastically change the country’s energy landscape: the Flex Fuel Vehicle. This vehicle is designed to be able to use E100, gasoline (E22), or any combination of these fuels. As the name suggests, this type of vehicle affords its drivers flexibility when it comes to purchasing fuel. Different types of fuels essentially become perfect substitutes for one another. When oil prices are high, they can choose to use fuels that have higher concentrations of ethanol, and they can resort to fuels with lower concentrations of ethanol when ethanol and sugarcane prices are high.

Figure 7: Production of Ethanol-Reliant Automobiles in Brazil\textsuperscript{25}

\textsuperscript{25} Ibid., 9.
Figure 8: E100 Fueled Vehicle Sales from 1998-2002

Figure 9 demonstrates the drastic increase in popularity of these vehicles over the ten years since their introduction.

Figure 9: Sales of Flex Fuel Vehicles from 2003-2013

Ibid., 9
Ibid., 11
In 2009, 92% of all new cars and light vehicles were equipped with flex-fuel technology. By 2011, flex-fuel vehicles made up 51% of all Otto cycle vehicles\textsuperscript{28}, which include passenger cars, light commercial vehicles, and motorcycles. \textsuperscript{29}

The advantages of flex-fuel vehicles are many, as consumers can choose the fuel that is most profitable for them without further consideration. Consumers simply perform a cost-benefit analysis to decide which fuel would be more beneficial for them to use. According to the ANP (The Brazilian National Agency of Petroleum, Natural Gas, and Biofuels), hydrous ethanol has approximately 70% of the calorific value of gasoline, meaning that when hydrous ethanol is priced at above 70% the cost of gasoline, it is more economical to fuel a vehicle with gasoline. Figure 10 shows the ratio between hydrous alcohol and gasoline prices. In the first decade of the 21\textsuperscript{st} century, it is clear from Figure 10 that ethanol was the cheaper option.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Price ratio of Hydrous Alcohol to Gasoline over Time\textsuperscript{30}}
\end{figure}

\textsuperscript{28} UN Energy Knowledge Network. Ethanol Fuel in Brazil
\textsuperscript{29} Gomez and Legey. An Analysis of the Impact of Biofuels, 697
\textsuperscript{30} Ibid., 701
This is consistent with our data above showing the increase in ethanol production in the period leading up to, and during, the time series depicted in Figure 10, as increases in ethanol supply generally result in a price decrease in ethanol. The rising oil prices during this period, as shown in Figure 11, help to explain the price ratio depicted in Figure 10.

In the past few years, global oil prices have fallen drastically, resulting in consumers opting to use more gasoline to fuel their vehicles. This has resulted in financial hardship for the Brazilian ethanol industry, an industry that generates gross revenues totaling $86 billion annually, and employs over 1 million workers. The industry’s importance was highlighted this past year (2015), when the Brazilian Senate passed a new biofuel mandate, raising the ethanol blend rate with gasoline from 25% to 27%. This change is expected to increase domestic consumption of ethanol by 1.2 billion liters, and is complemented by an increase in federal taxes on gasoline.

---

31 MacroTrends. Crude Oil Prices  
32 SugarCane.org, Impact on Brazil’s Economy  
33 Barros. Brazil Raised Federal Taxes and Blend Mandate, 2.
Outside of the realm of energy, ethanol plays an important role in the Brazilian economy. Until recently, Brazil was the world’s leading exporter of ethanol fuel, and is now only behind the United States in ethanol exports. Brazil reached its peak of ethanol exports in 2008, when they sold $2.4 billion’s worth of ethanol, mostly to the United States. Figure 12 shows the change in Brazil’s ethanol exports from 2003 to 2010.

![Brazil’s Ethanol Exports from 2003-2010](image)

**Figure 12**: Brazil’s Ethanol Exports from 2003-2010

Brazil has been tipped as the country most capable of meeting the world’s ethanol demands, as a result of the efficiency and availability of its main feedstock, sugarcane. This global ethanol demand has been increasing in recent years, due to international concerns regarding greenhouse gas emissions. However, Brazil’s capacity to export ethanol depends on several factors, including domestic ethanol demand, oil and sugarcane prices, and transportation infrastructure required to move ethanol to ports for export.

---

34 Valdes. Brazil’s Ethanol Industry: Looking Forward, 3.
In recent years, mandates such as the one implemented in 2015 mentioned above, have increased domestic consumption of ethanol, leaving less of a supply for the global market. Brazil is the world’s second largest consumer of ethanol, behind the United States, and consumed 22.7 billion liters in 2009, accounting for 31% of global consumption. Above, we showcased the recent trend of decreasing oil prices. This, combined with the relative increase in sugar prices in recent years, as shown in Figure 13, has resulted in the profitability of ethanol decreasing and decreased ethanol production, and thus has reduced Brazil’s ability to supply the world with ethanol.

Figure 13: Sugar Prices from 1990-2015\textsuperscript{35}

As we have mentioned numerous times throughout this publication, Brazil is well positioned to be the world’s main ethanol exporter. The Brazilian economy, which is currently in a recession, could benefit from the increased global demand for ethanol, and Figure 14 illustrates Brazil’s export market potential projections all the way up to 2018. As the table shows, Brazil stands to gain a lot from the global ethanol market, but as we have mentioned before, it may be difficult for the country to meet this demand as it currently stands. We mentioned that the

\textsuperscript{35} Index Mundi, Sugar Futures End of Day Settlement Price.
country’s currently utilizes a relatively small amount of its entire landmass to produce sugarcane and ethanol at their current levels. While it could be costly to do so, it could be profitable in the long-run for the country to expand the scale of its operations.

Figure 14: Projections of Brazil’s Ethanol Export Market Potential

In order for an increase in the scale of the ethanol industry to benefit from the revenues of international exports, it must improve its transportation infrastructure. Figure 15 shows the current infrastructure, and as expected, most of the infrastructure is around the major sugarcane production hubs in southern Brazil. It remains to be seen if expanding the operations of the ethanol industry and widening the scope of its transportation infrastructure is economically feasible, given the current state of the Brazilian economy. Additionally, it is unclear whether it would be ultimately profitable for them to do so, even with the enormous ethanol global market potential.
However, given the fact that sugarcane is the world’s most efficient and successful biofuel feedstock, and the fact that Brazil already boasts a strong infrastructure dedicated to its ethanol industry, it is clear that Brazil is the world’s best option for meeting the rising demand for ethanol.

**Conversion of Corn into Ethanol: Energy Inputs**

In this section of the paper, the process, as well as the energy requirements for converting corn into ethanol fuel will be examined. The energy required to cultivate corn (in GJ/ton) was discussed above, and the energy input required was found to be roughly 1.55 GJ/ton. This will now be combined with estimates of the energy required to transport corn to ethanol fuel distilling.

---

36 Valdes. Brazil’s Ethanol Industry: Looking Forward, 16.
sites, and to convert corn into ethanol. First, however, we will explain the process of distilling ethanol from corn.

Distilling ethanol from corn involves one of two processes: dry-milling or wet-milling. In either case, corn is mashed, allowed to ferment, and then distilled into ethanol. In the case of wet-milling, corn is soaked in a solution which separates it into its component parts. Corn oil is a byproduct of this process, and is bottled and sold. Additionally, the gluten proteins in the corn can be extracted and turned into a nutritious feed for livestock. While these byproducts do not reduce the amount of energy required to produce the ethanol, the ability to sell them does help to offset the cost of the energy used to produce ethanol.

The process of dry-milling does not produce the same byproducts as wet-milling, but is completed more quickly. Dry-milling skips the step of separating the corn meal into its component parts, and merely ferments the corn meal and distilled ethanol from it.

We will now proceed with our estimates of the required energy inputs. For our analysis of the energy inputs of transportation of corn, we used an average of a 90-mile round-trip. This figure has been used in several studies, and seems a respectable estimate. Given this, to transport 10kg of corn, roughly 4,700 BTU of energy is required. Converting this to our preferred units of measurement, this gives us 2.182 GJ/ton.\(^37\)\(^38\)

Estimates for the energy required to convert corn into ethanol, as well as for the energy conversion rate (BTU/gal) vary fairly widely. In general, it appears that the process has grown more efficient over time, and as such, recent studies provide lower figures for energy


\(^{38}\) \(470\text{BTU/kg} = .000496\text{GJ/kg} = .001091\text{GJ/lb} = 2.182\text{GJ/ton}\)
requirements, and older studies provide higher figures. For instance, Pimental’s above cited study suggests far higher energy input requirements than does a report written by Shahpouri in 2008.\textsuperscript{39} The estimate we chose to use reflects this tendency towards the increasing efficiency of ethanol conversion.

### Table 1: Energy input assumptions of corn-ethanol studies

<table>
<thead>
<tr>
<th>Study/year</th>
<th>Corn yield</th>
<th>Nitrogen fertilizer application rate l/acre</th>
<th>Nitrogen fertilizer lb/acre</th>
<th>Corn ethanol conversion rate gal/bu</th>
<th>Ethanol conversion process MJ/bu</th>
<th>Total\textsuperscript{1} energy use MJ/bu</th>
<th>Co-products\textsuperscript{1} energy credits MJ/bu</th>
<th>Net\textsuperscript{1} energy value MJ/bu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pimentel (1991)</td>
<td>110</td>
<td>136</td>
<td>37,551</td>
<td>2.50</td>
<td>73,687</td>
<td>131,017 (LHV)</td>
<td>23,500</td>
<td>-33,517</td>
</tr>
<tr>
<td>Pimentel (2001)</td>
<td>127</td>
<td>129</td>
<td>35,547</td>
<td>2.50</td>
<td>75,118</td>
<td>131,016 (LHV)</td>
<td>23,500</td>
<td>-33,562</td>
</tr>
<tr>
<td>Kenya and DeLuce (1992)</td>
<td>119</td>
<td>125</td>
<td>37,955</td>
<td>2.20</td>
<td>48,670</td>
<td>91,190 (LHV)</td>
<td>8,078</td>
<td>-8,438</td>
</tr>
<tr>
<td>Merland and Tuthillow (1999)</td>
<td>119</td>
<td>127</td>
<td>31,135</td>
<td>2.50</td>
<td>50,105</td>
<td>75,954 (HHV)</td>
<td>8,127</td>
<td>18,154</td>
</tr>
<tr>
<td>Lorenz and Morris (1995)</td>
<td>120</td>
<td>123</td>
<td>27,605</td>
<td>2.55</td>
<td>53,556</td>
<td>81,000 (HHV)</td>
<td>27,579</td>
<td>30,589</td>
</tr>
<tr>
<td>Ho (1995)</td>
<td>90</td>
<td>NR</td>
<td>NR</td>
<td>2.55</td>
<td>57,600</td>
<td>50,000 (HHV)</td>
<td>10,500</td>
<td>-4,000</td>
</tr>
<tr>
<td>Wang et al. (1999)</td>
<td>125</td>
<td>131</td>
<td>21,092</td>
<td>2.55</td>
<td>40,850</td>
<td>68,450 (LHV)</td>
<td>14,950</td>
<td>22,500</td>
</tr>
<tr>
<td>Agril. and Agri-Food Canada (1999)</td>
<td>116</td>
<td>125</td>
<td>NR</td>
<td>2.60</td>
<td>50,415</td>
<td>64,450 (LHV)</td>
<td>14,055</td>
<td>29,826</td>
</tr>
<tr>
<td>Shapouri et al. (1995)</td>
<td>122</td>
<td>125</td>
<td>22,159</td>
<td>2.53</td>
<td>53,277</td>
<td>82,824 (HHV)</td>
<td>15,056</td>
<td>16,193</td>
</tr>
<tr>
<td>This study (2002)</td>
<td>125</td>
<td>129</td>
<td>18,392</td>
<td>2.66</td>
<td>51,779</td>
<td>77,228 (HHV)</td>
<td>14,372</td>
<td>21,105</td>
</tr>
</tbody>
</table>

\textsuperscript{NR. Not reported.}

\textsuperscript{LHV. Low heat value = 76,000 Btu per gallon of ethanol. Kenya and DeLuce used 74,680 Btu per gallon of ethanol.}

\textsuperscript{HHV. High heat value = 83,961 Btu per gallon of ethanol. Lorenz and Morris used 84,100 Btu per gallon of ethanol.}

\textsuperscript{1 The midpoint or average is used when studies report a range of values.}

**Figure 7:** Table showing various estimates of energy inputs. Table does not reflect all studies taken into account in our research.\textsuperscript{40}

The estimate we will use for the energy requirement for the conversion of corn feedstock to ethanol is 9.5 MJ per Liter of ethanol produced.\textsuperscript{41} This energy is comprised of natural gas and electricity. Additionally, our analysis will assume a 2.8 gallon/bushel conversion rate. This is


\textsuperscript{40} Shapouri et al. *Energy Balance of Corn Ethanol: An Update*, 3.

\textsuperscript{41} This figure is derived from an average of several studies and factoring in the increasing efficiency of ethanol conversion technologies.
based also on improving technologies, and that the average conversion rate stood at 2.76 gal/bu in 2006, and has been growing steadily over the past decade and a half.\textsuperscript{42}

Taking all this together, we have a total energy input:

\[
1.55\text{GJ/ton} + 2.18 \text{GJ/ton} + 3.47 \text{GJ/ton}\textsuperscript{43} = 7.2 \text{GJ/ton}
\]

This gives us an estimate of the energy needed to grow, harvest, transport, and convert into ethanol, one ton of corn. An analysis of the energy balance of corn/ethanol production will follow, but first, we will perform the above analysis on sugarcane ethanol production.

**Conversion of Sugarcane into Ethanol: Energy Inputs**

In the analysis of the energy inputs required for the conversion of sugarcane into ethanol, we were able to draw from an excellent study by Coelho et al. A table created by the research team presents two breakdowns of the energy inputs required: one for the average Brazilian cane mill, and the other representing the most efficient of the Brazilian cane mills.


\textsuperscript{43} 2.76 gal/bu = 2.76gal/56lbs = 10.45L/56lbs = 365.63L/ton \times 9.5 \text{MJ/L} = 3474.63 \text{MJ/ton} = 3.47\text{GJ/ton}
The figures listed above are extremely helpful, although need some adjusting, due to near-decade lapse since their measurement. As with corn production and conversion, the processes for growing and converting sugarcane into ethanol have been steadily becoming increasingly efficient. Therefore, it stands to reason that the energy inputs in 2015 to produce a gallon of ethanol have decreased, and our figures will reflect that. For the purposes of our analysis, we used:

\[ 0.19 \text{ GJ/ton}^{45} + 0.038 \text{ GJ/ton} = 0.228 \text{ GJ/ton} \]

This energy requirement is remarkably lower than the requirement for corn ethanol. This stems from the way that sugarcane ethanol is distilled. When the sugar is extracted from the sugarcane, a byproduct called “bagasse” is created. The bagasse can itself be used as a biofuel, and is used to fuel the distillation process. Coelho et al. included the 0 KJ/ton input from electricity in ethanol production in their table to illustrate this effect. Once the sugarcane arrives

\[ 44 \text{ Coelho et al. Brazilian Sugarcane Ethanol, 28.} \]

\[ 45 \text{ 190,000 KJ/ton} = 0.19 \text{ GJ/ton}; \text{ this figure includes transportation as well as cultivation and harvest} \]
at the distillation site, no fossil fuel energy input is required. The bagasse from the sugarcane produces more than enough energy, and makes the distillation of sugarcane a closed system with regards to energy.

This analysis of energy input shows that production of ethanol from sugarcane is far more efficient than the production of ethanol from corn. This is due both to sugarcane being relatively less energy-intensive to grow, and also to bagasse, the byproduct which allows sugarcane to

---

46 NCGA. *Sugarcane as a Feedstock for Biofuels*, 11.
power its own conversion to ethanol. While corn-ethanol has been much maligned for it inefficiency, it appears that sugarcane – at least from an energy standpoint – provides a superior alternative source for ethanol.

**Energy Inputs Required to Produce Crude Oil**

As this paper aims to provide a cost-benefit analysis of the production and consumption of ethanol-based biofuel against the production and consumption of traditional unleaded gasoline, a brief study of the latter is required.

There has, unsurprisingly, been much research conducted on the topic of energy input required to extract crude oil. There are many different kinds of crude oil sources, as well as many different kinds of extraction methods. Convening a consensus of several studies, we will use 1,280 MJ/barrel as the total energy required to extract (331 MJ), transport (880 MJ), and refine (70 MJ), one barrel of crude oil into unleaded gasoline.\(^{47}\)\(^{48}\) This translates to .0081 GJ/L of oil. This compares to .0095 GJ/L for corn-ethanol, and .0031 GJ/L for sugarcane-ethanol. The energy efficiency of the production of gasoline is slightly better than corn, but worse than sugarcane by a factor of more than 2.

**Energy Density of Ethanol vs. Gasoline**

The paper thus far has focused on the energy inputs necessary to produce each fuel. In this section, we will turn to the energy outputs produced by each fuel. Namely, we will compare

---

\(^{47}\) Glanfield Jr. *Energy Required to Extract Petroleum Products*, 33

\(^{48}\) In this paper, we will deal only with estimates for U.S. oil.
the energy density of each fuel, and note the corresponding change in fuel consumption that different levels of energy density necessitate.

It is broadly known that ethanol contains roughly 67% of the energy density that gasoline does. This means that 1 gallon of ethanol will produce 67% less energy than 1 gallon of gasoline. As seen in the figure below, this translates fairly simply to an increase in fuel consumption rate as the proportion of ethanol blended into the gasoline increases.

*Figure 10: Charts fuel consumption rate against percentage of ethanol content in fuel. Shown at different rpm*[^1]
Comparing this with our findings from previous sections where we determined the energy input for a given liter of corn-ethanol, sugarcane-ethanol, and gasoline; and taking into account that 67% more ethanol must be consumed to generate the same amount of energy; we can derive relative energy input figures that reflect ethanol’s deficiency in energy density. The new figures for ethanol are .0143 GJ/adjusted-L for corn-ethanol, and .0047 GJ/adjusted-L for sugarcane-ethanol. Gasoline remains unchanged, at .0081 GJ/L. Corn-ethanol, which was already less energy efficient to produce than gasoline, falls even further behind gasoline; yet, sugarcane-ethanol remains more energy efficient to produce even under our new constraints.

**Comparison of Emissions from Ethanol vs. Gasoline**

Ethanol’s selling point is obviously not energy density – though sugarcane-ethanol did prove more energy efficient under our analysis than traditional unleaded gasoline. Instead, a primary virtue of ethanol is that it alleges to burn cleaner than petroleum-based fuels, thereby providing a similar level of energy output with reduced negative externalities. This, for the most part, is borne out in the data. Research shows GHG emissions fall as the ethanol content in fuel increases.
Figures 11-13: (from top-left clockwise) CO, Hydrocarbon, and NOx emissions against % of ethanol in fuel blend.

That is, GHG emissions fall with one notable exception: CO₂. Ethanol consumption actually releases more carbon dioxide than does the consumption of traditional unleaded gasoline. It should be noted that the three emissions shown in Figures 11-13 are more potent GHG’s than CO₂, however, it is still an important consideration. Ethanol may burn cleaner on the whole than unleaded gasoline, but it does not perform strictly better across all types of emissions.

Additional Considerations

If we are to consider the energy efficiency of each fuel’s output, we must not only examine energy density, but also each fuel’s octane rating. Ethanol has a higher octane rating than gasoline does. This means that ethanol fuel can withstand higher rates of compression without prematurely combusting. This allows for higher levels of performance, as well as increased thermodynamic efficiency. Furthermore, the higher a given fuel’s octane rating the more energy it will be able to generate from a given amount of fuel. Given the diversity of car engines, and the numerous different blends of ethanol gasoline, however, it is very difficult to isolate to what extent this compensates for ethanol’s lower energy density.\(^5\)

Another consideration is the energy balance of these types of fuel; or in other words, how much energy does each fuel produce in return for the energy that it took to produce each source of fuel. The energy balance of gasoline is often expressed as Energy Returned on Energy


\(^{52}\) Though it lies beyond the scope of this paper, more research should certainly be done on this topic. It certainly would be difficult to isolate an effect for reasons above mentioned, but if, for example, automakers were to make a concerted effort to make engines with higher compression ratios – or perhaps include some kind of energy recovery device – able to make better use of ethanol-blended gasoline, the landscape might shift dramatically
Invested (EROI). EROI ratios can vary extremely: some oil wells out of the ground by itself, whereas some oil takes the form of tar sands. In the former case, it would not be unreasonable to see an EROI of 100:1; in the latter, it would not be unreasonable to see an EROI in the single digits. As oil consumption continues at a precipitous rate, EROI continues to drop, as conventional sources of crude oil become fewer in number and more difficult to find.

On the other hand, ethanol (both corn- and sugarcane-) has been experiencing increasing net energy balance over the past decade. Based on our research, corn-ethanol generally returns around a 2.5-fold increase in energy, and sugarcane-ethanol returns between an 8 and a 10-fold increase in energy. Both figures should continue to rise as technology continues to improve the distillation process.

**Ethanol vs. Gasoline**

Based on a relatively cursory body of research, this paper will stop short of making normative prescriptions. However, we will conclude this section of the paper with a ranking of the examined fuel sources, based on their energy efficiency and energy balance. Corn-ethanol clearly lagged behind unleaded gasoline and sugarcane-ethanol. It is far more energy-intensive to produce than both gasoline and especially sugarcane-ethanol. Moreover, the bagasse that is a byproduct of the sugarcane distillation process now provides more energy than is needed to power sugarcane conversion to ethanol, and so is being sold off, further offsetting production costs. In light of this, sugarcane-ethanol is the most efficient fuel of the three.

---

54 Ibid.  
55 Coelho et al. *Brazilian Sugarcane Ethanol,* 28.
Renewable Identification Numbers and Their Effect on the Biofuel Industry

The Renewable Identification Number (RIN) system was created as a result of the United States Environmental Protection Agency’s Renewable Fuel Standard (RFS), implemented according to the Energy Policy Act of 2005. Each year, the United States Congress decides on a quota of biofuel that must be produced and blended into gasoline and diesel. The RIN itself is a serial number assigned to a batch of biofuel for the purpose of tracking its production, use, and trading as required by the RFS. At its inception, the RIN program was initially meant to benefit the refining industry by providing fuel producers an alternative to biofuel production. For example, a refiner without the infrastructural capacity to produce biofuel has the option to replace its mandate with a series of RINs. RINs may be obtained by two methods: a batch may be separated from its original biofuel and retired as part of an obligated party’s quota, or a batch may be traded openly on the market. RINs are a cleared product, mostly traded over-the-counter, and are thus traded at a premium to factor in the cost of production of biofuel. However, the program incurs several flaws; a qualitative analysis reveals that RIN prices are greatly affected by biofuel mandate announcements and may incur an adversarial cost to the obligated party. Furthermore, fraudulent RINs prove easy to produce, adding further costs to the obligated party and inadvertently creating a buyer-beware market.

There are five types of RINs: D3 (cellulosic biofuel), D4 (biomass-based diesel), D5 (advanced biofuel), D6 (ethanol), and D7 (cellulosic diesel). D4 and D6 RINs are the most

---

56 Here, the term obligated party is used to refer to the party collecting RINs for retirement to the EPA

57 A buyer-beware market requires the buyer to perform due-diligence checks before trades can be cleared
common, by virtue of their obligations as set by the EPA. A graph of the prices of D4, D5, and D6 RINs is shown below:

![Graph of the prices of D4, D5, and D6 RINs during the RINs price crisis of 2013](image)

**Figure 1:** The prices of D4, D5, and D6 RINs during the RINs price crisis of 2013

As we can see above, the price of D4 RINs is generally higher than those of the other available RINs. In times of price shocks, we see the prices of all RINs converge, as obligated parties become less picky about which types of RINs they would like to retire. In order to understand this dynamic, we must first understand some of the rules of the regulation for RINs retirement.

Each obligated party is required to retire a quota of RINs at the start of the calendar year—RINs quotas are finalized in May. The system incurs a two-year delay. For example, the quota for 2014 RINs may be finalized in May of 2015, and an obligated party will retire RINs to meet its quota in January of 2016. For this reason, the EPA offers several retirement allowances:

1. Obligated parties may retire a limited amount of RINs created two years prior to the current year quota, and a limited amount created one year prior to the current year quota.
2. Obligated parties are required to commit a specified quota of each type of RIN, and may satisfy the rest of its quota by any other RIN.

---

Let’s revisit our example above. In this case, the obligated party would be required to retire its 2014 quota of RINs at the start of 2016. To do so, it may use a limited amount of 2012 and 2013 RINs in addition to its 2014 portfolio. It may also choose to satisfy the rest of its requirement with the cheaper D6 RIN. See the chart below for context on individual RINs quotas:

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulosic biofuel</td>
<td>0.033</td>
<td>0.106</td>
<td>0.206</td>
<td>n/a</td>
</tr>
<tr>
<td>Biomass-based diesel</td>
<td>1.630</td>
<td>1.700</td>
<td>1.800</td>
<td>1.900</td>
</tr>
<tr>
<td>Advanced biofuel</td>
<td>2.680</td>
<td>2.000</td>
<td>3.400</td>
<td>n/a</td>
</tr>
<tr>
<td>Total renewable fuels</td>
<td>15.930</td>
<td>16.300</td>
<td>17.400</td>
<td>n/a</td>
</tr>
<tr>
<td>Implied corn ethanol</td>
<td>13.250</td>
<td>13.400</td>
<td>14.000</td>
<td>n/a</td>
</tr>
</tbody>
</table>

The proposed volumes are in billions of US gallons

The effects of RINs on the biofuel industry—and vice versa—are not just affected by the intricacies of the retirement structure. Before we can properly discuss the adverse effects of RINs on the biofuel market, we must also examine their lifecycle. The diagram below summarizes this life cycle:

From *Figure 2* above, we observe the flow of RINs in the primary and secondary markets. Biofuel producers create biofuel—mostly biodiesel (D4) and ethanol (D6)—which they then sell
to obligated parties, consisting of rendes and blenders. The obligated parties then blend this biofuel into their product, and sell the finished gasoline and/or diesel to the retail market. During this process, the attached RINs are separated, and may be retired to the EPA. They also may be sold into the secondary market, from which the obligated party may buy detached RINs to retire.

There is one key step missing in this diagram—the production of the corn, soybean, or sugar used to create the biofuel. Producers are unable to create biofuel without the necessary agricultural inputs. Thus, it is possible that a shortage of these inputs—such as corn—may increase the cost of biofuel production, and inadvertently increase the price of RINs. Additionally, corn ethanol is transported by railcar. The combination of these two factors make the RINs market susceptible to bad weather, primarily in the winter when cold temperatures can reduce crop yield and heavy snows and congest rail traffic. This is precisely what happened in early 2014. Between the months of January and March 2014, Chicago spot ethanol prices increased over 74% due to brutally cold weather delaying train traffic. See Figure 3 below:59

![Figure 3](image-url)

*Figure 3: This figure depicts train speed and dwell time, causing the spike in ethanol prices in early 2014.*

---

59 EIA, *Rail Congestion, Cold Weather Affect Ethanol Spot Prices.*
We can see in the figure above that between November 2013 and February 2014, railcar dwell increased by 50%, contributing to higher ethanol prices.

With this information in mind, let us revisit Figure 1 from this section, and observe the effects of this phenomenon on the price of RINs. Particularly between late January and early February 2014, we see an obvious shock to the price of D6 RINs, rising from around $0.30/gallon to nearly $0.60/gallon. This makes sense intuitively—as corn prices rose, the cost of producing ethanol became higher than what it was worth. As a result, biofuel producers did not produce as much ethanol, and thus D6 RINs became more scarce. As the price of RINs is primarily ingested by the consumer of gasoline or diesel, the consumer also bore the burden of this crisis. A cursory analysis of the price of New York Harbor conventional gasoline reveals that gasoline prices increased from $2.65/gallon to $2.90/gallon, a 9.4% increase. The $0.25 price change internalizes nearly the entirety of the $0.30 change in the price of D6 RINs. For a government mandate intended to help both producers and consumers, weather can serve as a detriment to its goal. A government mandate affected so easily by the weather is not effective or safe, and should be redressed.

Furthermore, we look to the effects of the mandate itself on RINs prices. The RINs market is already illiquid, and is only traded by a small portion of the energy industry. Shocks in this industry—such as a sudden change in the original mandate—may cause unexpected or disproportional changes in the price of RINs. A very recent example is the May 2015 announcement for the 2014, 2015, and 2016 RFS mandate, detailing what obligated parties’ RINs quotas would be for those years. Immediately following the announcement, there was a

---

60 Quandl, *Conventional Gas Prices.*
steep drop in the price of D4 and D6 RINs, attributed as a direct reaction to requirements that were less-than-expected. See Figure 4 below:

![Figure 4: A graph representing the price of D4 and D6 RINs after the May 29 proposal release](image)

Following the May 29th proposal release, 2014 D6 RINs lost about half their value—a direct effect of the EPA’s announcement.

We can look to similar examples of this phenomenon in history as well. Once again, let’s revisit Figure 1 of this section, particularly the period in the summer of 2013. All RINs prices soared well above their averages, increasing the price of gasoline and causing panic in the biofuel markets. Dallas Burkholder of the Office of Transportation and Air Quality of the EPA, writes about this event in his paper, *A Preliminary Assessment of RIN Market Dynamics, RIN Prices, and Their Effects*. In his paper, he analyzes the potential causes of this price shock in

---

61 Good and Irwin. *Why isn’t the price of ethanol RINs plummeting?*
the RINs market, and attempts to understand the role of the mandate itself. Key to his argument is the *E10 blendwall*, or the concept of a maximum of 10% ethanol blended into gasoline. The E10 blendwall\(^63\) is considered optimal for consumption of gasoline, and is enforced by the RFS mandate.

“Prior to reaching the E10 blendwall in 2013,” he argues, “the demand price for ethanol was primarily based on that of gasoline on a volumetric basis and D6 RINs were only a few cents, effectively representing transaction costs. After reaching the blendwall the demand price for ethanol shifts to being based primarily on the price of gasoline on an energy-equivalent basis.” (p. 11) Ethanol blending in the United States did indeed reach this blendwall in 2013. There were no longer enough D6 RINs in the marketplace to counteract the rising demand for E10 gasoline. As a result, the price of D6 RINs spiked, and producers hurried towards cheaper alternatives to meet its D6 requirements—such as the production of the lesser quality E85. E85 gasoline is not only worse for the environment, but is also corrosive to internal combustion engines and thus, cheaper for the consumer. Blenders are then forced to create a less profitable product that is worse for the environment—this was the result of the E10 blendwall crisis in 2013, furthering the argument that the mandate indeed does more harm than good.

Finally, there is the question of the very integrity of the RINs market. A Congressional Research Review reports that in 2011 and 2012, three companies were alleged to have fraudulently generated 140,000,000 RINs, representing 11% of the total biodiesel RINs generated between 2010 and 2011\(^64\). Fraudulent RINs have no backing, and come at a tremendous cost to the obligated party. The RFS mandate specifies that fraudulent RINs “cannot

---

\(^63\) For comparison, some states in the U.S. also allow E85, or 85% ethanol in gasoline. In Brazil, this number may even increase to near 100.

\(^64\) Yacobucci. *Analysis of RINs in the RFS.*
be used to achieve compliance with the Renewable Volume Obligation (RVO) of an obligated party or exporter, regardless of the party’s good faith belief that the RINs were valid at the time they were acquired.” This language reinforces this “buyer-beware” system, in which the buyer of the RINs is forced to perform due diligence checks on the seller before any transaction. On top of the additional legal costs of due diligence, obligated parties bear an expensive burden in case they unknowingly retire fraudulent RINs:

“1. the original cost of the fraudulent RINs (spot prices ranged between $0.70 and $2.00 per RIN over that time);
2. penalties to EPA for Clean Air Act violations ($0.10 per RIN, capped at $350,000 per party);
3. the cost of all make-up RINs (trading at the time of settlement at roughly $0.50 per gallon); and
4. any legal costs in pursuing restitution from fraudulent actors.” (p. 11)

The market for Renewable Identification Numbers was originally created to provide obligated parties with the flexibility of blending biofuel into gasoline, or going out onto the market to purchase the RINs necessary for its requirement. However, as this paper demonstrates, there are many holes in this system that are an active detriment to the obligated parties. Sudden changes in requirements, factors beyond government control such as the weather, and the very integrity of RINs themselves all provide reason as to why this system is flawed and should be redressed. Of course, as this paper argues, RINs are a small piece of a larger problem that is biofuel mandates in general, which cause more harm than good to the producer, the consumer, and the planet.

**Conclusion and Further Questions**
We sought out to reexamine biofuel mandates in the United States and Brazil, in order to determine their efficacy and understand the possible negative externalities. In order to do so, we looked at several key indicators of performance of biofuel mandates in these two countries, as well as industries that could potentially be harmed by their unintended consequences. Previous literature suggests that ethanol prices greatly impact the price of its agricultural inputs—such as corn—with statistical significance. Therefore, we started by testing this claim with OLS regression.

Several challenges arose with the data, regarding its granularity and non-stationary properties. In order to conform the data to meet the requirements of OLS regression, it was necessary to treat it appropriately. Following treatment and testing of the data, we determined that there was no statistically significant evidence to prove the claim that corn prices are affected by ethanol production, as a result of biofuel mandates. However, we did find qualitative evidence to support the claim that biofuel production could have a negative impact on corn prices given certain conditions, such as the weather. We consider this a weakness in the Renewable Fuel Standard, and one reason why it should be re-evaluated.

We also analyzed the redistribution of land usage before and after the biofuel mandates were set in place. In the United States, corn’s share of land usage has increased tremendously, coinciding with the expansion of the Renewable Fuel Standard. Additionally, the amount of corn used in the production of ethanol has grown exponentially. However, there is a common misconception that corn production for ethanol directly takes away from corn used for feedstock. In our analysis, we concluded that corn used in the production of biofuels is an entirely separate type of corn, and cannot be consumed. Therefore, while land usage changes are an indirect
consequence of biofuel mandates, this proven misconception sheds important light on their effects on agricultural prices.

Relative energy efficiency was an important consideration in our analysis of the costs of biofuel mandates. We compared the energy inputs for conversion of corn and sugarcane into ethanol, crude into gasoline, and the energy densities of ethanol compared to gasoline. Through our analysis, we determined that the production of corn ethanol net consumes energy, and that gasoline is strongly preferred. However, we also determined that the production of sugarcane ethanol has a higher yield potential than that of gasoline. In fact, in an analysis of the three fuels, sugarcane ethanol provides the greatest energy output for its inputs. Given that the comparison of ethanol emissions and gasoline emissions yielded a relatively zero-sum game, we can conclude that sugarcane ethanol is indeed the better choice. However, the share of ethanol production in the United States is dominated by corn ethanol, which lags behind gasoline. In essence, this result is good for the Brazilian ethanol industry, and is more of a negative externality than its worth for the American ethanol industry.

In order to reaffirm this conclusion, we more deeply analyzed Brazil, and the effects of biofuel mandates on its country. We determined that sugarcane ethanol is the ideal choice over corn ethanol and gasoline, but we wanted to ensure that Brazil was not harmed by its own biofuel mandates. Through our analysis, we discovered that the Brazilian economy has benefited tremendously from the production of sugarcane ethanol, and the introduction of flex-fuel vehicles. The country managed to provide energy self-sustainability to its people, and also rise as the world’s second largest exporter of ethanol. However, one further question to examine is how Brazil’s economy may rely on its ethanol industry—that is, if the industry did not do well, would the economy suffer with it. Exogenous factors such as weather also come into play. This is not
the scope of this paper, but we can claim from our analysis that biofuel mandates in Brazil have been more beneficial than harmful.

We conclude by reaffirming our claim—the costs of biofuel mandates in the United States largely outweigh the benefits. This claim does not hold in Brazil, however. The economic, legislative, and ethical effects of the Renewable Fuel Standard simply do not provide enough backing to the consumer or the producer, as exemplified by our analysis. In particular, the Renewable Identification Numbers trading system comes at a huge burden to the obligated parties—the target the program was supposed to have helped. As a result of our analysis, the Renewable Fuel Standard in particular, should be reevaluated.
Works Cited


Soccol, Carlos R., Luciana P. S. Vandenberghhe, Bill Costa, and Adenise L. Woiciejchowski.


MLA formatting by BibMe.org.