Ethanol Supply Chain and Industry Overview: More Harm than Good?

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Abstract

This thesis is a comprehensive study that aggregates the key aspects of ethanol including its supply chain, government legislation that impacts the use of, and the inherent material characteristics of the fuel as well as its environmental impact. Based on existing research, this study suggests whether or not mandating biofuels in today's energy portfolio makes sense and if so, to what extent. The objective of this research was to compile and analyze the large body of existing working knowledge regarding ethanol and distill some key takeaways for actionable recommendations. The findings in this research may be useful to policy makers, and those unfamiliar with the industry and wanting to learn more about ethanol. The key takeaway is that ethanol does not provide a quick fix to the world's energy problems but when combined with improved energy conservation, continued research and development to improve ethanol's carbon footprint, it can provide some help to reducing the environmental impact along with other benefits such as energy independence and rural economic stimulation.

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1. Introduction

1.1 Motivation

As the world's energy industry has been evolving rapidly over the last decade and in order to meet existing energy challenges, it has become more important to diversify national energy portfolios. Some of the factors influencing energy evolution are: a global focus on the regulation for the reduction of Greenhouse Gas (GHG) emissions in order to help control global climate change; traditional fuel sources becoming increasingly more expensive to extract and refine; and instability in regions that currently provide much of the world's oil. Arguably, an important part of a country's successful energy strategy includes (or will include) biofuels in order to reduce the risk of energy shortages and decrease environmental impacts.

As a result of these issues, the biofuel industry has made significant strides that have demonstrated biofuels can be a viable alternative to fossil fuels. The U.S. Energy Independence and Security Act of 2007 mandated production of biofuels as a way to decrease our impact on the environment from the production of CO2 and other Greenhouse Gases (GHG) as well in the interest of national security.

1.2 Problem Statement

Despite the recent advances, many hurdles still remain in making this energy source both environmentally and financially sustainable for many reasons. Part of the problems include: existing inefficiencies in the ethanol production process; technical challenges while scaling pilot plants to commercial levels; problems from increasing demand of land for crops for fuel over food; increasing land development not just from growing biofuel and food crops (but also from speculators and other developers such as in the construction industry); and with more land converted to farmland, an increase in the use of pesticides, fertilizers or genetically modified crops that could potentially do more harm than good to the environment. Some of these problems are due to the technical complexity of ethanol but are amplified due to the complex nature of the ethanol supply chain.

The purpose of this thesis is to first characterize the ethanol supply chain, including understanding, contracts, pricing, distribution and the supply chain structure as of early 2013. This will include understanding the environmental implications and the state of the industry. The industry can be characterized by several dimensions including governmental policy, consumer preferences, and new technology developments. The thesis concludes with aggregating and developing recommendations intended to help identify and eliminate supply chain barriers obstructing the long-term viability of this industry.

Finally, it concludes with a discussion about the net effect of ethanol with a focus on whether or not it may reduce environmental impacts relative to traditional energy sources through a review of recent reports to attempt to answer the elusive question- does ethanol net more harm than good?

2. Literature Review

2.1 What are biofuels and ethanol

Biofuels are a class of liquid fuels derived from renewable, usually plant-based feedstocks. They are a renewable source of energy unlike traditional fossil fuels derived from petroleum, like diesel and gasoline. Ethanol[1] is a type of biofuel made by fermenting sugars from sugar cane, corn, or a variety of other feedstocks. Biodiesel is made from the esterification of feedstocks including oils from vegetable or animal fat oils. Feedstocks are the raw matter used as the baseline carbon source. Feedstocks for biofuels can include many different materials including what are considered "first generation fuels" based on easy-to-process starch-based plant matter, such as corn or sugar. Some ethanol or biodiesel can be generated from woody, cellulosic plant matter such as from the stalks and leaves. Non-food feedstock sources are typically considered "second generation" feedstocks.

Certain yeasts can convert sugar to ethanol, producing an ethanol-water mixture, which then must undergo a distillation process to eliminate the water and further purify the ethanol. Currently there is a lot of research on developing different enzymes and yeasts that can convert more complex starches from non-food materials (such as corn cobs or switchgrass, instead of corn or sugar) to ethanol. Ethanol from these more complex starch sources is referred to as cellulosic ethanol. Cellulosic ethanol is considered a class of advanced biofuel according to Renewable Fuel Standard (RFS2) mandate, a section of the Energy Security and Independence Act of 2007 – which set the first mandates for alternative fuel use in the US. . The term "advanced biofuel" is sometimes defined as any biofuel derived from non-corn based feedstocks. However, advanced biofuels are defined more narrowly by the RFS2 as any biofuel that reduces lifecycle GreenHouse Gas(GHG) emissions by 50% compared to baseline gasoline lifecycle GHG emissions. Greenhouse Gases are gases that trap heat in the atmosphere (US EPA, 2013) and the net amount of GHG emissions are the total amount of these

[1] Ethanol can be derived from petroleum sources, therefore it should be distinguished from ethanol derived from bio-based sources such as plant matter. For the purpose of this thesis however, it shall be assumed to refer to the biobased version and bio-ethanol shall be referred to as ethanol.

gases that are emitted over the entire course of the products lifecycle, from cradle to grave- or in this case from the field to the tailpipe of the car.[2] The worst offending greenhouse gases are carbon dioxide, methane, nitrous oxide and fluorinated gases (US EPA, 2013).

Of the available renewable fuels in the US, ethanol is the most widely used. This thesis will examine the complexities of biofuels and their implications in meeting today's global energy needs. The literature review will introduce general background and historical information on the ethanol industry as well as identify some of the key pieces of legislation globally and the U.S. in particular, that highlight underlying motivations in national energy policies. Finally, it will synthesize the current landscape of the energy and biofuel industry and some of the on-going ethical and environmental debates.

2.2 General Industry Background

Biofuels are a complex and constantly evolving industry. This section will review the history of ethanol in order to better understand some of today's challenges that affect this controversial energy source.

2.2.1 A Brief History of Ethanol in the US

The use of ethanol dates as far back as the 1820s in lamps for lighting. In the 1860's the US government taxed ethanol to fund the civil war. It was taxed two dollars a gallon in comparison to kerosene which was only taxed at ten cents a gallon; this resulted in higher demand for kerosene than ethanol. In 1898, Rudolf Diesel, the inventor of the diesel engine, used oil derived from peanuts to fuel his first engines (Pacific Biodiesel, 2012). In 1906, Roosevelt repealed the ethanol tax from the Civil War. Following the repeal, Henry Ford designed the first Model T's to run on ethanol in 1908. During World War II, demand increased for fuel-based products. As a result, companies in the Midwest built and supplied many ethanol stations. However following the war, with a resulting decrease in demand, this resulted in a corresponding decrease in the price of petroleum (Siegal, 2012). Oil companies offering cheaper prices prevailed and ethanol

[2] This subject will be covered in more detail in the Lifecycle Analysis Chapter.

disappeared from the US energy portfolio until the energy crisis in the 1970s[3]. During the 1970s, due to increasing gas prices along with the interest in achieving energy independence for national security reasons, ethanol again began to garner interest and resources. Shortly thereafter, gas availability increased, resulting in prices falling making the ethanol industry untenable once again (see Table 1).

In 1992, The United States' Energy Policy Act required auto-manufacturers to produce a certain percentage of automobiles that ran on alternative fuels in order to reduce our dependence on imported petroleum. More recently, there are multiple factors that have impacted the world's return to bio-based fuels including climate change and national security interests. In addition there is also the concern of the planet reaching "peak oil" and being entirely dependent on a non-renewable fuel source. Peak oil is the point when humans reach the maximum amount of available fuel on the planet and fuel reserves and/or recovery rate of fossil fuels will start to decrease until there is no longer any oil to extract left. This phenomenon is characterized by what is called the Hubbert curve (Hubbert, 1956). However, this phenomenon is contested by M.A. Adelman (MIT Professor Emeritus in Department of Economics) who argues that as readily available supply declines, oil prices will increase. As oil becomes more difficult and costly to extract and refine, the world will gradually transition to other energy sources as they become more cost viable against fossil fuels and prevent the world from tapping its entire oil supply. He argues that price and availability is impacted more from Organization of Petroleum Exporting Countries (OPEC)'s price collusion and production constraints then true product scarcity (Adelman, 2004).

[3] There are more interesting historical points here: http://www.icminc.com/innovation/ethanol/ethanol-timeline.html

Table 1. Brief History of Biofuels

Brief History of Biofuels	
1820	Used for Lighting
1860s	During civil war ethanol was taxed at $2/gallon versus kerosene only $.10/gallon
1898	Rudolf Diesel used diesel from peanuts to run his first engines
1906	Roosevelt repealed the ethanol tax
1908	Model Ts were designed to run on ethanol
1939-1945	Demand for fuel increased, gas prices went up and ethanol stations in midwest appeared
1945-1970s	Fosssil fuels returned to being the cheapest source of fuel
1970	Energy crisis- demand for national security and fuel prices spiking
1992	Energy Policy Act requires auto manufacturers to produce percentage of vehicles

2.2.2 Current Economic State of the US Ethanol Industry

The United States ethanol industry at the end of 2010 had an approximate nameplate[4] capacity of **13.8 billion** gallons a year of ethanol produced at 200 processing plants (Urbanchuk, 2011). In contrast, the amount of finished motor gasoline products produced by refiners and blenders in 2010 in the US was about 138.8 billion gallons for the year[5]. By the end of 2012, this amount grew to approximately 211 ethanol plants located in 28 states totaling approximately 14.7 billion gallons in nameplate capacity. (Urbanchuk, 2013) Primarily these refineries are located in the Midwest, focused in the corn producing states; 38% of these refineries are owned by Limited Liability Corporations (LLCs) or by farmer co-ops. Recently there has been a large influx of venture capital into this market and the farmer owned share of ethanol refineries declined (Cardno Entrix, 2010) and (Hofstrand, 2012).

In 2012 it was estimated that the ethanol industry generated $4.6 billion dollars for the federal government and $3.9 billion in state and local governments from tax revenue. The ethanol industry also directly and indirectly created about $30 billion worth of income and created about 383,260 jobs in combined direct and indirect employment; 87,292 of those jobs are estimated to come directly from the ethanol industry. See Table 2. Economic Impact of the Ethanol Industry: 2012 **Error! Reference source not found.** which summarizes the economic impacts of ethanol in the United States during 2012.

[4] **Nameplate capacity** is estimated maximum capacity of the plant. Actual production output varies.

[5] http://www.eia.gov/dnav/pet/pet_sum_snd_d_nus_mbblpd_a_cur-2.htm and assuming 365 days/yr and 42 gallons per barrel. (USEIA)

Table 2. Economic Impact of the Ethanol Industry: 2012 (Urbanchuk, 2013)

	GDP (Mil 2012$)	Employment (Jobs)	Income (Mil 2012$)
Ethanol Production	**$8,177**	**84,575**	**$4,831**
Direct	$783	11,971	$783
Indirect	$4,419	37,231	$2,384
Induced	$2,975	35,373	$1,663
Agriculture	**$32,399**	**267,605**	**$23,380**
Direct	$1,596	66,057	$1,240
Indirect	$16,347	42,172	$14,061
Induced	$14,455	159,376	$8,080
R&D	**$2,815**	**31,081**	**$2,035**
Direct	$967	9,264	$966
Indirect	$594	6,897	$368
Induced	$1,254	14,920	$701
Total	**$43,391**	**383,260**	**$30,246**
Direct	$3,347	87,292	$2,990
Indirect	$21,360	86,300	$16,813
Induced	$18,684	209,669	$10,444

There are many factors at work that influence how the ethanol industry continues to grow, and are covered in more depth in this research including government policy, environmental and economic impacts, and the refueling infrastructure and its ability- or inability- to handle higher blends of ethanol.

2.3 Key Biofuel Legislation

This chapter reviews the major pieces of legislation in the US, European Union, and in Brazil that have shaped today's energy policies with respect to ethanol. In order to begin to understand the complexities of ethanol it is first important to gain an understanding on some of the policies of the government. It is also useful to compare policies around the world, and the impacts other countries can have on policies within the US. There is special focus on Brazil because of their role in the production of sugar ethanol, which interestingly plays a part in the US meeting its own renewable fuel obligations. Additionally, Brazil is a country who has successfully incorporated ethanol into its energy portfolio and when combined with their rich fossil fuel resources became essentially energy independent in 2006. A country that uses significantly less energy per capita than the US (27 barrels of oil per capita versus Brazil's 4.2 in 2005), they were able to foster an ethanol industry that replaced about 40% of their gasoline use (Feller & Philpot, 2006)[6].

2.3.1 United States

Table 3. Key US Legislation

United States	
Year	Act
1868	**Civil War Ethanol Tax** the price of ethanol was taxed $1.90 more than that of kerosene.
1906	Roosevelt revoked the tax on ethanol; however lighting markets already developing in U.S.
1970	**Clean Air Act (First passed 1970, amended in 1990)** helped cultivate a market for alternative fuels by establishing a renewable fuels (RF) program and requiring that alternative fuels must be blended into traditional fossil fuels (Environmental Protection Agency (EPA), 2012)
1972	**Energy Policy and Conservation Act** – (amended in 1992) Imposed energy efficiency goals and fuel economy standards for vehicles and required a certain number of vehicles in the federal fleet be either electric or run on alternative fuels. Also includes other mandates that encourage the use of alternative energy (Library of Congress, 1972).
1978	**Grain Products Utilization Act**- Mandates the study of agricultural products in the development of fuels and provides tax deductions for ethanol-producing facilities. (Library of Congress, 1978)
1975	**Corporate Average Fuel Economy (CAFE)-** Regulation intended to reduce fuel consumption by increasing the fuel economy of cars and light trucks. First introduced in 1978, continues to guide automakers' fuel economy standards. Revised since 1975. (National Highway Traffic Safety Administration NHTSA)
1978-2011	**Tax and Tariff Excise Tax Credit (Volumetric Ethanol Excise Tax Credit** (VEETC)) of $0.45 blenders credit per gallon) along with a $0.54 per gallon tariff on ethanol imports.
2000	**Biomass Research and Development Act of 2000**-established a Biomass and R&D Board and a Technical Advisory Committee. It created a joint venture between the US Department of Agriculture (USDA) and the Department of Energy (DOE) and other federal agencies such as the EPA and allocates federal grant money for biomass/biofuel programs.
2004+	**Methyl Tertiary Butyl Ether (MTBE) ban-** was used as a gasoline additive (instead of lead since 1979) for anti-knock properties and helps gasoline burn cleaner. It is banned in many states starting in CA and NY in 2004. Ethanol is a viable substitute, though slightly more expensive than MTBE. Some state governments incentivized the use of ethanol over MTBE (Environmental Protection Agency, 2004)

[6] This has changed since 2006 and Brazil has imported some corn ethanol from the US. Reduced output from Petrobras is partially to blame as well as US willingness to pay more for advanced biofuel in the form of sugar ethanol. (Romero, 2013)

2005	**Energy Policy Act of 2005-** "Sets forth renewable energy initiatives that address: (1) Renewable energy resources and production; (2) renewable content of motor vehicle fuel; (3) federal agency purchasing requirements for ethanol-blended gasoline and biodiesel fuel; (4) a sugar cane ethanol program; (5) an advanced biofuels technology program; ..." Set the original Renewable Fuel Standard (RFS1) (Energy Policy Act, 2005)
2007	**Low Carbon Fuel Standard (LCFS) (California Only)-(Bill 32)** Regulates the amount of Greenhouse Gas (GHG) emissions and the amount of carbon of California's transportation fuels. Sets goal to reduce carbon intensity by 10% by 2020. Requires blenders, refiners, producers and importers to perform a Life Cycle Analysis of GHG emissions and work to decrease by the requisite amount. (Executive Order Governor of California, 2007)
2007	**Energy Independence and Security Act (EISA)-** Amends the Clean Air Act and the Energy Policy Act of 2005 to mandate a specific amount of renewable fuel, including advanced biofuels, biomass-based diesel, and cellulosic biofuel to be blended into the country's gasoline or diesel. Depending on the category of renewable fuel they must achieve at least a 20%-60% reduction in lifecycle GHG emissions compared to baseline gasoline lifecycle GHG emissions in order to meet the category requirements. This part of the EISA is called the Renewable Fuel Standard 2 (RFS2) (Library of Congress, 2007).
2008	**Food, Conservation and Energy Act**-(early version called **Farm, Nutrition, and Bioenergy Act of 2007)** provided grants to develop and build demonstration scale bio-refineries for advanced biofuels and established tax credits for cellulosic biofuels among other things.
2009	**American Reinvestment and Recovery Act-** provided loan guarantees and additional funding for renewable energy industry (111th Congress, 2009)
2009	**Presidential Memorandum on Biofuels**- created the **Biofuels Interagency Working Group (BIWG)** and tasked it with fostering a marketplace for Biofuels (see information on RIN credits) and the logistics surrounding its transport, storage and dissemination. The group was also assigned to analyze the whole system to ensure the success of the policy, by studying and mitigating any indirect impacts from other aspects such as land use, water usage, crop diversity etc, during the production of alternative fuels. The BIWG was also to analyze the total greenhouse gas emissions over the course of the life cycle of the alternative fuel. (Biomass Research & Development, 2011)

2.3.2 Global Legislation

Table 4. Key Brazilian Legislation

Brazil	
Year	Act
1933	Creation of a national agency, **The Institute of Sugar and Alcohol**
1941	**Sugar Cane Agriculture Statue** was enacted and created a quota system for sugar cane production.
1975	**National Program of Alcohol (Proalcool)** - mandated the use of ethanol and types of feedstock and in 1977, raised the mandated levels.
1979	Automobile manufacturers signed an agreement with the government to manufacture a certain amount of ethanol-only vehicles. Federal government initially used them for its fleet and mounted an advertising campaign.
1980	The national government declared that the price of ethanol could not exceed 65% more than gasoline.
1985	"85-90% of Brazil's new cars were alcohol powered. Two million of the total ten million cars were fueled completely by ethanol, the rest by gasohol." (gasohol- gasoline mixed with ethanol) (Cordonnier, 2008)

Table 5. Key EU Legislation

European Union	
Year	Act
2003	**Biofuels Directive COM 2003/30/EC**-Additional mandates on biofuels and reporting on progress.
2009	**Renewable Energy Directive 2009/28/EC**- set biofuel mandates and limitations on indirect land use change. Limited food crop-based biofuels, provided market incentives.
2009	**Fuel Quality Directive 2009/30/EC**- included more regulations on fuel quality, more reductions in Life cycle GHG emissions, emission performance standards for new passenger cars, and other. (European Biofuels Technology Platform)

2.4 Unintended Consequences of Biofuel Mandates

When an industry transitions from a set of practices to another, there are often unanticipated implications for both related and unrelated industries. The two most prominent social and environmental issues purportedly stemming from the shift from gasoline to bio-based liquid fuels are the use of corn for fuel instead of food and indirect land use change (iLUC).

2.4.1 Food Versus Fuel

One of the hotly contested unintended consequences due to the rapid push for biofuel adoption is the use of food crops (namely corn in the U.S.) as the feedstock of choice in order to fulfill the EPA's renewable fuel requirements (RFS2- Renewable Fuel Standard 2). US corn is controversial, first because the conversion process from corn crops is not nearly as energy efficient as sugarcane or other types of ethanol. Second, US corn is used as a food crop, not only at home in the US, but abroad in many poorer countries and a substantial amount of corn (20% of our crop in 2012/2013) is exported to other countries[7], (USDA Economic Research Service, 2012). The increasing demand in corn from biofuels helps drive up the price of corn and many argue that this will be catastrophic for the poorest countries because it does not just affect the price of corn for human consumption. It additionally impacts the type of corn (different than the varietal used for direct human consumption) that is used to feed livestock which in turn increases the price of meat, since it increases the cost to maintain the livestock. These "first generation" renewable fuels (as they are often referred to in the industry) use food crops such as corn or soybeans because the sugars are readily available and the technology that transforms this crop to fuel is relatively mature. The RFS2 mandates specific amounts and types of renewable fuels to be blended into traditional fossil fuels each year. For instance, by the year 2022, the fuel industry must blend a minimum of 36 billion gallons of renewable fuels into its transportation fuels (gasoline or diesel, as appropriate). However, a maximum of 15 billion gallons of those

[7] A small percentage of this is for aid purposes

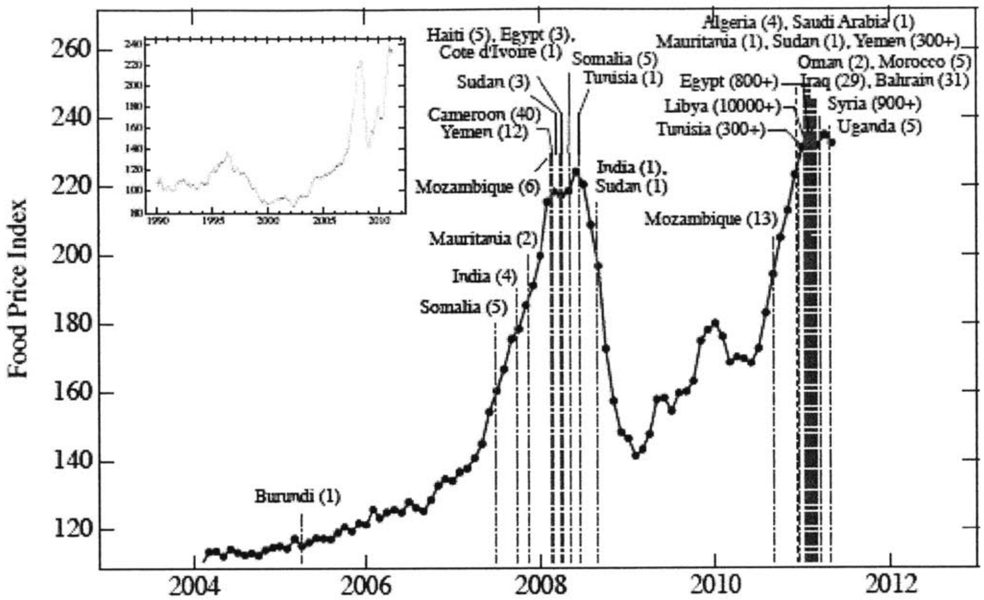
36 billion gallons renewable fuels are allowed to be corn starch-derived[8] ethanol (Schnepf & Yacobucci, 2013). A more detailed discussion of the blending requirements is included in the next chapter.

Additionally contributing to the food versus fuel debate occurred during 2008, at the same time that the U.S. was ramping up its corn ethanol production, the US economy also went into recession. The RFS2 was revised that year and increased the mandated amount of corn starch-derived ethanol to 9 billion gallons. This created a large increase in demand for bushels of corn. Biofuel mandates increased the percentage of the US corn crop dedicated to ethanol production. "In 2000, national ethanol production was using about 6% of US corn supplies; by 2012 it was expected to use about 40%" (Schnepf & Yacobucci, 2013). US farmers planted more corn and advanced existing technologies to produce better yields (from less than 30 bushels per acre in 1930 to approximately 152.8 bushels per acre in 2010 (Schnepf & Yacobucci, 2013)), however the world continued to see corn prices and other grain prices increase.

Countries such as Mexico, who have historically relied on the U.S. as a net corn exporter, found less corn was exported from the US in 2012 thanks to the severe effects of a drought in combination with biofuel mandates. This caused corn prices to rise sharply internationally and countries such as Mexico had to find corn from other sources such as Brazil (Anonymous, 2012). One recent study by Lagi, Bertrand & Bar-Yam (see Figure 1) mapped food price spikes with riots occurring around the world. In the figure, the location is listed with a number in parentheses that show the number of people that were killed during the riots.

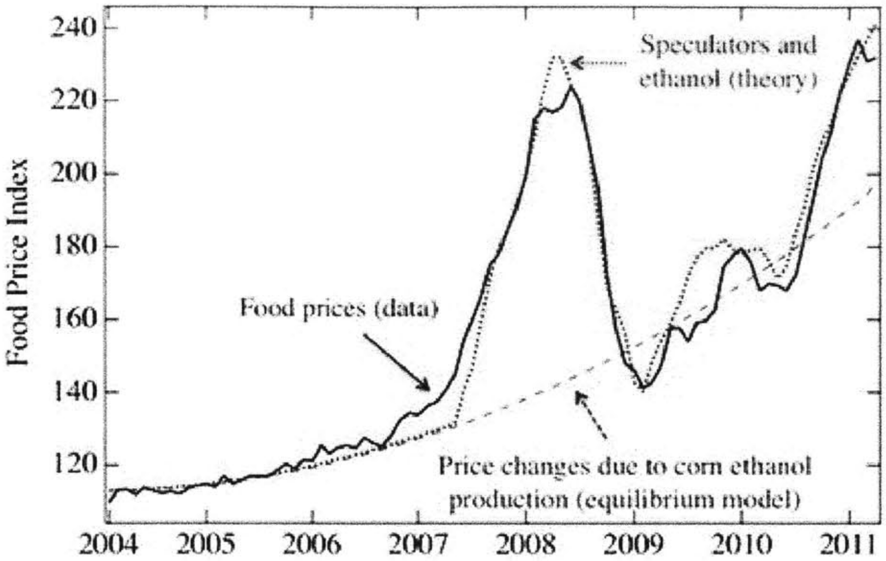
[8] Corn starch-derived ethanol is from the kernels of corn. Ethanol derived from the stalks, cobs etc is considered cellulosic corn ethanol.

Figure 1. Food Price Index 2004 to 2012 and Food Riot events (Lagi, Bertrand, & Bar-Yam, 2011)



In addition, the authors of this study constructed an economic model predicting food prices that tracked very closely to the food price index (see Figure 2 below). "Here, for the first time, we construct a dynamic model that quantitatively agrees with food prices. The results show that the dominant causes of price increases are investor speculation and ethanol conversion." (Lagi, Bar-Yam, & Bertrand, 2011). This model helps link the relationship between food price spikes and civil unrest. Research such as this can help policy makers understand some of the unintended impacts of governmental policy and that after a policy is made, it is critical to continue analyzing and evolving policy in order to help prevent unintended negative consequences.

Figure 2. Food Price Index 2004-2011 (Lagi, Bar-Yam, & Bertrand, 2011)



Because of this rapid increase in biofuel production, some land dedicated to food crops transitioned to growing crops for ethanol and therefore, increased prices because of a smaller land supply to grow food crops.

It should be noted that the corn used for food is sweet corn, whereas the corn used to produce ethanol is "#2 Dent" or "Field corn". Approximately 10% of the US corn crop is used for human consumption (American Coalition for Ethanol, 2007)[9]. According to Bob Dinneen from the Renewable Fuels Association, of the total corn crop in 2012, about 40% of the corn produced in the US is used for ethanol and 35% is used for livestock feed. About 33% of the ethanol portion produces "distiller's dry grain" which is a high protein, high quality by-product that is also used as livestock feed. This results in approximately 48% of the total corn crop able to be still used as livestock feed. (Siegel, 2012)

In addition to this, the increase in demand for grains for the manufacture of ethanol increases the price due to the basic economic theory of supply and demand: as supply fails to meet demand, prices increase. Initially, it is this rise in price that hits the poorest the hardest. However as prices rise, it can incentivize

[9] This statistic was from 2007- given the sharp rise in corn for fuel, the percentage of crop for food has decreased.

production to meet that increase in demand. "Rising food prices are not always bad or bad for everyone. Modest increases in food and agricultural prices above past trends can help generate investment and foster productivity." (Joachim van Braun, 2008). This phenomenon is resulting in more people in more countries able to sustain a living from farming, because with higher prices, their ability to sustain a living becomes more possible. A debate hosted by the Economist about the increasing price of food presents both sides of the issue of food price increases. Homi Kharas, Senior Fellow at the Wolfensohn Centre for Development at the Brookings Institution, cited a study performed by the Asian Development Bank (ADB). "The ADB report also analyses China in some detail. It concludes that rural households in China should enjoy a significant reduction in the incidence of poverty as a result of high food prices." (Kharas, 2008)

Furthermore it is not solely high crop prices that result in high food price indexes. "What matters for poor people is local price volatility, and changes in global prices are just one factor behind domestic price changes. In fact, in countries which do not import much, local crop conditions, supply costs, and policy measures are often much more relevant than global prices." (Zaman, 2011) Weather, import policies, price of oil and other regional political issues are all things that can contribute to the fluctuation of food prices at the local level. One way to help offset impacts from global price variability due to biofuels may be to evaluate price impacts more specifically at more susceptible locations. Instead of trying to globally keep prices from rising, focusing more on the local policies in these vulnerable regions and more importantly to concentrate on eliminating wild price fluctuations, instead of necessarily preventing a gradual price increases may do more to help offset impacts from biofuels.

In addition, to help address the impact from rising food prices on the citizens in poverty-stricken regions is to help support the farmers in these impoverished areas. Instead of relying on foreign food aid to survive some of the more difficult food price cycles, is to help prevent the brutal swings and put more aid resources into creating a financially sustainable market for local goods. Currently, the federal administration of the US is moving to reform the US foreign aid system similar to moves made by the EU and other NGOs. The reforms are intended to modify our current system which mandates that money allocated to buy food for aid is US grown crops (including corn) which then gets shipped to foreign countries. The idea is to create a system that focuses on buying goods from local markets and farmers. The former system of buying US grain can be expensive due to large shipping costs and can take up to 4 months to arrive at its destination due to the long lead times crossing the ocean and possible civil unrest in-country. "20 percent to 25 percent of the Food for Peace budget is the cost of ocean shipping. If you buy the food in the area, you don't have to pay those costs, you can buy more food." (Natsios, 2013) Sourcing food aid locally reduces the transit time (when people are literally starving to death, this is not just a matter of inconvenience), reduces costs, and supports the local economy and farmers.

On the other hand, there are also difficulties with making the switch to solely locally sourced crops, such as finding reliable sources that can produce such large quantities needed with short notice and also potential issues with drought, civil unrest that can impede the safe transport or cultivation of goods. Additionally crop prices benefit from economies of scale and depending on local farming practices, could sometimes be worse for the environment. Presently the legislation requires that all grains for food aid be purchased from US suppliers, but likely the best compromise in the future will be a modification of current legislation to enable NGOs to source some grain locally and continue to rely on some grain sourced from the US.

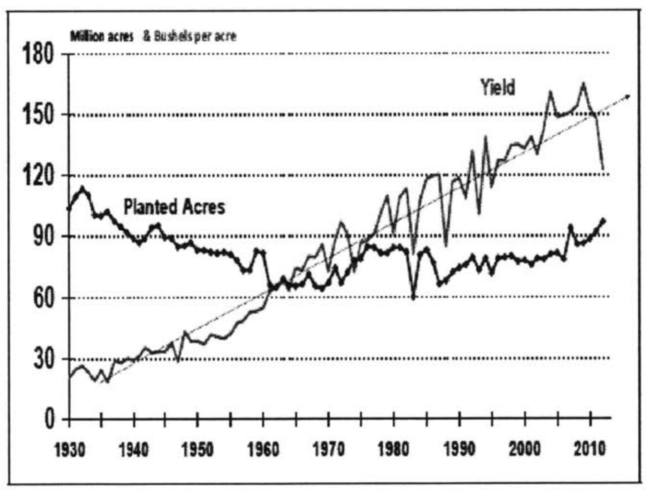
Despite the huge looming demand for biofuels, some agribusinesses are still protesting this kind of food aid reform, claiming it will cost American jobs. They argue that "...eliminating the grow-pack-ship steps in the U.S. would cost thousands of jobs in the shipping and farming sectors, not to mention millions and sales and household earnings each year." (Khazan, 2013)

The issue of biofuel demand increasing food prices is complex and there are clearly many interconnected factors involved. In the short term, it is difficult to dispute that increasing demand for crops does in turn increase food prices to some extent.

2.4.2 Land Use Change (LUC)

The amount of land dedicated to farming in the US has decreased over the last century due to advances in seed technology and from producing varietals with higher yields and more robust survival characteristics to meet our increasing food demands. However this trend of shrinking the amount of land under cultivation has begun to reverse as the demand for biofuels and in turn its feedstocks has increased significantly (See Because of biofuel mandates and its resulting increase in demand for farmland, other land is sought out to plant. "Other sources of land for increased corn plantings include cropland used as pasture, reduced fallow, acreage returning to production from expiring Conservation Reserve Program[10] contracts, and shifts from other crops, such as cotton." (USDA, 2013)

Figure 3. US Annual Corn Planted Acres and Yield. (Schnepf & Yacobucci, 2013)



There are two classes of land use change (LUC), direct and indirect. ***Direct*** land use change, when land is converted from one purpose (for example grassland, forest, or idle farmland) directly to growing feedstocks to be used for biofuels. ***Indirect*** land use change (ILUC) is when the land used to grow biofuel crops forces out another crop, such as wheat, which in turn converts another parcel of land from its original use, to grow the wheat. If one was to only measure the amount of land needed to grow corn it wouldn't account for the

[10] Conservation Reserve Program is a program intended to help protect environmentally sensitive land from cultivation. It effectively pays farmers to remove sensitive land from cultivation and to grow plants instead that help protect the land and water quality, wildlife habitat and prevent erosion. (USDA, 2013).

entire impact of the biofuel crop, since now land is needed to grow other crops, such as wheat. The land used to plant that wheat displaces another use such as other food crops, building development, or conservation. This land has been indirectly impacted by the original land used for corn. The land use change from the growing demand for biofuels, whether direct or indirect, has a significant impact on the net impact that ethanol can have on the environment and its net greenhouse gas (GHG) emissions when compared with gasoline.

A method for calculating this net impact is called a lifecycle analysis or an LCA. A lifecycle analysis is a methodology of capturing all the inputs and outputs to a system. In the case of manufacturing biofuels, a common calculation of the LCA will measure the total energy in versus energy one gets out of the system, as well as the net amount of carbon dioxide or other greenhouse gases (GHG) that are emitted or consumed throughout the life of the fuel. Generally the LCA includes everything from growing the feedstock to producing the ethanol to transporting the fuel to retail outlets to combusting the fuel in the vehicle. Various LCA methodologies attempt to capture these direct and indirect land use changes, though some choose to skip the complexity of land use change altogether. Depending on the scale of this calculation, it can have a huge impact on the effectiveness of biofuels and ethanol to achieve their goals of GHG emission reduction and dependence on fossil fuels. More detailed information on ethanol LCAs in the LCA Chapter of this thesis.

Crop yields in the last two to three years (2010 to 2012) were reduced due to drought and other weather-related issues. On top of this there is a growing controversy over land use changes attributed to the increasing demand for space from biofuel mandates around the world. For example, there are 52 countries with biofuel mandates as of November 22, 2012 (See Table 6Table 6). The countries with the largest impact are Brazil, India, US, China and the EU (acting as one regulatory body for the 27 countries it represents) together requiring approximately 60 billion gallons of renewable fuel by 2022 (Lane, 2012).

Table 6. Countries with Biofuel Mandates as of 2012

Americas	Ethanol	Diesel	Future Targets
Argentina	E5	B7	
Brazil	E18	B7	B10 in 2014, B20 for 2020
Canada	E5	B2	4 provinces have E8.5 mandate
Colombia	E8	na	
Chile	E5	B5	Targets, not mandates
Costa Rica	E7	B5	
Jamaica	E10	na	
Mexico	E2*	na	
Panama	E2	na	E5 in 2014 to E10 in 2016
Paraguay	E24	B1	
Peru	E7.8	B2	
Uruguay	B2	na	B5 by 2015 and E5 in 2015 expected. Only domestic biofuel
USA	E10		36 Billion gallons of renewable fuel by 2022
Europe			
EU-27	E5	B5	10% biofuels by 2020
Asia-Pacific			
Australia	E4	B2	
China	E10**	na	10% biofuels by 2020 mandated, Target 15%
Fiji	E10***	B5***	
India	E5	na	Target: 20% biofuels by 2017
Indonesia	E3	B2.5	
Malaysia	na	B5	
New Zealand	na	na	
The Philippines	E10	B2	
South Korea	na	B2.5	(From Malaysian Palm Oil)
Taiwan	na	B1	E3 maybe
Thailand	na	B5	
Vietnam	E5		
Africa			
Angola	E10		
Ethiopia	E5		
Kenya	E10		Only in Kismu (3rd largest city)
Malawi	E10		
Mozambique	E10		
Nigeria	E10		
South Africa	E10		
Sudan	E5		
Zimbabwe			Pushing for E10 by Dec 2012

Notes:
E10 notates a blend of a maximum of 10 percent ethanol is blended with gasoline. E85 is 85% ethanol and so on.
B5 refers to a maximum of five percent biodiesel blended with standard diesel, B7 is 7% biodiesel and so on.
*In Guadalajara, Mex City and Monterrey Only
**Only in 9 provinces
***Target, not mandated

These regulations create a substantial demand for feedstocks which are rapidly being planted by farmers world-wide as a result. In Brazil , there is trouble with cropland encroachment on the Amazon rainforest and is of particular concern because of the unique biodiversity as well as the substantial amount of carbon dioxide these forests can absorb. The more farmers that plant crops to be used for fuel, the less land (and crops) are available for food, living, development. The additional demand for land could jeopardize land set aside for conservation or more effective for CO2 absorption, like forest or jungle. One of the largest environmental concerns that as biofuel mandates grow, available arable land will decrease and forests or other fragile ecosystems could be cleared for harvestable monocultures.

In short, biofuel mandates are proliferating across the world and have created an increasing demand for both crops and crop*land*. This research examines these indirect effects in more detail and distills important takeaways for policy makers, technology developers, and the public to consider when determining whether to, and if so how, to support biofuels in the upcoming decade. An important aspect of analyzing biofuels are the metrics used in order to capture both the direct and indirect effects of biofuels. One critical metric used is the reduction of greenhouse gas emissions which are measured using a lifecycle analysis. Current lifecycle analyses based on updated ethanol generation techniques estimate an reduced lifecycle emission of carbon dioxide can vary anywhere from 22% higher than gasoline (using a coal-powered ethanol plant) (Liska, et al., 2009) up to an almost 60% reduction (California Air Resources Board, 2012) using the left over corn plant matter to heat the distillery and other newer process efficiencies. From these numbers it suggests that ethanol can produce very different results in reducing the amount of carbon dioxide released during a product's lifecycle. Therefore it is of critical importance to understand some of the complexity within the biofuels industry to ensure that the benefits are harnessed and help mitigate the negative effects.

3. US Policy that Impacts Ethanol

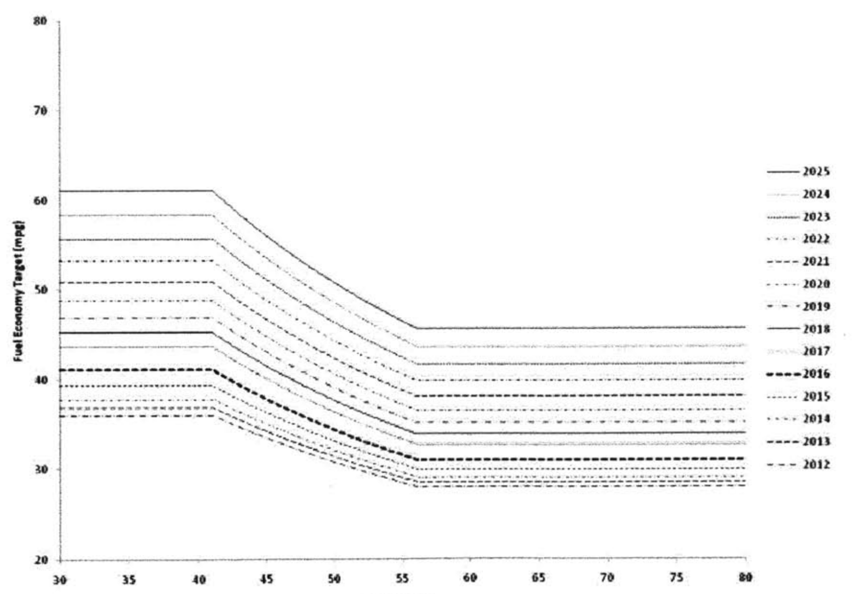
This chapter discusses the current US legislature that has the greatest impact on the use of ethanol. It is possible that without these mandates or incentives that there would be a market for ethanol, but more than likely it would not have achieved today's demand of nearly ten percent of the gasoline supply. The following legislative acts have significantly increased the demand for biofuels.

3.1 Corporate Average Fuel Economy (CAFE) Standards 1975-2012

The federal CAFE standard is legislation that regulates the fleet fuel efficiency of cars and light duty trucks and ensures that manufacturers are producing increasingly more efficient vehicles. It was first passed in 1975 and has been revised periodically since. The most recent ruling was in August 2012 by President Obama and has mandated goals of an average of 54.5 miles per gallon by 2025. "The CAFE standards are based on a vehicle's size, or footprint[11], where every size vehicle has a fuel economy target. Generally, the larger the vehicle footprint, the lower the corresponding vehicle fuel economy target." (NHTSA, 2012). The CAFE standards help to improve the average fuel economy across all of the different cars and manufacturers and does not mandate a specific fuel economy for any specific car, car type, or manufacturer.

The CAFE regulations are some of the predominant legislation that forces the auto industry to build a fleet with an ever increasing average fuel economy. The figure below shows the updated requirements in fuel economy due to the CAFE regulations for 2017-2025 (See Figure 4 below).

Figure 4. CAFE Target Curves for Passenger Cars 2017-2025 (EPA; NHTSA; DOT, 2012)



[11] Vehicle Footprint- essentially, the space between the points at which the tires touch the ground

3.2 Clean Air Act 1990 and MTBE Ban 2004+

The Clean Air Act was passed in 1990 and required refiners to add a certain amount of oxygenate to gasoline in order to reduce the levels of lead and help the fuel burn more cleanly and completely (US EPA, 2013). MTBE and ethanol are two additives that would meet this requirement. MTBE is produced by the petrochemical industry and was one of the cheapest ways to meet the Act's requirements; however there was increasing pushback against the dangers of this product because it can leak from underground fuel storage tanks and contaminate groundwater. MTBE is not water soluble, so it does not breakdown easily nor adhere to soil if it leaks from storage tanks or other distribution methods. It has been found to have detrimental health effects in laboratory animals and a maximum contaminant level has been set for drinking water by the EPA. Unfortunately the EPA did not regulate this chemical before the Clean Air Act was enacted so companies were not discouraged through regulation from using it.

Currently, it has been formally banned in at least 19 states (US EPA, 2004) and the use of MTBE has effectively been eliminated due to the RFS2 mandate requiring so much ethanol. The inclusion of MTBE was an effect of the Clean Air Act which required an oxygenate to be included in gasoline, but only in certain areas with high-density populations and significant air pollution. Today, given the percentage of ethanol that is needed to be blended into gasoline in order to meet the RFS2 requirements, there is no longer any need to use MTBE as a gasoline additive and as of 2007 the use of MTBE has effectively been eradicated in gasoline as you can see in the table below (See Figure 5).

Figure 5. Alternative Fuel and Oxygenate Consumption 2003-2010 (Thousand Gasoline- equivalent gallons) (US DOE EIA, 2012)

	2003	2005	2006	2007	2008	2009	2010
Alternative fuel							
Liquefied petroleum gas	224,697	188,171	173,130	152,360	147,784	129,631	126,354
Compressed natural gas	133,222	166,878	172,011	178,585	189,358	199,513	210,007
Liquefied natural gas	13,503	22,409	23,474	24,594	25,554	25,652	26,072
E85[a]	26,376	38,074	44,041	54,091	62,464	71,213	90,323
Electricity[b]	5,141	5,219	5,104	5,037	5,050	4,956	4,847
Hydrogen	2	25	41	66	117	140	152
Biodiesel	18,220	91,649	267,623	367,764	324,329	325,102	235,188
Other	0	2	2	2	2	2	0
Subtotal	**421,161**	**512,427**	**685,426**	**782,479**	**754,658**	**756,209**	**692,943**
Oxygenates							
MTBE[c]	2,368,400	1,654,500	435,000	0	0	0	0
Ethanol in gasohol	1,919,572	2,756,663	3,729,168	4,694,304	6,442,781	7,343,133	8,527,431
Total	**4,709,133**	**4,923,590**	**4,849,594**	**5,476,783**	**7,197,439**	**8,099,342**	**9,220,374**

As an example of the long term unintended consequences, recently Exxon Mobil was found responsible for the contamination of a New Hampshire community's drinking water from the use of MTBE. (Jeffrey & Earle, Bloomberg, 2013) This is not only an example of a negative unintended consequence of the Clean Air Act, but also an example of a positive unintended benefit of the RFS2 mandates- ethanol has now become much more available and is now a more viable substitute to MTBE. Because of the lack of other substitutes for MTBE and to be able to meet the gasoline requirements of the Clean Air Act refiners can now use ethanol to meet this regulation.

3.3 Renewable Fuel Standard (RFS2) 2007

The original Renewable Fuel Standard was passed in 2005 as a part of the Energy Policy Act. The federal Energy Independence and Security Act passed in 2007 and increased the amount of mandated biofuels with the RFS2. The RFS2 requires that refiners[12] blend a specific amount of renewable fuel into US transport fuels (both gasoline and diesel) each year. It allows for some flexibility in these amounts through Renewable Identification Number (RIN) credits. RIN credits create a type of currency for refiners so that in years when it is difficult to meet the standards due to technology limitations or weather related biofuel crop shortages,

[12] For example Exxon Mobil or Shell

refiners can redeem RIN credits instead of forcing the renewable fuel blending mandates. See the RIN chapter for more information on RIN credits.

The RFS2 defines four types of renewable transport fuel and accompanying quantities by specific due dates. These categories are Total Renewable Fuels, Advanced biofuels, Cellulosic biofuel, Biomass-Based biodiesel (BBD) (see Table 7Table 7). All advanced and cellulosic biofuels and biodiesels help achieve the total Renewable Fuel levels.

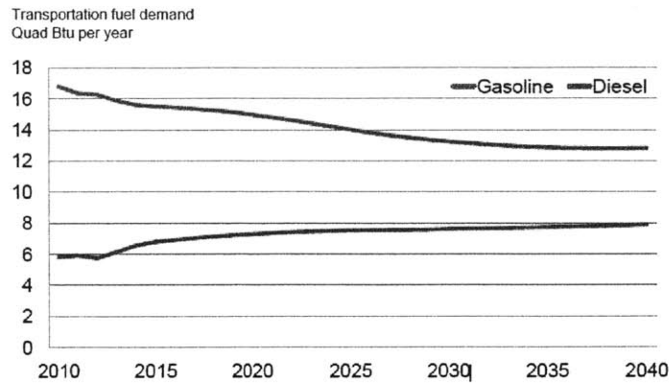
Table 7. Description of Different Categories of Biofuel as Defined by the RFS2 2007

			Amount in 2010 (billion gallons)	Amount 2022 (billion gallons)
Total Renewable Fuel	All Renewable Fuel	Must have a minimum of 20% reduction in GHG emissions compared with gasoline throughout its lifecycle. Examples of renewable fuel include corn ethanol but can also include advanced biofuels or cellulosic biofuels.	13	36
	Advanced Biofuels	Must reduce GHG emissions by 50% compared with gasoline. Examples include ethanol from sugarcane and can include cellulosic ethanol.	1	21
	Cellulosic	Must reduce GHG emissions by 60% and is derived cellulose or lignin sources, such as residual plant mass sources Examples include ethanol from corn stover, stalks, cobs, and other waste material from plants, trees	0.1	16
	Biomass-based Biodiesel	Biomass-based biodiesel must achieve 50% reduction in GHG emissions when compared with gasoline.	0.5	na

However the industry has had trouble meeting the cellulosic requirement due to the difficulty developing commercial scale plants and sought a waiver from the EPA each year since it started being required in 2010 (Schnepf & Yacobucci, 2013). 2013 is the first year refiners expect to start delivering cellulosic biofuels.

Gasoline consumption in the US actually decreased from 2008-2009 due to the financial recession and has stayed lower through 2011 (US Energy Information Administration, 2012) thanks in part to more vehicles with better fuel efficiency on the road. For ethanol, since the mandates are given in gallons not percentages, the amount of ethanol required to be blended results in a larger percentage of the base gasoline. The decrease in gasoline consumption is expected to continue through 2040, according to the EIA in the Annual Energy Outlook (AEO) 2013 Early Release (see Figure 6).

Figure 6. EIA Projections through 2040 (US EIA, 2013)



A blend of ten percent ethanol with a remaining ninety percent gasoline (E10) has nearly been achieved across the US. E10 does not require any changes to the fueling infrastructure and has been deemed safe for all vehicles and other non-road motors (US Department of Energy , 2011). In order for the market to meet the increasing mandated amounts of ethanol as decreed by the RSF2, the market and its supply chain must be able to either accept a higher percentage of ethanol in gasoline (or the entire gasoline market would need to increase in size- which would be counterproductive).

3.4 California's Low Carbon Fuel Standard (LCFS)

The Low Carbon Fuel Standard is California's legislation to reduce greenhouse gas emissions regulated by California's Environmental Protection Agency's Air Resources Board (CARB). It was passed in 2007 and the regulations it set forth was to start in 2010. The goal of the legislation was to reduce the amount of greenhouse gas emissions and for transportation fuels to become ten percent less carbon intensive by 2020. (Air Resources Board, 2013) It compares the entire life cycle emissions of various fuels from traditional gasoline and diesel, to the range of renewable fuels. In theory it is technology neutral- it does not discriminate based on the type of technology and allows the market the freedom to find the most efficient way at reducing carbon dioxide emissions.

However despite this free-market approach, the act was called "protectionist" and that it discriminates against fuels generated outside of California because of the increased carbon needed to transport the fuel into California's borders. "Out-of-state refiners and ethanol companies say the score discriminates against their products because transportation to California alone raises it. They argue the law violates the commerce clause of the U.S. Constitution by imposing limits on interstate commerce." (Dearen, 2012) The injunction against LCFS however was lifted on December 29, 2011 and allowed California to continue its enforcement of the law.

This type of legislation is one of the first of its kind, punishing carbon dioxide emissions as opposed to imposing subsidies or trying to force a specific type of behavior or technology like the RFS2[13]. Because of the large population of California, the state's tight environmental regulations often set precedent for the entire US because many car companies do not want to manufacture multiple models to sell in the US. Therefore manufacturer's produce their vehicles to the tightest set of standards, which in most cases is California's. The LCFS look-up tables with the scores calculated by the Air Resources Board plot out very specific carbon intensity values for all the different types of fuels that can substitute for gasoline. The scores include the methods used to distill and process ethanol, transport, and also includes land use change. It uses the same LCA methodology to chart the greenhouse gas emissions for gasoline, ethanol from US corn, ethanol from Brazilian sugarcane, compressed natural gas and liquefied natural gas (California Air Resources Board, 2012). Unfortunately, Brazilian sugarcane ethanol emissions are still lower than many kinds of US corn ethanol despite the long shipping distance. Some example values are included in Table 8 below.

[13] It should be noted however that the RFS2 is a part of the Energy Independence and Security Act whose primary goal was not only to reduce carbon emissions, but also to create national energy independence and other benefits.

Table 8. Comparison of Total Carbon Intensity of Various Fuels in (gCO2e/MJ) (California Air Resources Board, 2012)

Gasoline[14]	99.18
Corn Ethanol	74.70[15]-120.99[16]
Sugarcane Ethanol	58.40[17]-78.94[18]
Compressed Natural Gas	11.26-68.00
Liquefied Natural Gas	15.56-93.37
Electricity	104.71-124.10

These values show that it is very important to examine process details and evaluate the entire system from feedstock to combustion in order to get the complete story. From these numbers it becomes clear why there is such a debate around ethanol and if it truly meets all the promises of being a clean energy source. If processed in a plant powered by coal, it can do more harm (with respect to carbon) than gasoline. If processed using other methods, it comes out ahead.

In theory, the LCFS helps discern between these different types of fuels and picks the fuel with the smallest carbon footprint regardless of geography, politics or otherwise. This policy still does not manage to avoid any unintended consequences, for instance the US now imports Brazilian sugarcane ethanol because of its smaller carbon intensity, despite the long distance over the ocean. Given the current US biofuel incentive structure, the US is willing to pay higher prices for ethanol with a smaller greenhouse gas emission footprint. Brazil's ethanol consumer is essentially indifferent about the type of ethanol used, and in 2011 was a net importer of US corn ethanol. Our current method of analyzing lifecycle GHG emissions does not account for the reciprocal demand and shipping of corn ethanol to Brazil. In the long run, maybe the RFS2 or LCFS mandates will incentivize US ethanol producers (and their investors) to upgrade their plants and bring cellulosic ethanol online and we can replace Brazilian ethanol completely. Until then we are still bringing in

[14] More specifically: California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB)
[15] 2A Application*: Dry Mill; Dry DGS; Raw starch hydrolysis/biogas process fuel; Amount and type of fuel use, and amount of grid electricity use not to exceed a value the applicant classifies as confidential.
[16] Midwest; Wet Mill, 100% coal
[17] Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit
[18] 2B Application*: Brazilian sugarcane processed in the CBI with average production process; Thermal process power supplied with NG

sugar ethanol from Brazil and sending ethanol from corn to Brazil (Radich, 2013) which neither moves us closer to energy independence nor a smaller net carbon footprint.

3.5 Existing Taxes and Subsidies in the US

Taxes and Subsidies are a mechanism that governments can use to encourage or discourage the use of products or services. Previously (1978-2011) the federal government incentivized the use of US grown ethanol and biodiesel and enacted a blending credit[19] of $0.45 per gallon of ethanol and $1.00 per gallon blending credit of biodiesel. Additionally, it instated a tariff of $0.54 per gallon on ethanol imports which primarily impacted sugarcane ethanol from Brazil.

As of 2013 in the US, the ethanol blending credit expired at the end of 2011 along with the ethanol import tariff. However, the biodiesel credit was extended through 2013 and made retroactive for 2012 along with a tax credit for cellulosic biofuel of $1.01 per gallon. (Radich, 2013). Given that these are blending credits, it is money that goes to gasoline refiners[20] who are blending the fuel, in order to incentivize the use of ethanol. However given the price of ethanol versus the price of crude this has varied greatly from one year to the next (more on pricing and the break-down of the price of gasoline in chapter on Pricing). However, the subsidies help offset some initial risk for nascent cellulosic ethanol producers by helping to create a market for cellulosic ethanol producers as well as providing loan guarantees for capital investment in the construction of cellulosic ethanol processing plants.

3.6 Legislation Discussion

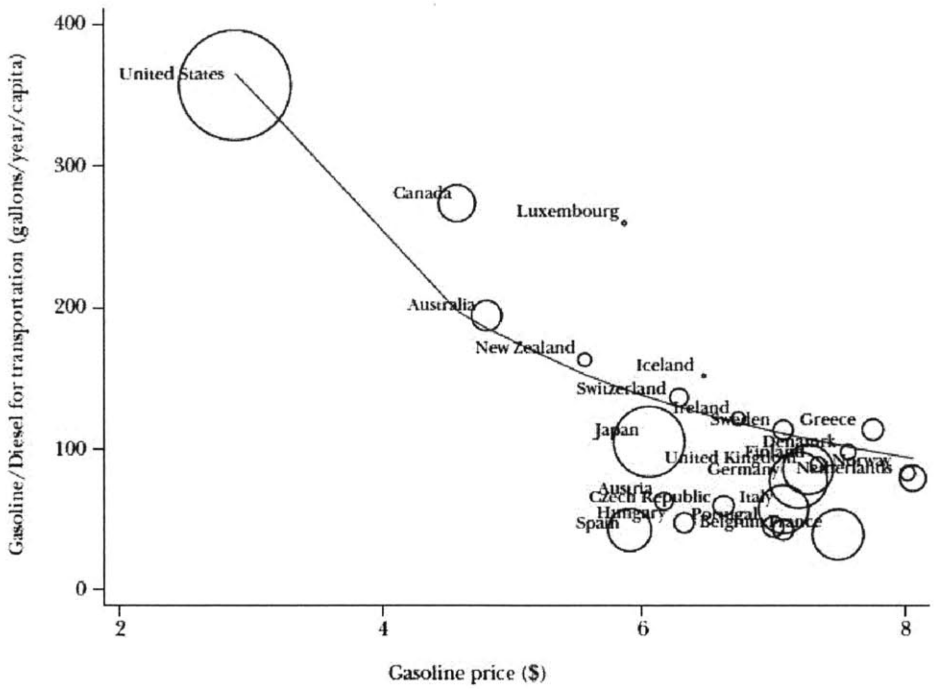
Policies such as the above will start to move the country towards a smaller carbon footprint, however it will not happen overnight. These policies may help the country move toward energy independence and reducing greenhouse gases, but some policies may cost the average tax payer more than others. A study by Holland et al compared costs to society of each policy type, including the effects of the RFS2, LCFS, subsidies and a cap

[19] VEETC- Volumetric Ethanol Excise Tax Credit
[20] Example: ExxonMobile, Shell

and trade system. The authors found that with a cap and trade on greenhouse gases, the results were 2.5 to 4 times less expensive for an equal reduction in GHG emissions, than subsidies, LCFS or the RFS program. (Holland, Hughes, Knittel, & Parker, 2011). "We find that regulation with more concentrated private benefits, the RFS, is maintained over a CAT[21] system which would offer larger social benefits but with less concentrated private benefits." It is necessary to have government intervention to help citizens reduce the carbon footprint, and help to achieve energy independence. Perhaps the current legislation is the best compromise that the US can do to move the country towards those goals, however one could argue that much more could be done on the underlying issue- too much fossil fuel consumption. In addition to saving the tax payer money, the US could also faster attain the goals of reducing its carbon footprint and achieving energy independence from more aggressive energy conservation policies in conjunction with finding energy alternatives. With the US as the number one consumer of petroleum products per capita in the OECD countries (see Figure 7) by a significant amount, it indicates there is plenty of room for improvement.

[21] Cap and Trade (CAT)

Figure 7. Transportation Fuel Price per Capita versus Fuel Price (Knittel C. , 2011)



4. US Ethanol Supply Chain

This next chapter will discuss the structure of the ethanol supply chain. This provides the foundation for a more thorough analysis on policy and a better understanding of the environmental and social costs and benefits of ethanol. In this chapter we shall analyze the basic steps to make ethanol, some of the complications of its supply chain, and the relationship to ethanol's eventual success or failure in the market.

4.1 Supply Chain Basics

The ethanol supply chain starts with the feedstock growing in the field, and follows ethanol through processing, distribution and use in a vehicle. It is important to appreciate the different components of the ethanol supply chain in order to understand the lifecycle models which are critical to weighing the pros and cons of ethanol as a gasoline alternative.

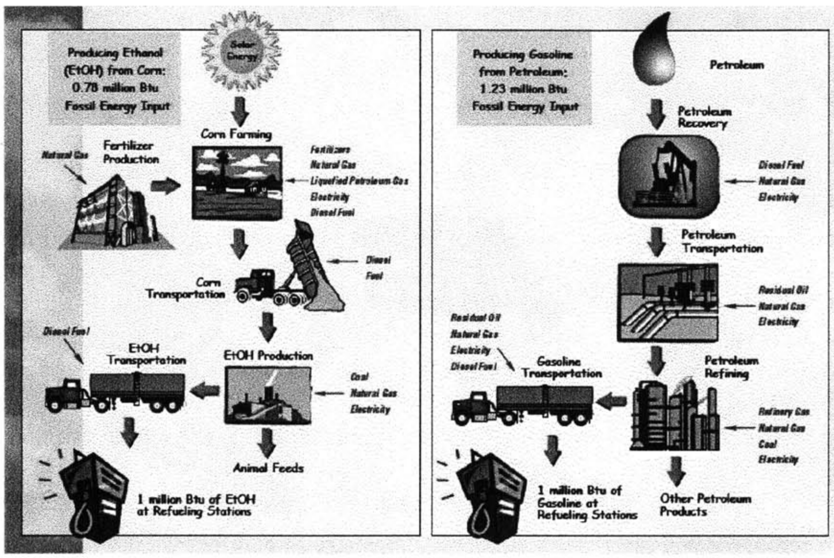
The terms "Well to Wheels" and "Well to Tank" are terms that are used to help describe the boundaries of the analysis of a system regardless of the technology (gasoline versus ethanol versus electricity). In this chapter we discuss the supply chain from Well to Tank. In this case the well is the farmland and the tank is the gas tank on the vehicle and includes what all needs to take place in order to get ethanol from the crop in the field to a combustible fuel at a retail station. "Tank to wheels" includes the emissions from combustion.

The basic overview consists of the following (see also Figure 8):

1. The feedstock or crop is grown in the field.
    a. Corn ethanol is mostly grown in the Midwest of the US and is considered a first generation biofuel crop. Other common feedstocks are sugar cane in Brazil.
    b. Second generation or "advanced" feedstocks: Ethanol and Biodiesel producers are moving to other non-food feedstocks, considered second generation, such as jatropha, camelina, switchgrass etc. Cellulosic ethanol is slowly coming on line and uses woody plant mass, residual crop waste (corn cobs, stalks etc) to process into ethanol reducing impact on food stocks.
    c. There are various inputs with environmental considerations for a life cycle analysis at this stage such as pesticides, herbicides, fertilizers, water for irrigation if necessary, labor, machinery required for harvesting.
2. It gets harvested and transported (typically by truck given the distributed nature of farm fields) to a nearby processing plant.
3. Ethanol is pretreated, processed and distilled from the grain (using either wet or dry milling process)
    a. Distillers grain can be up to 70% of the resulting products which can be used as high protein feed for livestock, the rest is ethanol. (Depends on using wet or dry mill process- wet produces more, but consumes more energy)
    b. Typically there is some kind of enzyme or chemical requirement to break down starches or in the case of cellulosic ethanol- lignose.

4. Ethanol gets transported (via truck or train or barge) to blenders
5. Blenders mix ethanol with gasoline at requisite levels (See Policy Chapter RFS2)
6. Blended Fuel is transported to gas stations (points of sale) and stored in tanks.
7. Fuel is pumped into consumer's vehicle and combusted resulting in emissions.

Figure 8. Fossil Energy Inputs Required to Produce and Deliver a Million BTUs of EtOH and Gasoline to a Refueling Station (Argonne National Laboratory, 2007)



4.2 Ethanol Fuel Complications

There are many complications in this supply chain that affect the sustainability and environmental benefit of ethanol with each step of this process. The following chapters will discuss these in more detail.

4.2.1 Energy Density of Ethanol and Gasoline

One important factor that can impact consumer acceptance is the difference in energy content between gasoline and ethanol. According to the Alternative Fuels Data Center, gasoline contains an average of 116,090 Btus per gallon while ethanol contains 76,330 Btu per gallon (Alternative Fuels Data Center, 2013). This translates into ethanol containing approximately 67% of the energy density of gasoline on a volumetric basis, resulting in a reduction of approximately 25-30% in fuel economy. (GAO, 2011). This is important to note with respect to price, that in order to achieve equivalent pricing with gasoline, E85 needs to be priced sufficiently below that of E10 in order to compensate for the additional fuel the consumer would need to purchase. Brazil's legislative mandates ensured to account for this difference in performance also by subsidizing the price of ethanol so that the price was on par with gasoline in order to eliminate price as a roadblock to ethanol's success. On top of this consideration there are also material properties that lead to difficulties in fuel distribution that help contribute to what is referred to as the "blend wall".

4.2.2 Ethanol Blend Wall

In the US, there is difficulty in achieving higher levels of ethanol blends above ten percent or E10 because there are material compatibility issues. "Ethanol attracts water. If even small amounts of water mix with gasoline-ethanol blends, the resulting mixture cannot be used as a fuel or easily separated into its constituents." (GAO, 2011) Because of this and the naturally corrosive nature of ethanol, the addition of ethanol to gasoline means that it can create corrosion issues with components in the infrastructure that transport, store, and distribute the fuel, including internal components of the engines that are intended to burn the fuel. If water gets into the fuel, it can interfere with the combustion properties, on top of corrosion issues. Additionally the combustion characteristics of ethanol are slightly different than gasoline, which requires some fine tuning of the fuel-oxygen mix.

This has created what is referred to as the "blend wall". The blend wall is the metaphorical barrier that obstructs the increased consumption of ethanol due to its corrosive properties and lesser energy content that creates compatibility issues with its transport and combustion. Currently the blend wall in the US is considered ten percent ethanol, or E10. "E10" is the nomenclature used to indicate the percentage of ethanol in the fuel, for example E85 has 85% ethanol. Until engines and other fueling infrastructure components can function with a higher percentage of ethanol, and until the gasoline blends become available at the local gas station, consumers cannot buy the fuel for their vehicles in order to create the demand for this fuel.

Today, there are more cars being produced that are capable of consuming higher gasoline-ethanol blends, for example cars produced after 2001 have been approved by the EPA for blends up to E15. Also there are many more "flex-fuel" vehicles which can handle up to E85 (in Brazil E100). Flex-Fuel Vehicles are cars that have been designed to take any blend of gasoline and ethanol, up to E85. However there are still other non-road motors (boats, chain-saws, blowers) whose manufacturers are reluctant to make the engine modifications needed to handle these blends due to increasing expense and complexity. They, however, represent a small fraction of total gasoline consumed in the US. The EIA reports that nonroad, offhighway transportation motors (includes recreational, agricultural, industrial and construction) equipment consumed 205.9 trillion BTUs of gasoline in 2010 or 0.74% of the 27,639 trillion BTUs consumed by the total transportation segment in 2010.

Additionally, until there is demand, gasoline vendors have limited incentive to update their pumps and storage equipment to handle the higher blends of ethanol. The fuel blenders are reluctant to update their distribution equipment including trucks or pipelines because of significant upfront costs. However without a supply, users cannot purchase higher blends of ethanol. (Simnick, 2013) There are governmental incentives through tax deductions to encourage this transition, but costs are somewhat prohibitive for the average gas station owner. More on this topic in the **Storage: Pumps and Tanks** section. "At the maximum allowable blend, in which gasoline at the pump contains 10 percent ethanol [E10], updated projections suggest that the country is unlikely to be able to use all the ethanol that Congress has ordered up. So something has to give." (New York Times, 2009)

With the RFS2 mandates and the current levels of gasoline consumption, the industry will soon exceed a 10 percent blend, as the advanced fuel requirements continue to grow (see Table 9). The next steps are to upgrade the transportation fuel distribution infrastructure by updating storage tanks, pumping stations, and other distribution mechanisms such as trucks, trains, or pipelines.

Table 9. Ethanol and Biodiesel Summary, 2009-2011 (US EIA, 2012)

(million gallons unless otherwise noted)

	2009	2010	2011
Ethanol			
Consumption	11,037	12,858	12,871
Consumption (Percentage of Gasoline by Volume)	8.0	9.3	9.6
Production	10,938	13,298	13,948
Gross Imports	198	16	172
Gross Exports	NA	399	1,195
Biodiesel			
Consumption	326	263	878
Consumption (Percentage of Distillate Fuel by Volume)	0.6	0.5	1.5
Production	516	343	967
Gross Imports	77	23	36
Gross Exports	266	105	73

The EPA, the Renewable Fuels Association and others are working to push the available blends to E85 or higher by working with the automobile market to test if vehicles are compatible with higher gasoline/ethanol blends and encouraging fuel vendors to provide higher blends to the marketplace. The advanced biofuels portion of the RFS2 mandate has not yet been met by ethanol producers, and therefore this additional source of biofuels has not yet entered the market in the US. As of the beginning of 2013, the first commercial-scale cellulosic or biomass-based ethanol and biodiesel plants are starting to come on line.

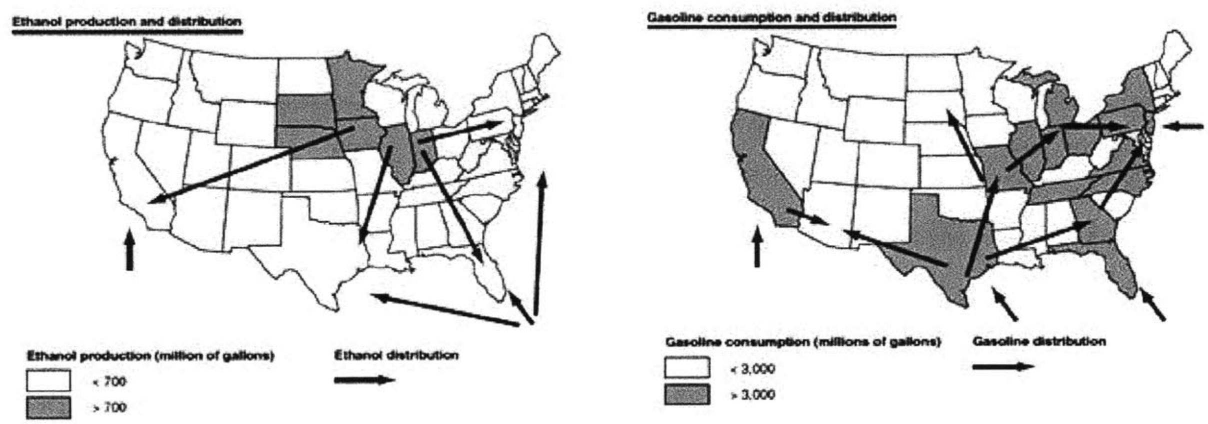
4.3 Contracts, Transportation, and Distribution Network

The movement of the feedstocks and ethanol through the US must consider things like the bulky inefficiency of transporting unprocessed grains and having to be blended with conventional gasoline. The following chapter analyzes some of the complications with today's transportation fuel infrastructure impinging on the success and the environmental impact of ethanol.

4.3.1 Transport Grain Phase: From Field to Ethanol Plant

Part of the challenge with increasing ethanol use in the US is in part due to the flow of ethanol as it travels in the opposite direction of gasoline. The fields of corn grown for use in ethanol are mostly located in the Midwest. The harvested feedstock must be transported to an ethanol processing facility (biorefinery) which, given the bulky nature of the feedstock in order to be more economically viable are located close to the harvest site. "...ethanol is generally produced in the Midwest and needs to be shipped to the coasts, flowing roughly in the opposite direction of petroleum-based fuels. The location of renewable fuel production plants (such as bio-refineries) is often dictated by the need to be close to the source of the raw materials and not by proximity to centers of fuel demand or existing petroleum pipelines." (GAO, 2011)

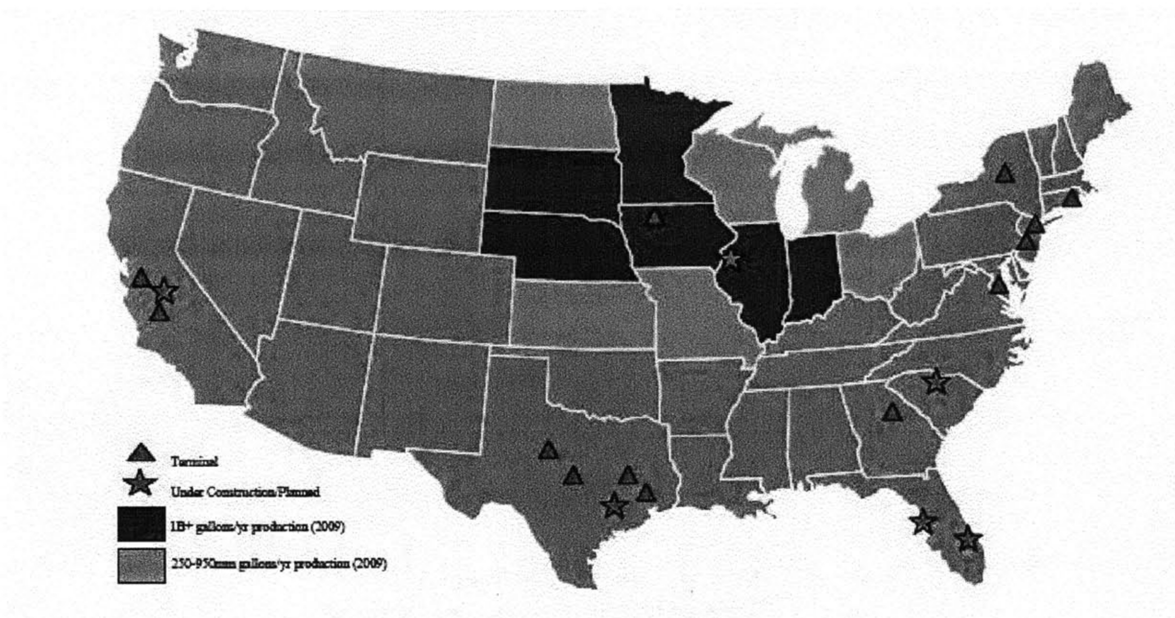
Figure 9. Distribution Patterns for Gasoline and Ethanol (US Department of Energy, 2010)



A study by the US Department of Energy researched the supply and distribution of ethanol and the feasibility of an ethanol pipeline. In 2010 ethanol was "transported by rail (66%), truck (29%) and barge (5%) with less than 1% now moving via the Florida pipeline." (US Department of Energy, 2010). The maps above show the general flow of ethanol on the right and gasoline on the left, from refineries to points of sale. The majority of the population of the US lives on the coasts, so both gasoline and ethanol are primarily distributed along the east, west, and gulf coasts. For gasoline, oil is shipped to a refinery (predominantly located in southern California, Texas and Florida), gasoline is produced, and then the majority is distributed along the coasts.

In contrast, ethanol is produced mostly in six states in the Midwest. The feedstock is gathered from farmers across these states, processed at a nearby ethanol plant, sent to a blending terminal (see Figure 10 below) to be blended with gasoline, and then distributed to the point of sale (US Department of Energy, 2010).

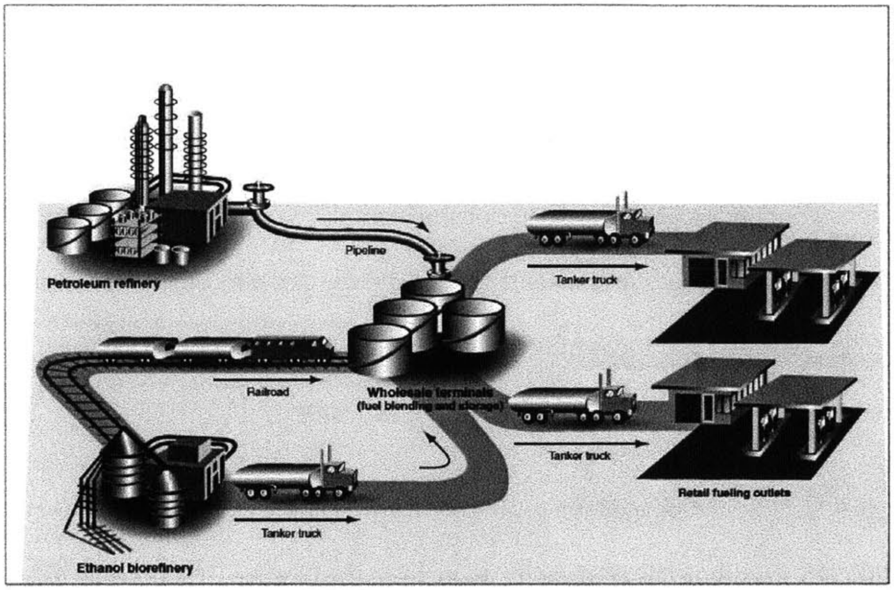
Figure 10. Blending Terminal Locations in the US. Source: (US Department of Energy, 2010)



4.3.2 Transport: From Blender to Pump via Pipeline, Train or Truck

This chapter discusses how ethanol is transported after it leaves the processing plant and what impact this has on its cost viability and improving ethanol's greenhouse gas emissions. See Figure 11 for an overview of the transportation of the fuels.

Figure 11. Primary Transportation of Petroleum Products and Ethanol from Refineries to Retail Fueling Outlets (GAO, 2011)



Source: GAO.

Note: Other means of transportation are also used to move petroleum and ethanol products to wholesale terminals. For example, for ethanol, barges are also used to a limited extent.

In order to move ethanol from distiller to blender, it is currently extremely difficult and expensive to use pipelines, which is how a lot of gasoline is moved. Gasoline, like ethanol, also uses a combination of train, boat, barge, and trucks, but also can leverage the use of pipeline which dramatically lowers its transportation costs and reduces its lifecycle GHG emissions. Because of ethanol's corrosive properties and hydrophilic nature, it results in compatibility issues with the pipeline itself and other components like seals etc., and typically requires either upgrades, severe cleaning of existing infrastructure or its own dedicated fleets for transportation or dispensing. Once ethanol has been blended with gasoline at levels less than ten percent, with respect to its corrosive nature it can then generally use existing infrastructure, however the challenge still remains that if water comes in contact with ethanol, it can pull the ethanol out of suspension. So even with E10, it remains difficult to avoid encountering water during the transport phase particularly via pipeline. In the case of gasoline, water and gasoline are relatively easy to separate and can be stored and allowed to settle and the water can be removed from the bottom (petroleum is lighter than water). With ethanol-gasoline blend, water brings the ethanol out of suspension, and what remains are two liquid combustibles, neither of which meet standards that can be sold. Both need to return to a refiner to be re-blended. (Mahon, 2013)

A study was undertaken by the US Government Accounting Office (GAO) to look at the additional challenges the ethanol industry will face in the near future. It found that "Existing ethanol infrastructure should be sufficient to transport the nation's ethanol production through 2015 according to DOT officials and industry representatives, but large investments in transportation infrastructure may be needed to meet 2022 projected consumption, according to EPA documentation." (GAO, 2011). Gasoline is heavily dependent upon the use of pipelines to transport fuel. Given the characteristics of ethanol, it is not suitable to "drop-in" to gasoline pipelines and today effectively still needs to be transported via truck, rail, or barge unless a dedicated ethanol pipeline were constructed.

However even given a dedicated pipeline there are still many technical challenges, due to ethanol's affinity for water and the difficulty in completely eradicating water from the pipeline. It is possible to convert existing pipelines, but difficult and costly. Kinder Morgan successfully converted one pipeline in 2007-2008 from Tampa to Orlando in Florida to handle ethanol batches between gasoline moves. It cost them approximately $27.5 million dollars ($13 million of which was directly related to modifications of the pipeline, the remainder was spent at injection and receiving terminals to modify storage for ethanol) to convert about one hundred miles of pipeline (Mahon, 2013) the current transport system in the US has had little investment over the past decades to keep up with increasing demand. The predictable increase of the transport of ethanol puts additional burden on the US transportation system of rail and highway. "...the Association of American Railroads, which predicted that without system improvements, the expected increases in rail volume by 2035 will cause 30 percent of primary rail corridors to operate above capacity and another 15 percent at capacity. The study stated the resulting congestion might affect the entire country and could shut down the national rail network." (GAO, 2011)

The CO2 footprint or additional GHG emissions from transporting ethanol via train or truck instead of pipeline will also need to be taken into consideration during the lifecycle analysis (LCA) which will be discussed in more detail in the chapter following. For more information on the different GHG emissions of different transport modes see Table 10 below.

Table 10. Transportation Greenhouse Gas Emissions by Mode 2010 (million metric tonnes of carbon dioxide equivalent) (US DOE EIA, 2012)

Highway Total	1482.5	85%
Cars, Light Trucks, & Motorcycles	1077.2	62%
Medium & Heavy Trucks & Buses	405.3	23%
Water	42.6	2%
Air	142.4	8%
Rail	43.5	2%
Pipeline	38.8	2%
Other	0	0%
Total	1749.8	100%

Generally transporting ethanol via pipeline would help build the case for improving the GHG and CO2 footprint of biofuels as well as the cost viability, and will be one more hurtle the industry faces as it ramps up to start displacing some of the demand for gasoline. The impact of greenhouse gas emissions due to transporting and distributing ethanol is approximately 3.4%[22] of the total greenhouse gas emissions of the lifecycle of corn ethanol, depending on the method used to generate ethanol[23]. (California Air Resources Board, 2009). See Table 11.

[22] Not including blender's credits (which would make the impact from transportation percentage contribution slightly larger, (from 3.4% to 4%, since blender's credits contribute a negative impact on total GHG emissions)

[23] Dry Mill

Table 11. GHG Emissions Summary for Wet and Dry Mill Corn Ethanol (California Air Resources Board, 2009)

	Dry Mill		Wet Mill	
Well to Tank	GHG (gCO2/MJ)	% GHG Contribution	GHG (gCO2/MJ)	% GHG Contribution
Corn Farming	5.65	7.1%	5.81	6.4%
Ag Chemicals Production	30.20	38.2%	31.35	34.5%
Corn Transportation	2.22	2.8%	2.28	2.5%
Ethanol Production	38.30	48.4%	48.78	53.7%
Ethanol Transportation & Distribution	2.70	3.4%	2.63	2.9%
Sub Total	79.07	100.0%	90.85	100%
Co-Products	-11.51		-16.65	
Total Well-to-Tank	67.60		74.2	
Tank-to-Wheel				
Carbon in Fuel	0.00		0	
Total Tank-to-Wheel	0.00		0	
Total Well-to-Wheel	67.60		74.2	

In addition to reducing the lifecycle greenhouse gas emissions, transporting fuel via pipeline reduces costs as well. Because of ethanol's difficulty travelling via pipeline, it has had to rely more heavily on other methods such as rail. Advances in the use of unit trains has reduced transportation costs for ethanol at around $.25-$.30 per gallon, however they are still significantly more expensive than pipeline $.03-$.07 per gallon. (Mahon, 2013).

4.3.3 Storage: Pumps and Tanks

Other aspects of the supply chain including the storage and dispensing at the point of sale. Gasoline is stored in an Underground Storage Tank (UST) at the retailer, which is difficult to inspect given that it is buried. This means that it is difficult for the station owner to see if there has been any impact from ethanol blends on fittings, valves, or other important components of the ethanol-blend distribution systems. In addition, retailers generally make most of their money from selling accoutrements like food, drinks or cigarettes, not from the gasoline itself. This greatly diminishes the incentive to upgrade the fueling infrastructure such as pump dispensers and storage tanks. For example, a new ethanol-compatible dispenser would cost approximately $20,000 per dispenser. A totally new UST would run about $100,000 per site. Upgrading components for a UST would run approximately $25,000 per site. (GAO, 2011). Based on this data just providing one fueling dispenser per refueling station and upgrading the UST (not replacing) to outfit every gasoline station in the US as of 2013, based on 156,065 gasoline stations (US DOE , 2013) would cost on the order of $7 billion dollars.

The owners of these pump stations fall under three main arrangements for fuel distribution between retailers and their suppliers in the U.S.

- **One percent** are owned and operated by big oil corporations (ex. ExxonMobil, Chevron)
- **Fifty two percent** are branded, independent vendors (ex. CITGO, Sunoco) and the remaining
- **Forty eight percent** are unbranded, independent retailers that are private business owners. (GAO, 2011).

These numbers imply that in order to make the transition to higher blends of ethanol it might require a higher level of managing, educating, and convincing the 99% of independent station owners. Without the financial backing or management structure of a central company (like a Chevron or BP) it could prove more challenging to begin this infrastructure changeover. However there are some federal incentives in place to help this transition including a "Tax credit up to 30% of the costs to install E85 infrastructure not to exceed $30,000. Expires 12/31/2013" and "USDA REAP program provides grants for blender pumps[24] (which offer E85) up to 25% of project costs for communities with populations of 50,000 or less." (Moriarty, 2013)

These type of incentives will help the conversion process for retailers and it might be advisable to take advantage of them sooner rather than later, because no one knows how long they will last. Next we will discuss the use of ethanol from the eyes of the consumer.

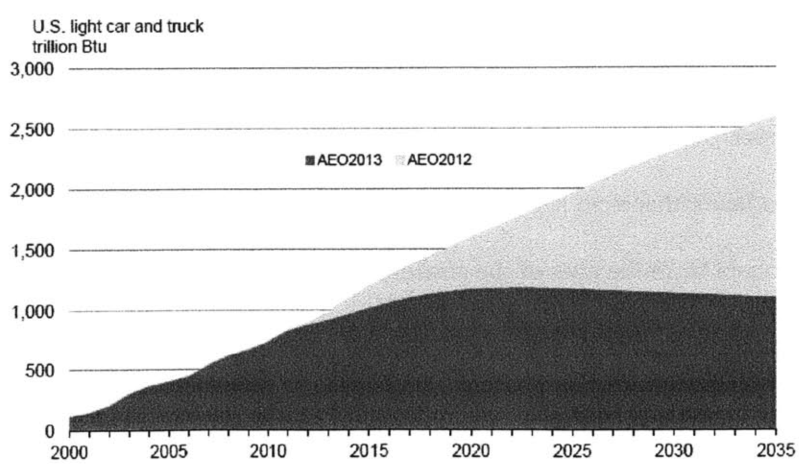
[24] **Blender pumps** mix gasoline and E85 to output blends of any range between such as E20 or E30.

4.3.4 End Use: Consumers and Vehicles

The difficulties with ethanol's material properties also translate into incompatibility with many vehicles available on the market today. Currently "Flex-Fuel" vehicles (FFVs) in the US can take up to 85% ethanol and consume any combination of gasoline and ethanol below that. This means a person could fill their car with gasoline, and top up with E85, or E10 or any combination thereof. Because of this refueling flexibility there is little downside to purchasing an FFV and in fact, many car owners don't even realize they own one. "The only major differences are a computer chip to let the engine automatically adjust to gasoline/ethanol mixtures and a special fuel line and fuel tank to allow for the higher blends of ethanol." (FlexFuel Awareness Campaign, 2013). There are markings throughout the car and you can check the VIN to see if it is an FFV. FFVs have started to proliferate across the US "U.S. automakers pledged to make 50% of their new vehicles FFVs by 2012."(FlexFuel Awareness Campaign, 2013).

According to the EIA in the 2012 outlook, they predicted strong FFV use, but in 2013, the US EIA significantly revised these estimates down. See Figure 12 below. "Sales of alternative-fuel vehicles in the *AEO2013* reference case are lower than those in *AEO2012*. The majority of the reduction relative to *AEO2012* is reflected in sales of flex-fuel vehicles (FFVs), which in 2035 are about 1.3 million, or less than one-half the 2.9 million FFV sales in the *AEO2012* Reference case." (US EIA, 2013)

Figure 12. Flex Fuel Vehicle Forecast change from 2012 to 2013 (Maples, 2013)



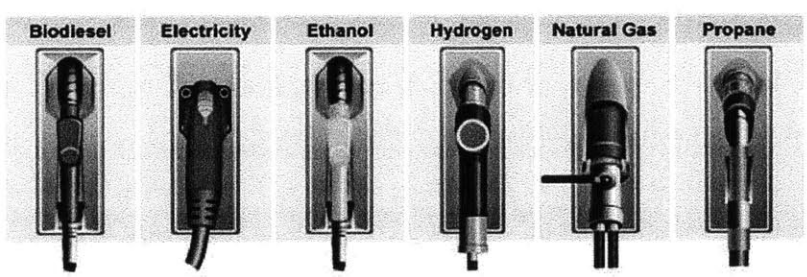
Studies done by the EIA that show that once station availability reaches about 10%, consumers basically no longer have trouble refilling with E85, however there is an apparent learning curve with respect to the energy content of the fuel. The consumer learns that ethanol has a lower energy density and therefore their car will cover less miles for the same volume of fuel and they have to stop more frequently to fill up (Liu & Greene, 2013). Additionally, currently a significant majority of Flex Fuel Vehicles are part of a government purchased fleet where there is less price sensitivity to filling up the vehicle. The study by Liu & Greene showed that previous forecasts did not discern between the two and recent data shows that private owners are learning about the lower energy content in ethanol and E85 sales have started to plateau. The price of a gallon of ethanol generally is less than a gallon of gasoline, but is rarely less per unit energy.

This implies that in order to gain wider acceptance, it is not just retail sales of FFVs that matter, but also the price and improved communication with the consumer. It would be beneficial for consumers if they could compare price based on equivalent energy content or number of miles, rather than to compare price per gallon. Additionally with respect to consumer communication, the EPA approved E15 to be used for vehicles manufactured after 2001 (EPA, 2012). However it remains a difficult task to not only physically manage different compatibility at the fueling stations, but also in educating the consumer about the differences between E10 and E15 and other fuels that may become available, and ensuring that the engine being refueled is compatible with the fuel the consumer is purchasing (including non-road engines).

Another factor that could increase demand for ethanol, but with lower costs than buying a new flex fuel vehicle, is through the use of an aftermarket kit that converts a traditional gasoline vehicle to a Flex Fuel Vehicle. There is some debate about what constitutes a sufficient conversion for example, whether or not the fuel tank and the fuel delivery system components need to be swapped out. These conversion kits depending on the manufacturer retail for around $1300. Consumers can also often benefit from other tax rebates to reduce this to much less (for example $300 in Illinois) (FlexFuels US). However, there are only certain car models that these kits are compatible with.[25]

It begs the question, what goes first- the cars or the infrastructure? Supply or Demand? Without ethanol available at retailers, there is no reason for consumers to seek out the purchase of an FFV that can take ethanol. Additionally, unless the price of ethanol is sufficiently below that of gasoline to make up for the decrease in performance, consumers don't want to pay more to power their vehicles the same distance. And on the retailer side of this, without consumer demand, fuel retailers generally don't want to upgrade their pumps until they have to. As the infrastructure grows old and needs replacing, retailers may slowly transition to ethanol compatible tanks and pumps, but it won't happen overnight. Additionally, ethanol is competing with other vehicle technologies like Compressed Natural Gas (CNG) and electric cars which also require infrastructure investment. As of April 2013 there is no clear technology winner and many sources indicate that there will not be one single technology solution. It is likely refueling stations will look very different in years to come (see Figure 13).

Figure 13. Future of Fuel Pumps? Source: (Alternative Fuels Data Center)



4.4 RINs

RIN stands for Renewable Identification Number, it is a sort of serial number for biofuel. A RIN is "a unique 38-character number that is issued (in accordance with EPA guidelines) by the biofuel producer or importer at the point of biofuel production or the port of importation. Each qualifying gallon of renewable fuel has its

[25] For a list of the car models, see the EPA website on EPA Compliant Conversion Systems. http://www.epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm#4

own unique RIN. " (Schnepf & Yacobucci, 2012) RINs are generated as a part of the production process by ethanol producers. This means that there is no "currency" regulator like the federal reserve who can print money, there is only the EPA who enforces the minimum quantity of biofuels produced or blended by refineries and ensures that there is no counterfeiting or other types of RFS2 violations.

Because there are four different types of biofuels that are mandated and tracked by the EPA, RIN credits must provide a way to track the biofuel producer and the type of biofuel. This helps the EPA study the effects of the mandates and ensure that the required amount of biofuels are blended into the requisite amount of fossil fuel. Parties that are obligated to adhere to the mandates include refiners, blenders, and those who import gasoline and diesel fuels. These obligated parties are required to purchase and blend a certain amount of biofuels per gasoline sold or produced.

"The obligated party establishes its "Renewable Volume Obligation" by taking the RFS percentage (7.76% in 2008) and multiplying that number times the total volume of gasoline produced or imported. The obligated party then submits its pro-rata share of gallon-RINs to EPA in order to demonstrate compliance with its portion of the RFS.

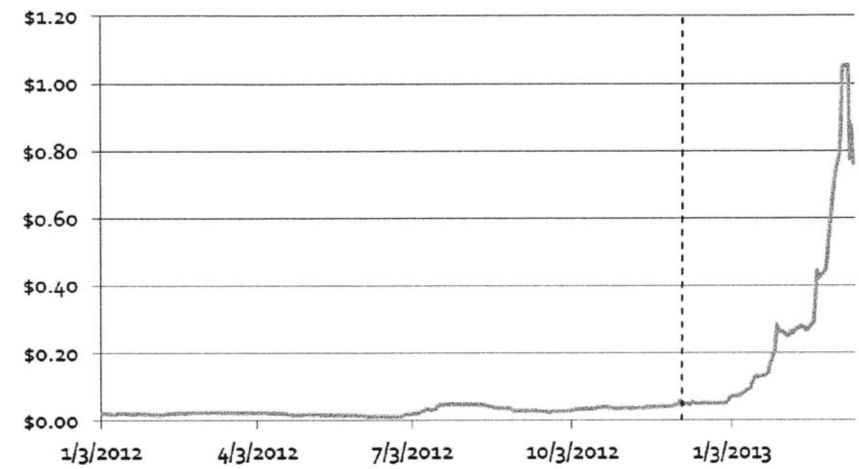
The RIN, in essence, is now a credit used as a method to keep score. If an obligated party blends more renewable fuel than its share, it generates excess RINs. These excess RINs can then be traded or sold to another company that finds it more economical to purchase RINs instead of blending ethanol or biodiesel. Banking and trading of RINs as renewable fuel credits forms the basis for an open RIN market" (McMartin)

RINs can be bought and sold independent of the batch of biofuel that was produced once the renewable fuel has been blended into the gasoline or diesel[26]. This can create a separate market for these credits and help blenders and fuel producers buy or sell RINs during years when renewable fuels may be difficult to obtain.

[26] For more information on RINs: ethanoltoday.com or biofuelsdigest.com

This occurred in 2013 after supplies were diminished from the drought and caused ethanol to be scarcer than years past. RINs, after they have been separated from the fuel at the blender, can then be bought or sold by essentially any interested parties, which can impact the prices of RINs due to speculation.

Figure 14. Conventional RIN prices 2012-2013

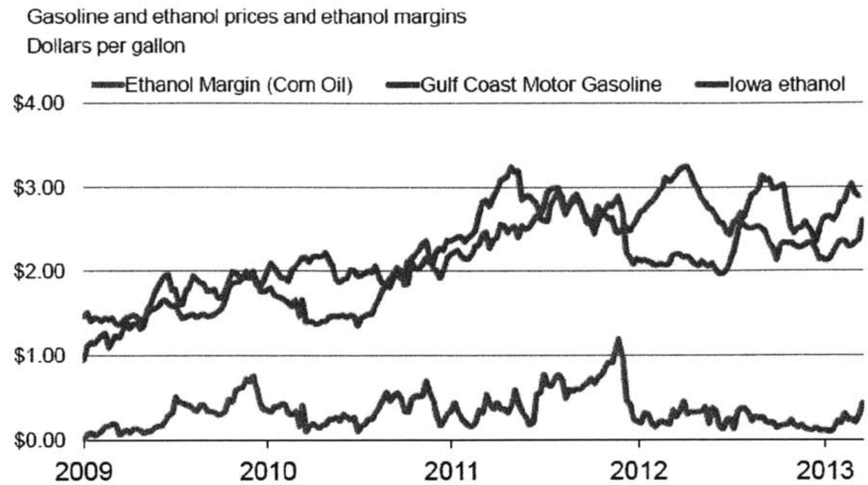


Note: price data in 2012 are for 2012 vintage RINs and price data in 2013 are for 2013 vintage RINs.
Source: Oil Price Information Service (OPIS).

4.5 Fuel Pricing (Ethanol and Gasoline Prices)

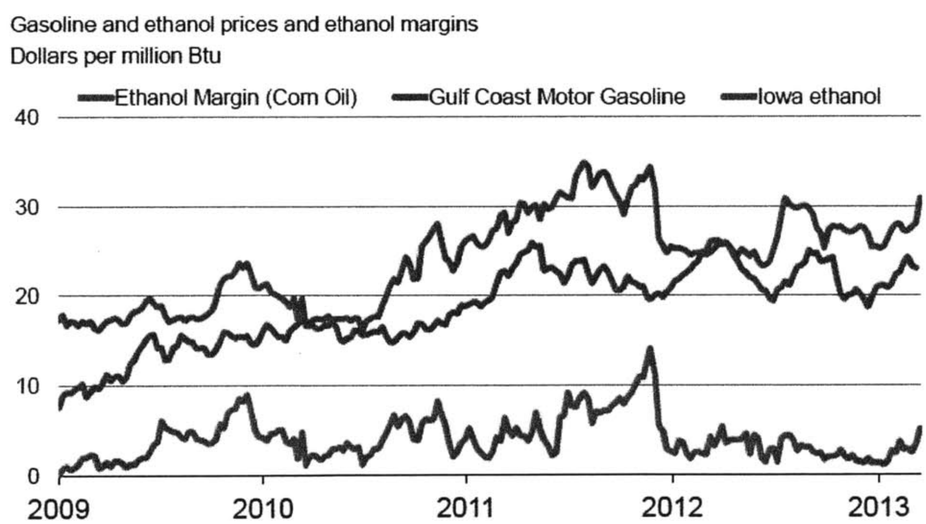
Ethanol pricing inspires a heated debate about how it impacts the price of gasoline whether it increases or decreases it. Ethanol prices between the past two years have declined on average, despite price increases due to the drought of 2012 and average price increases since 2009.

Figure 15. Gasoline and Ethanol Prices (and Ethanol Margins) per Gallon (Gruenspecht, 2013)



Given the differences in energy content of the two fuels, ethanol started to make gains to be on par or better than with gasoline for a given BTU in the middle of 2012, however in the latter part of 2012, ethanol again began to be more expensive than gasoline given its reduced energy content.

Figure 16. Gasoline and Ethanol Prices per BTU (Gruenspecht, 2013)



Looking at an average spot price across the US for 2011 and 2012, ethanol is getting closer at achieving equivalent pricing (see Table).

With ethanol containing roughly two thirds of the energy content of gasoline for the same volume of fuel, (Alternative Fuels Data Center, 2013) 67% of the price of gasoline is the data shown in the figure below [27]:

Table 12. What Ethanol Should Cost To Be Equivalent To Gasoline for a Given BTU

	Average Ethanol Price	Average Gasoline Price	67% of Price of Gasoline	% Diff
2011	$2.54	$3.58	$2.40	-6.01%
2012	$2.23	$3.68	$2.47	9.57%

Source: (US EIA, 2013) and (Alternative Fuels Data Center, 2013)

There have been many studies attempting to quantify the exact impact of ethanol on fuel prices with varying levels of success. Below is summary of two studies; one that is heralded as proof that ethanol is decreasing the price of gasoline. This study is important because it has high visibility and is used by both the Renewable Fuels Association and by members of congress that can determine energy policies. Currently, the Renewable Fuels Association claims on its website that ethanol reduced gas prices by more than $1 in 2011 based on a study performed by Iowa State University professor, Dermot Hayes and Xiadong Du (University of Wisconsin-Madison) (Hayes & Du, May 2012).

This working paper was rebutted by Professors Christopher Knittel (MIT Sloan) and Aaron Smith (UC Davis) in a paper entitled, "Ethanol Production and Gasoline Prices: A Spurious Correlation" (Knittel & Smith, July 2012) which expressed concern over the paper being held up as truth by the industry and US Secretary of Agriculture Thomas Vilsack.

The first study presents the case that ethanol prevented gasoline prices from climbing and saved the average consumer over a dollar a gallon. The latter study states that the methods that Hayes and Du use are unreliable and incorrect and are doing an injustice to policy makers (and thereby the public) who are making decisions based on poor data.

[27] However the 67% energy content does not directly translate into the same amount of energy to move your car one mile as there are other engine efficiencies or inefficiencies to take into consideration. In reality, the best comparison is through testing with both gasoline and different ethanol blends. This calculation was merely to put some perspective on the price of ethanol.

Outside of these studies, the EIA describes its take on the rising price of gasoline and its causes (note the lack of mention of ethanol) "Some of the factors contributing to rising crack spreads (or margins) for gasoline, and therefore to rising retail gasoline prices, include:

- **Refinery outages.** There have been multiple refinery outages, both planned and unplanned, that reduced U.S. capacity to manufacture gasoline.
- **Global demand for petroleum products.** Year-over-year global product demand is up, and further rises are expected. That rise in demand affects domestic refinery utilization rates, maintenance needs, and product balances.
- **Prior low crack spreads.** Throughout much of November and December 2012, gasoline crack spreads were very low, and in some cases negative (a barrel of gasoline was worth less than a barrel of Brent crude oil)." (US EIA, 2013)

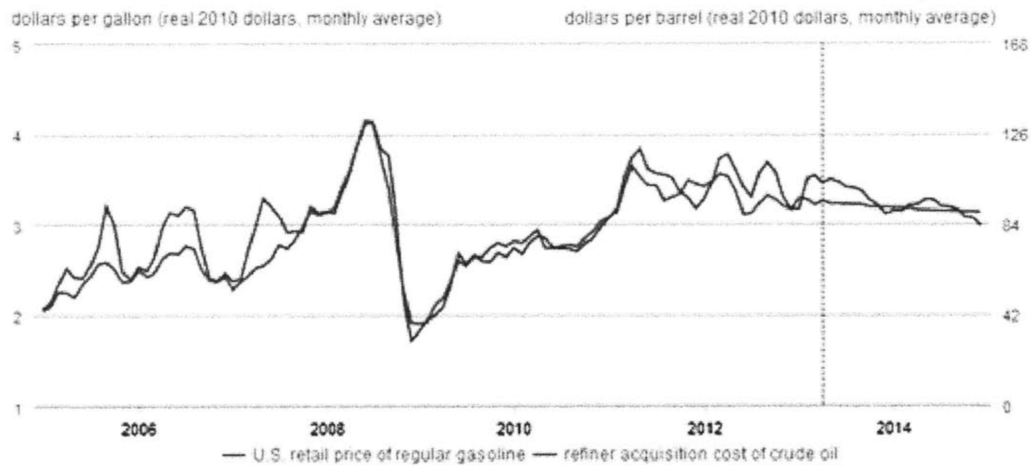
The graphic below from the US EIA helps show the impact of various characteristics on the price of a gallon of gasoline.

Figure 17. What do we pay for in a gallon of regular grade gasoline? (US EIA, 2013)

In 2012 the price of crude oil accounted for sixty-six percent of the price of gasoline while refining costs (which may partially include other ingredients added at the refinery such as ethanol) only accounted for 12 percent of the cost of fuel. The other contributing factors besides crude are federal and state taxes, refining costs and profits, and distribution and marketing.

Additionally Figure 18 below includes data from the EIA which shows how closely gasoline prices fluctuate with the cost of crude.

Figure 18. US Retail Regular Gasoline Prices and Refiner Acquisition Cost of Crude Oil[28] (US EIA, 2013)



Ethanol prices are impacted by implications from the RFS2, but it was designed to give some flexibility in the mandatory amounts of biofuels through the RIN credits, which were intended to alleviate price spikes. It allows blenders to purchase RIN credits in years that they need them or to store them for years when there is a deficit- for example in the case of the Midwest drought in 2012, or other foreseeable harvest-limiting set of conditions. In 2012 there was a drought of great impact across the Midwest, substantially depleting the fall corn harvest resulting in higher prices and availability of both corn and ethanol. Many people called for the removal of the RSF2 mandate for 2012, such as the National Council of Chain Restaurants due to the increase in corn prices. This information was compiled in an industry study performed by Pricewaterhouse Coopers and showed that the impact on an individual fast food ("quick service") restaurant could be between $18,190 and $2,894 annually. An average fast food restaurant pulls in $1,252,312 in annual revenue with an

[28] Assumes a typical $1 per gallon markup of gasoline over the refiner acquisition cost of crude oil (US EIA, 2013)

average annual spending of $181,869. This represents approximately a 10% increase in spending or a decrease of 1.4% of revenue in the worst case scenario. (Pricewaterhouse Coopers, 2012).

However despite concerns from different industries such as the chain restaurant industry, the EPA ruled in 2008 and again 2012 (EPA, 2012) in the face of one of the largest droughts on record, that it would maintain the mandate. The EPA justified its decision because its research indicated that waiving the RSF mandate would have little impact on the economy or on corn prices (EPA, Office of Transportation and Air Quality, 2012).

Studies from Iowa State University show that "Removal of the [RFS2] mandate decreases corn prices by $0.58 per bushel relative to the flexible mandate average corn price- a decline of 7.4 percent. Ethanol prices only drop by $.15 per gallon, and ethanol production only declines by 500 million gallons." (Babcock, 2012) The EPA keeping the mandates, helps create consistent demand and eliminate bullwhip effects from fluctuating demand and creates more stability for investors as well. Determining the exact amount of impact ethanol has on gasoline and food prices is difficult to determine because of many other factors including indirect effects. Some studies say it decreases the price of gasoline, most say it increases the price of food, but the price of crude has a much larger effect on all of these aspects. Eliminating the dependence on foreign oil and creating a more diverse energy portfolio through solutions like ethanol can help mitigate huge price fluctuations which can benefit consumers in the long run.

5. Ethanol Environmental Impact

Though ethanol has both social and economic impacts to consider, one of the most fundamental considerations is whether ethanol does in fact benefit the environment over the alternatives. In this chapter we shall look at different lifecycle analysis (LCA) studies to determine the environmental impacts through two lenses; the first, ethanol's net energy balance an examines the amount of energy input to generate the fuel versus the net amount of energy captured from the fuel. And the second, its net greenhouse gas (GHG) emissions which today focuses primarily on carbon dioxide emissions.

These shall be compared against gasoline and other transport fuel alternatives. The US EPA defines an LCA as "… a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential environmental impacts associated with identified inputs and releases
- Interpreting the results to help you make a more informed decision." (US EPA, 2012)

The system boundaries, or in other words the definition of what is included in each model, depend on the author of the model and vary depending on the LCA study. This makes it difficult to compare different studies against each other, as well as even different types of ethanol because of the variation in different processes, transportation distances and other things that impact its net efficiency. The following chapter will examine some of these differences so the reader can understand ethanol's environmental limitations in more detail.

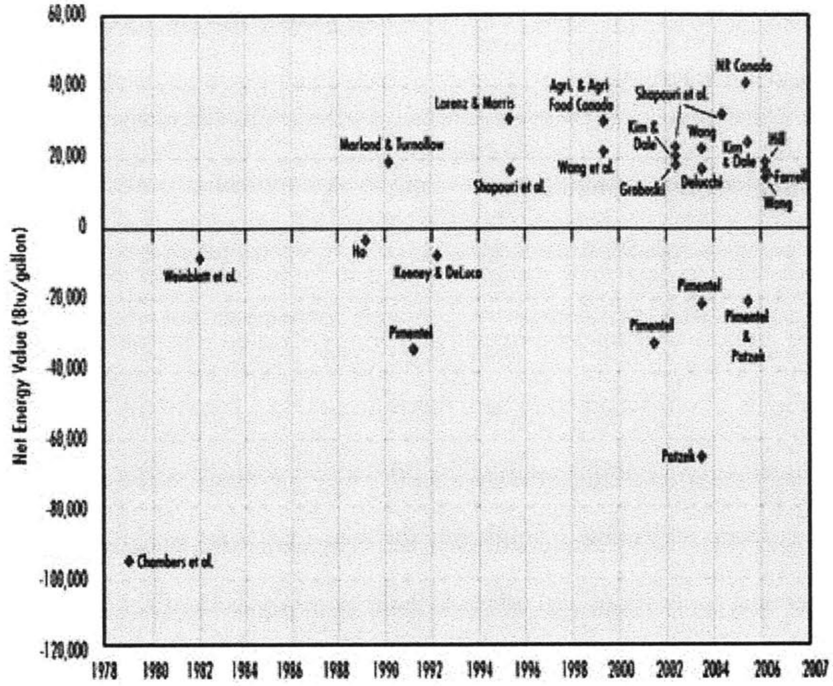
It is very important with renewable fuels like ethanol to look at the entire production process and identify whether the proposed solutions is causing more environmental harm than the initial problem. This should include both direct and indirect impacts. Part of the problem with new technologies attempting to replace gasoline is that there is no perfect solution; each has their benefits and drawbacks. Unfortunately this can create an environment that stalls, waiting for the "perfect" technological solution. Instead it is important to continue developing promising technology that will continue to improve as developments mature and evolve. That being said, it is of critical importance to continually evaluate solutions as they progress to avoid causing more harm than good over the long term.

5.1 Net Energy Balance: More out than in?

Many studies have been done to determine the net energy gain (or loss) from ethanol. A net energy loss would indicate that the process consumes more energy than is generated. The source of discrepancies between different studies is often attributed to how the author defines the system boundaries. In other words- what all is included as energy inputs during the production phase. For example, some studies take into account things like the carbon released to manufacture the farm machinery used for harvest and pesticide/fertilizer chemical applications and others include by-products like the distillers grains left over from the distilling process and are used for livestock feed.

Below is a chart that summarizes some of the prominent studies prior to 2007. This chart was printed by Argonne National labs whose Principal Investigator is Dr. Michael Wang with support from the US Department of Energy's Office of Energy Efficiency and Renewable Energy. It shows some of the major studies prior to 2007 that focused on determining the net lifecycle energy balance of corn ethanol. The only studies that were found to have a negative net energy value were either done prior to 1993 or were authored by Pimentel and Patzek. Many scientists have faulted Pimentel's studies of using outdated data for both ethanol plant efficiencies and farm yields, and not including by-products such as distiller grains that can be used for animal feed.

Figure 19. Comparative Results of Corn Ethanol Fossil Energy Balance Studies (Argonne National Labs, 2007)



The Wang study is based on the GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) model created by Argonne labs. This GREET model is a peer-reviewed model that was designed to create a standard that "allows researchers to evaluate various vehicle and fuel combinations with a consistent methodology." (Argonne National Laboratory, 2007). This model evaluates net energy as well as net greenhouse gas emissions. See next section for more information on the different models and the GHG emissions used for Life Cycle Analysis.

5.2 Life Cycle Analysis: Net Green House Gas Emissions Less than Gasoline?

Aside from the net energy balance of ethanol, it is important to evaluate net GHG emissions. This is critical in determining the net environmental benefit of ethanol. Some models created focused primarily on the Life Cycle Analysis in order to analyze both GHG emissions and net energy in versus energy out. This involves defining the boundaries of the system and each model does so differently. See Table 13 for a list of the more popular models available in the EU and US along with the research center or university that sponsored them.

GREET and BESS are both peer-reviewed models that are available for the public to download and input different parameters and attempt to quantify the environmental impacts of different biofuels (Liska, et al., 2009). The BESS (Biofuel Energy Systems Simulator) model was last updated in 2009 and GREET was last updated in 2012. (Argonne National Laboratory, 2012)

GREET is sponsored by the US Department of Energy and Argonne National Laboratory. BESS is sponsored by University of Nebraska-Lincoln. Both were designed to help producers and regulators evaluate their conformance with LCFS and RFS2 mandates of reducing GHG emissions. The GBAMM and EBAMM were designed to compare the BESS and GREET models by a professor at Berkley (Plevin). The findings show that there is some discrepancy between the two models, however they have fairly similar results. The FASOM model is used primarily to show the changing land use of the US and associated emission impacts. It is used in combination with the GREET model for the EPA to assess ethanol producers adherence to the RFS2 mandate. That is a critical part of the RFS2 standard; it does not just mandate the use of biofuels, but that the biofuel must meet a specific reduction in carbon footprint reduction as well.

Table 13. Popular Lifecycle Models

Year	Model	Name of Model	Model Purpose (Used by)	Name of Institution Created By	PI
2008	BESS	Biofuel Energy Systems Simulator	Energy Impact of Biofuel	University of Nebraska Lincoln	Liska
1996-2012	GREET	Greenhouse Gases, Regulated Emissions, and Energy use in Transportation	Net Greenhouse Gas Emissions and Energy Impact of Transportation Fuels	Argonne National Laboratory	Wang
2008-2009	CA-GREET	California-GREET 1.8	Net Greenhouse Gas Emissions (Used by CA EPA)	California Air Resources Board & Life Cycle Associates	Wang et al
2009	GBAMM	GREET-BESS Analysis Meta-Model	Compares GREET and BESS	Berkley	Plevin
1995-2012	FAPRI	Food and Agricultural Policy Research Institute	Land Use Change in US (Used by US EPA)		
1996	FASOM	Forest and Agricultural Sector Optimization Model	Land Use Change in US (Used by US EPA)	USDA Texas A&M	Darius Adams Ralph Alig Bruce McCarl Brian C. Murray
2008	GTAP-AEZ	GTAP-Agro Ecological Zones	Net Land Use Change (Used by CA EPA)	Purdue University	Hertel Lee Rose Sohngen
2010	RSB Methodology	Roundtable for Sustainable Biofuels GHG Calculation Methodology	Net Greenhouse Gas Emissions (Used by RSB)	RSB	Emmenegger Reinhard Zah
2011	OPGEE	Oil Production GreenHouseGas Emissions Estimator	Net Oil Greenhouse Gas Emissions (Used by CA EPA)	Stanford University for California Air Resources Board	El-Houjeiri Brandt
1987-2013	GHGenius	GreenHouse Genius: A model for Lifecycle Assessment of Transportation Fuels	Net Greenhouse Gas Emissions (Used for Canada)	Natural Resources Canada	Delucchi Levelton
2009	GTAP-E	Global Trade Analysis Partners- Energy	Economic Impacts of Reducing Greenhouse Gas Emissions with Policy	Purdue University	Alexander McDougall Golub

5.2.1 Models and Results

Part of the problem initially with many of the lifecycle models is that none of them took into account Indirect Land Use Change. Today, more models are being updated to include GHG emissions due to Land Use Change. These include FASOM, FAPRI, CA-GREET and GTAP-AEZ. FASOM's main function is to look at policy impacts of carbon sequestration within the US through the forest and agriculture sectors. "The FASOM Model initially was developed to evaluate welfare and market impacts of alternative policies for sequestering carbon in trees but also has been applied to a wider range of forest and agricultural sector policy scenarios." (Adams, Alig, Callaway, McCarl, & Winnett) Some studies that have attempted to take into account land use issues include Iowa State University, California's version of GREET (CA-GREET) and the US EPA which uses a combination of both the GREET model and the FASOM models. Given the complexity and variability of the land use issue, most models report GHG emissions due to land use changes separately.

Iowa State University published a study looking at the wider effects of ethanol policies and system boundary definitions and concluded that it is possible to generate more GHG emissions depending on boundary definitions. "If geographical limits are expanded beyond Iowa, then corn ethanol could generate more GHG emissions than gasoline. These results highlight the importance of boundary definition for both LCA and SWA[29]." (Feng, Rubin, & Babcock, 2010). This finding is corroborated by results by California's Air Resources Board for the LCFS. They provide look-up tables on their website for the carbon intensity results for different fuels with different processing methods.

Additionally a very comprehensive study was done by Purdue researchers using an adaptation of the GTAP model which had input from Dr. Wang[30], and attempted to assess the impact from LUC on GHG emissions of three types of biofuels, corn ethanol, sugarcane ethanol, and biodiesel. They found: "First, with almost a

[29] Systems Wide Analysis
[30] Dr. Wang was lead author of the GREET model

third of the US corn crop today going to ethanol, it is simply not credible to argue that there are no land use change implications of corn ethanol….This large range taken from another study using similar approaches clearly illustrates the uncertainty inherent in this analysis. It also concludes that zero is not within the error bounds. In other words, we know land use change induced emissions are not zero, but measuring them with high precision is not yet possible." (Tyner, Taheripour, Zhuang, Birur, & Baldos, 2010)

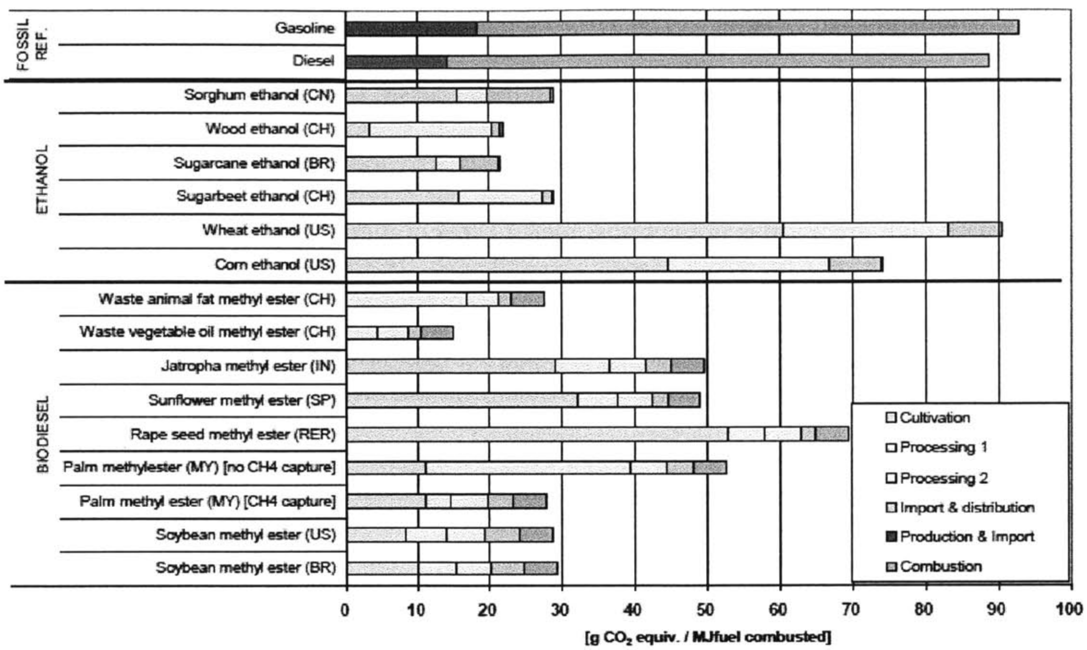
Table 14. Comparison of Carbon Dioxide Emissions According to Different Models (Emmenegger, Lehman, Osses, Reinhard, & Zah, 2010) and **(Liska, et al., 2009)**and **(California Air Resources Board, 2012)**

Emissions	GREET	EBAMM	BESS*	BESS**	BESS***	RSB Methodology	CA-GREET Lowest	CA-GREET Highest
Crop Production	44	37	29	35	34	-		
Biorefinery	43	64	30	31	25	-		
Coproduct Credit	-17	-25	-16	-19	-22	-		
Denaturant	-	-	-	-	-	-		
Land Use Change	-	-	-	-	-	-	30	30
GWI	70	76	45	48	38	74.2	74.7	120.99
Gasoline	92	92	92	92	92	93	99.18	99.18
GHG Reduction	-24%	-17%	-51%	-48%	-59%	-20%	-25%	22%

[1]units in g CO2-eq/MJ combusted fuel
BESS*: MidWest, New Natural Gas
BESS**: Nebraska, Natural Gas
BESS***: Nebraska & N. Gas with wet distiller's grains only
CA GREET Lowest: 2A Application*: Dry Mill; Dry DGS; Raw starch hydrolysis/biogas process fuel;
Amount and type of fuel use, and amount of grid electricity use not to exceed a value the applicant classifies as confidential
CA GREET Highest: Midwest; Wet Mill, 100% coal

These illustrate the different impacts of each step in the process, the RSB presented a useful graphic that shows the results of their lifecycle modeling with respect to carbon dioxide emissions and which part of the process contributes the most (see Figure). These results include cultivation, processing, transport to Europe and the combustion of fuel. However it should be noted this model does NOT include emissions due to indirect land use changes (and even without ILUC notice how large the RSB's estimation of GHG emissions from corn ethanol is). The other thing to highlight with the RSB results is that they are based out of Europe and therefore transporting the fuel to Europe is included in their LCA estimation.

Figure 15. RSB Methodology Results (Emmenegger, Lehman, Osses, Reinhard, & Zah, 2010)



From the above results it is easy to see that it is certainly possible to achieve improvements in the lifecycle emissions of US corn ethanol, but that it could be very possible to also create more, resulting in a worse problem. Many of the earlier models do not take into account land use changes, however more models are starting to account for this. Some do this by combining estimates from a separate land use change model (FAPRI, GTAP-AEZ). California's Air Resources Board (CARB) model which has been designed in order to enforce the LCFS, is one of the most current and detailed models. In addition it makes great steps forward in adding land use change to any evaluation of biofuels in the future.

6. Key Takeaways

In this final chapter, it is important to summarize the data discussed previously in order to distill the essential points and determine if the benefits outweigh the negative impacts. If it appears to be a net gain to society, what characteristics are preventing the proliferation of this beneficial technology? One framework in which to help analyze a product's potential success in the marketplace is through Porter's Five Forces. Porter's Five Forces was originally introduced in 1979 by Michael E. Porter. It was published in the Harvard Business Review to help "understand industry competition and profitability" (Porter, 2008). This framework gives a more thorough strategic analysis than what was commonly used at the time which was a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. Many people are conscious of threats from direct competitors, but there are many other factors that lead to a company's (or industry's) success or failure. Though introduced in 1979 and typically applied to markets that are not commodity driven like the fuel industry, the tool provides a useful framework to analyze the forces at work that may lead to ethanol's success or failure as an valuable energy solution.

6.1 Recap of Ethanol's Goals: Environmental, Social, Political and Financial

In order to evaluate ethanol's effectiveness, it is important to define the goal that ethanol is seeking to achieve. Because it is not just about finding a replacement to gasoline, ethanol also plays an important role in helping the US achieve:

- Decreasing Greenhouse Gas Emissions
- Reducing dependence on Fossil Fuels
- Becoming energy independent
- Stimulating the [Rural] Economy[31]

[31] White House seeing the economic vitality in rural communities wane: "These communities supply our food, fiber, and energy, safeguard our natural resources, and are essential in the development of science and innovation." More information http://www.whitehouse.gov/sites/default/files/docs/rural_communities_06_11_2012.pdf

6.2 Comparison of Benefits and Drawbacks of Ethanol

In order to achieve the aforementioned goals recall the lessons learned from the concepts explored in this thesis.

Benefits

1. Ethanol can reduce greenhouse gas emissions under some conditions and feedstocks
2. Ethanol does have a net positive energy balance (according to the majority of sources)
3. Ethanol can stimulate new job growth in rural areas
4. Ethanol can help the US towards becoming energy independent
5. Ethanol is a less harmful replacement to the chemical MTBE as an additive to gasoline, resulting in lower emissions for gasoline.
6. Price of ethanol is decreasing, sometimes less than the price gasoline per same energy per volume.
7. Ethanol increases crop prices, which can increase farmers wages in the US and world-wide.

Drawbacks

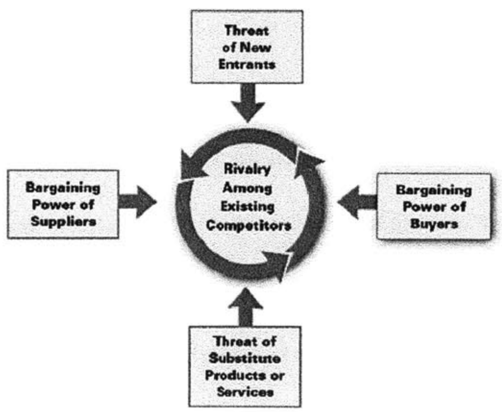
1. Ethanol does increase the demand for land, resulting in difficult to quantify land use consumption
2. Corn-based ethanol does increase the price of corn and possibly other food crops (Studies indicate that food aid reform can help mitigate some food price increases for the poorest.)
3. Ethanol infrastructure for distribution and retail needs upgrading (significant capital investment is needed)
4. Vehicles need modifications to accept ethanol, but vehicle manufacturers are already producing many options that can accept gasoline-ethanol blends of up to 85% ethanol.
5. Energy density of ethanol means that user needs to fill up more frequently and makes it difficult to compare fuel prices between gasoline and ethanol.
6. Ethanol can increase greenhouse gas emissions under *some* conditions.

7. Ethanol Pricing depend on blender's credits and RFS2 mandates from federal government to incentivize blenders to use.
8. Ethanol Prices are dependent upon crop prices which can be weather dependent.

6.3 Porter's Five Forces Analysis for Ethanol

There are five main forces that influence the competition of an industry as defined by Porter. These include the Threat of New Entrants, Power of Suppliers, Power of Buyers, Threat of Substitutes, and Rivalry among Existing Competitors. The following section examines the ethanol industry through the lens of these Five Forces in order to identify some things to help ethanol succeed in the marketplace.

Figure 20. The Five Forces That Shape Industry Competition (Porter, 2008)



First, it is important to define ethanol's suppliers and consumers for this analysis. In this case, suppliers primarily are: farmers including corn (US), sugar (Brazil) and other plant feedstocks both domestic and potentially global. Other suppliers could include commodities such as energy or water to run the plant and unique ingredients such as enzymes, and other consumables for the ethanol conversion process and which can give ethanol companies a competitive advantage. Buyers include refiners and blenders and also buyers of the distiller's grain and other byproducts that can be generated from the ethanol plant. Customers to the refiners are gasoline retailers and their customers are the end user purchasing fuel to fill their vehicle (or other non-road motor). It should be noted that there is a difference between ethanol's customer (who in this case is also their competition: refiners and blenders) and the user of ethanol. Competition for this brief analysis includes compressed natural gas (CNG), gasoline, and electricity.

6.3.1 Threat of New Entry

The threat of new entry can be described as how difficult it is for a new competitor to enter the industry. It is influenced by seven major barriers: supply-side economies of scale, demand side benefits of scale, customer switching costs, capital requirements, incumbency advantages independent of size, unequal access to distribution channels and government policy (Porter, 2008).

Supply side economies of scale are when a company can command lower prices from their suppliers because they consume large volumes and can negotiate a better price. This helps bring down prices for the company and deters new entrants because in order to achieve the same low prices they would need to enter the market at a large scale or they will suffer a cost disadvantage. When comparing ethanol to competition for *supply*, the competition in this case is food crops. Farmers sell their crop to food buyers and ethanol buyers. It is important for ethanol suppliers to understand that their raw materials compete with food for supply. Ethanol competitors (gas, CNG, electric) utilize a different supply chain then the ethanol industry. Given this, it would be a very high barrier to entry for any new market entrant to compete with ethanol for crops because of what a substantial demand ethanol represents. This highlights that suppliers limit the industry. Ethanol faces needing more inventory than what is currently available, which requires further technology developments for cropland output and the efficacy of plant to ethanol conversion. It is important for the ethanol industry to work on sourcing without being in direct competition with the food industry.

Demand benefits of scale are when a company's demand increases because of its larger size. There are benefits derived from being large, such as appearing to be more stable and more reliable. Additionally a consumer benefits from being a part of a large network because of compatibility with more users and can take advantage of more network externalities with the larger provider. Certainly in the case of ethanol the larger the industry gets and the more customers it can collect, it can compete more effectively with other competitive technologies such as gasoline, CNG, or electric hybrids. With a larger customer base, there are more investments in infrastructure, more methods of transportation, more retail outlets, more demand to manufacture vehicles that are ethanol compatible, and more places that will repair or maintain these vehicles. The faster the ethanol industry can ramp up, the faster it will benefit from its scale and compete more aggressively with other substitute technologies.

Customer switching costs refer to the upfront or fixed costs a customer must make in order to switch technologies. In ethanol's case, the customer actually refers to the refiners and blenders which have high switching costs to handle ethanol. Switching costs include costs for improving storage tanks, distribution or transportation equipment and the costs of switching fuel retailer infrastructure. One example is the case of underground gas tanks or pump components[32]. Many of these switching costs are getting addressed for ethanol because of the RFS2 mandates, resulting in the US infrastructure beginning to evolve so that it can transport ethanol. Interestingly, gasoline refiners represent both its competition as well as its customer, which creates a unique relationship.

While the ethanol market is protected by the RFS2, gasoline provides an assist to the ethanol industry in that it allows the consumer to gradually adapt to the fuel, and become familiar with its benefits (like added torque) and some of its drawbacks (like reduced energy content). It would be beneficial to develop business plans that treat gas companies as strategic partners and develop ways to foster this relationship where possible.

The ethanol industry has made great strides in reducing switching costs through the use of unit trains which put the cost of transporting ethanol much closer to the cost of pipeline transport. When compared with gasoline or electric or CNG the upstream methods of transport already exist for these other technologies (all can be shipped via already established pipelines or electric grid). What doesn't currently exist at scale comparable to gasoline for any of these new technologies is the infrastructure at the point of sale. For CNG,

[32] Example: Kinder Morgan costs were $10 million for 100 miles of pipeline and even then there are still technical limitations to accommodate ethanol throughout this short length of pipeline (Mahon, 2013)

a refueling station can cost anywhere from $10,000 to $2 million (Alternative Fuels Data Center, 2013) and Electric recharging stations are estimated to be between $1,000 to $7,000 with a total installed cost of anywhere from $15,000 up to $100,000 for a fast-charging unit.

User switching costs from gasoline to ethanol have been reduced due to an increase of flex fuel vehicles and the proliferation of ethanol refilling stations. There are 2,339 refueling stations offering ethanol, compared with 578 compressed natural gas stations. Ethanol, however, is at a disadvantage with 5,880 electric stations (US DOE , 2013) compared with approximately 156,065 gasoline refueling stations (National Petroleum News, 2013). Compressed natural gas vehicles are currently at a disadvantage to ethanol with approximately 8 million Flex Fuel Vehicles on the road and 112,000 natural gas vehicles (both compressed and liquid) in the US. The cost of converting existing vehicles to FFV is on the order of $1,300 (FlexFuels US) while CNG is approximately $5000 (American Alternative Fuel, 2012). This gives FFV a much greater advantage, especially since FFV may easily be installed at almost zero cost for future fleets. Thus, with this lens ethanol has an advantage over CNG, but it is still at a disadvantage to electricity and gasoline in this respect. It should also be noted that alternative fuel stations are increasing in number, while gasoline stations have been decreasing in number over the last seven years (National Petroleum News, 2013). Ethanol would again benefit against other technologies, the faster the distribution network can be developed.

Capital Requirements are the amount of fixed costs needed to start an ethanol plant and get it running. The capital costs ethanol has sustained over the last decade are substantial. On the other hand capital costs for gasoline refining and distribution are considered "sunk[33]" since the petroleum industry is much older. However the petroleum industry still faces substantial costs for continuing exploration and technology development for tight gas and unconventional oil extraction (shale gas, etc). As the ethanol industry matures, capital investment costs have plateaued but there are still substantial development costs needed for cellulosic processing plants to come online and for ethanol to achieve lower costs than gasoline. Capital costs still need

[33] In economic terms "sunk" costs are no longer considered in the balance sheets- they have already been paid out and therefore should not be included when making financial decisions.

investments in the 5 basic areas of the ethanol supply chain: sufficient growth of feedstocks, feedstock transport, more and improved ethanol plants- with the development of cellulosic ethanol plants specifically, increasing capacity on railways, and the ethanol dispensing infrastructure. One study performed by the National Renewable Energy Laboratory (NREL) completed a study comparing the amount of capital costs required to achieve varying amounts of cellulosic ethanol by 2017 (Sandor, Wallace, & Peterson, 2008). Their baseline model to achieve 500 million gallons per year estimated would require a combined $4.3 billion investment from private capital funding, along with $24.7 billion in government spending for a total of $29 billion. To achieve higher quantities of cellulosic ethanol it would require higher levels of capital investment. At the highest output rate they studied, 7.2 billion gallons of cellulosic ethanol, the study estimated that there needed to be a combined $27 billion dollars of private investment along with $24.4 billion in government spending for a total of $51.4 billion.

One estimate from the RFA puts the next generation (cellulosic) of ethanol plants, at approximately five times the cost of "grain-based facilities". (Dinneen, 2010) The ethanol industry requested loan guarantees up to $250 million representing 90% of the cost of a cellulosic plant.

On top of the capital costs of a new processing plant are the additional investments to the transport phase, the GAO reports on EPA estimates of, "Under its primary control case, EPA estimated that the necessary spending on transportation infrastructure due to increased ethanol consumption would be approximately $2.6 billion." (GAO, 2011)

And the refueling infrastructure would also need upgrades. This was estimated at around $100,000 to replace a UST and $20,000 to purchase a new a fuel dispenser (GAO, 2011). If ten percent of today's approximate 156,000 stations invested in these infrastructure changes the total cost would be about $1.9 billion.

Comparing ethanol with electric and compressed natural gas (CNG) both of these also have startup costs in order to develop the refueling infrastructure. However, the upstream infrastructure of both of these technologies already exists. Ethanol has a disadvantage next to these other technologies in this respect.

Incumbent Advantages Independent of Size refers to other logistics advantages. Clearly gasoline has the advantage in this case against all other entrants as it has been the existing solution. The faster ethanol can penetrate gasoline's market, the more of an advantage ethanol will have against other potential entrants (CNG, electric). Because ethanol is required to be blended with gasoline, ethanol can leverage this to its advantage, but it becomes increasingly more difficult with higher percentages. Again speed of deployment will give ethanol an upper hand against other technologies with respect to this competitive advantage.

Unequal access to distribution channels addresses the company or industry's ability to deliver their product relative to their competition. Given the size and first mover advantage gasoline currently holds over other technologies will be difficult for ethanol to penetrate. However, because of its unique partnership with gasoline (RFS2 and Clean Air Act mandates) ethanol can leverage some of gasoline's distribution channels to its advantage over other entrants. Because of the much longer refueling time, electric refueling stations actually are typically set up at very different locations than a gas station. They are typically installed at shopping centers, work places or homes where users can leave their vehicles for the hours required to refuel their vehicle.

Government Policy refers to legislation that is in place to encourage or discourage different technologies. Currently the legislation benefits ethanol tremendously and requires gasoline refiners to include ethanol in its own product. This means that refiners/blenders MUST help the ethanol industry find ways to distribute its product. This discourages other entrants to this market. Currently there are incentives in place for CNG and electric through subsidies and CAFE standards, but there is no mandate *requiring* these other technologies to be included in the current energy solution like ethanol or other biofuels. Ethanol has an advantage due to this policy over other new technologies.

6.3.2 Power of Suppliers

The power of supplier refers to the supplier that has a substantial market share has more influence on determining the terms of an agreement with respect to price, quantity sold, etc. Given the present condition of the industry, US farmers benefit from a strong hand over the ethanol industry because ethanol consumes the majority of their output. This emphasizes the dependence that the US ethanol industry has on its suppliers. Possible ways to alleviate this dependence is through developing other suppliers globally- such as Brazil- though while still reducing the net size of the carbon footprint or through the development of cellulosic ethanol, which would increase the amount of usable feedstock. Diversifying the supplier base may add complication to the supply chain, but can help mitigate risk and dependence on one set of suppliers. As demonstrated from the drought of 2012, a shortage of product can create price spikes and spreading the dependence over suppliers would help mitigate these risks.

6.3.3 Power of Buyers

Buyers can weld large amounts of power if they buy a substantial percentage of a company's output. In this case, by law, gasoline companies must purchase all of the ethanol industry's output up to the quantities mandated by the RFS2. This mandate creates a relatively secure market for the ethanol industry (provided that the law does not change). It also forces a lot of responsibility on the refineries and refueling stations to figure out how to effectively transport, store, distribute, and sell the mandated amounts of ethanol. In this case buyers would normally have the upper hand given that they purchase all of the output, but because it is law that they purchase it, this somewhat restricts their bargaining power. It also creates a competitive advantage for ethanol over other potential entrants like electric and CNG.

6.3.4 Threat of Substitutes

The threat of substitutes in today's dynamic energy environment as it searches for the best alternative to gasoline is substantial. There are not only other technologies to compete against such as CNG, electric and gasoline, but there are also alternatives such as taking public transportation, biking, or walking. The industry might also consider these choices and develop strategic partnerships with public transportation providers, such as metros, rapid transit, or school bus fleets. Given the difficulty with ethanol distribution perhaps it is possible to penetrate markets through centralized refueling stations such as bus depots, garbage collection fleets, or other government or nongovernment vehicle fleets. This is a very competitive space so, in order to succeed, the industry must continue to innovate, provide clear advantages on price, carbon footprint and develop creative distribution channels and partnerships.

6.3.5 Rivalry Among Existing Competitors

Because of the relative youth of this marketplace, there are many new ethanol suppliers vying for the same supply and same customers. They are facing tight margins and limited profitability in order to keep ethanol price competitive with gasoline and therefore must quickly hone their supply chains and technologies in order to compete with other ethanol providers in this space. It is critical for ethanol processing plants to be lean, efficient, and continue to invest and develop their technology.

As more studies highlight differences in greenhouse gas emission balances through the lifetime of different ethanol technologies as well as ethanol industries impact on land use, it will be important that each company is proactive about studying and improving their GHG emissions. For example, ethanol plants using coal fired technologies will be at a distinct disadvantage if they do not upgrade their sources of power. The industry as a whole must be concerned with competition from other technologies. Ethanol plants independently need to work to be competitive through continued innovation and process improvement. It is clear that there is a big push from governments, researchers and consumers, for the ethanol industry to achieve viable cellulosic solutions. It will help the industry gain favor through the lack of direct competition with food, will open up its supplier base (will have more accessible supply since it can use entire plant) which will free up competition with other land uses. It is these types of technology innovations that will determine the winners and losers within the ethanol industry itself.

6.3.6 Porter's Five Forces Conclusion

It is clear that ethanol has many advantages over other technologies both existing and potential future entrants that help it succeed in the marketplace. In order to continue its success, the ethanol industry can use these advantages and develop strategy to help leverage these strengths through creative and innovative market plans. It puts ethanol in a good place in that it will likely be around in years to come, but is dependent on developing strategic partnerships with farmers and gasoline companies alike and continued government backing. It also relies on continued technological improvements in order to achieve better environmental and financial sustainability.

On the other hand ethanol also has some very difficult and complex supply chain hurtles to overcome, particularly when compared with other technologies such as CNG and electric vehicles. Because of the corrosive and water absorbing properties of the fuel it presents many complications with storage vessels, dispensers, transportation, and in use. Some ways to offset these issues may include first raising consumer awareness. Some studies have shown that many consumers are not aware they are driving a Flex Fuel Vehicle. Many consumers may not understand the benefits of purchasing ethanol, and as some consumers are willing to pay a bit more to offset their carbon footprint, there are ways to educate consumers of the environmental benefits of purchasing ethanol. In addition many consumers may find it difficult to compare prices with gasoline given the lesser amount of energy content then gasoline or be surprised to find out that they will suffer lower fuel economy. If expectations are readied for this energy reduction, the consumer may be more willing to accept ethanol's deficiency in this category. Are there better ways ethanol industry can reach out to the average gasoline consumer? Also, in order to encourage ethanol distribution with ethanol's customers, the refiners and distributors, are there ways to help offset some of risk involved with installing ethanol ready tanks? Can refiners be more creative to help financially support their fueling retailers to be ethanol ready? Given the RFS2 mandates are currently the law of the land, gasoline refiners have an obligation to work at ensuring that the required amounts of ethanol are blended into the fuel supply and therefore need to be proactive. Gasoline is essentially a commodity product and it is difficult to compete on much more than price. Refiners could use ethanol to their advantage and actually achieve a competitive advantage aside from price if they can lead the way in incorporating ethanol into their product. Refiners can boast about their environmental friendliness over their competition, better technology, leading the way to meeting RFS2 mandates and avoiding fines will help refiners and blenders keep costs down and beat their other gasoline rivals.

7. Conclusion

This thesis examined the ethanol supply chain and how it interacts with other industries, legislative actions and their impacts, and other contextual information. Given this analysis, it is clear there are many controversial aspects about ethanol and other biofuels for their success and viability in the future. In order to drive the global energy situation towards sustainability both in the marketplace and in the environment, government, industry, and the public must work together to create a plan that takes into account indirect impacts through a systems perspective. Too many times special interest groups do not allow the right policies or legislation to pass that will benefit the greater good in the long run.

Developing countries can learn from the situation in the US and as they start to build up their fueling infrastructure, they will find that it is worth installing ethanol-ready equipment from the beginning. Fuel retailers should install the UST and dispensers when building new sites that are ethanol compatible. Transport vehicles should ensure that the large capital investment they are about to make includes ethanol ready equipment and fittings. Many developing countries can benefit from producing ethanol and developing the infrastructure up front. Growing crops can help farmers in developing countries develop an additional source of revenue besides just for food and developing ethanol processing plants can enable these countries to sell to other countries with biofuel mandates such as the EU or the US. Biofuels can provide another revenue source for their country. It is much cheaper to invest the money up front instead of having to switch out components or repurchase equipment altogether. This will maximize the fueling stations readiness for the future. Ethanol is mandated in many countries already and the amounts will likely continue to grow, as technology evolves and develops better cellulosic solutions. Ethanol provides many countries a way to decrease their reliance on foreign and non-renewable fuel sources and develop their economies and rural communities. In the US given the approximate costs of upgrading the transportation infrastructure at $2.6

billion and another $1.8 billion in upgrading a minimum number of refueling stations for a total of $4.4 billion of capital expenditure, it would take a $.03 tax for one year on each gallon of gas to pay off the infrastructure upgrades. Countries looking ahead would benefit from preparing for an ethanol future and preparing its infrastructure now.

In addition to recommending that developing countries foster an ethanol-ready supply chain, it is important that they also create programs that monitor the impact of biofuels on land consumption for cultivation. Land use change has such a large impact on ethanol's net environmental impact that in order for biofuels to have their intended effects, it is important that this is monitored and programs are put in place to conserve bio-diverse land such as rainforest and wetlands. The world today is such an interconnected community, countries rely so heavily on each other for different commodities, that almost all countries are dependent on each other for different crops and other resources. One country can't decide to stop exporting one crop without impacting people in a land across oceans. So it would be advisable that countries work together and develop biofuel strategies together to help offset risk from severe weather or pests, technology sharing and to ensure that the biofuel mandates don't put so much pressure on developing countries infrastructures that the negative unintended consequences don't outweigh the good.

One concept to consider is to look at transportation fuels regionally within the US. For instance, electric cars don't net an improved carbon footprint if the electricity they consume is from coal burning plants. Perhaps Electric cars are the solution in states that get their electricity from renewables like hydropower and wind energy. Perhaps ethanol should be the transportation fuel primarily in the Midwest states. Would US energy policy benefit by incentivizing usage more regionally? Perhaps this way it could help offset some of the unintended consequences of current energy policies.

Which leads to the final question, after studying this complex industry -does the ethanol industry benefit society more good in the long run?

Under the right set of constraints, ethanol can help achieve the goals of energy independence, reduce carbon emissions, dependence on nonrenewable fuel sources, and help strengthen our rural communities. Corn-starch based ethanol is a stepping stone on the path to a better ethanol solution, but a necessary part of the process. It is helping to ramp up infrastructure changes, in order to increase efficiency in the ethanol supply chain and to help create consumer awareness of the differences between ethanol and gasoline and helps to increase demand for Flex Fuel Vehicles. In order for Cellulosic ethanol to come on line, there needs attention to be paid to the discrepancy between consumer demand and the mandated supply. With ethanol representing nearly 30% of the total fuel supply[34] in 2022 and studies showing E85 sales plateauing after it achieves about ten percent availability in the marketplace, where will the consumer demand come from? Likely fuel stations will have to continue to sell E10 because of nonroad motor demand. As E20 and E30 become more available, it is likely consumers will begin to understand the fuel economy differences between gasoline and ethanol according to the study by the EIA (Liu & Greene, 2013). Demand for these higher blends may not exist unless after the consumer learns about the energy economy differences, and ethanol can become cheaper than gasoline which can then be communicated to the consumer in a way they can easily compare the effective prices between gasoline and ethanol. It is understandable investors in cellulosic ethanol are wary of this gap between likely consumer demand and anticipated supply. This is the challenge for industry and government groups to resolve because cellulosic ethanol holds the potential to relieve some of the land use change and food versus fuel issues.

And as cellulosic ethanol comes online, it is important to continually monitor the impacts on land use, food prices and other potential negative impacts. Examples of potential negative impacts include increased chemical inputs for farming and any unintended effects of genetic modification to improve crop yields. Substantial press is dedicated to criticizing ethanol for one aspect or another however it is important to look at the technology holistically and with all end goals in mind. The critical voices are important to keep the

[34] Gasoline used for Transportation was approximately 99bgals in 2009. Mandated amounts of biofuel are 36bgals with about 4 of those to biodiesel. The remainder will likely be ethanol similar fuels.

industry aware of unforeseen negative impacts. However, the question should not be whether to kill the industry or not, it should be how do we make the industry right? How do we avoid these negative impacts and make the right legislation and the right changes to mitigate these negative consequences? Today's energy portfolio is diverse and there is resiliency in this diversity. It is important to continue to develop and improve these solutions and ethanol is a strong part of this energy evolution.

So what is the answer? From this research, ethanol has the potential to net more harm than good, but also has the potential to do more benefit than the alternatives. Doing nothing is one possibility and is worse than starting with an imperfect solution like ethanol and improving on it. One solution could be in reducing our energy demand across the board through conservation and improved energy-saving technologies, incentivizing people and businesses to reduce their energy consumption. But cutting the world's energy consumption to eliminate gasoline and fossil fuel any time soon is likely impossible. This leads to the next best option, combining the power of conservation, along with improving energy technologies such as ethanol and other alternative energy solutions.

Appendix 1. RFS2 Mandates (Schnepf & Yacobucci, 2012)

(In billions of gallons)

Year	RFS1 biofuel mandate in EPAct of 2005	RFS2 biofuel mandate					
		Total renewable fuels	Cap on corn starch-derived ethanol	Portion to be from advanced biofuels			
				Total non-corn starch	Cellulosic	Biomass-based diesel	Other[a]
2006	4.0	—	—	—	—	—	—
2007	4.7	—	—	—	—	—	—
2008	5.4	9.00	9.0	0.00	0.00	0.00	0.00
2009	6.1	11.10	10.5	0.60	0.00	0.00	0.10
2010	6.8	12.95	12.0	0.95	0.0065[b]	1.15[c]	0.29
2011	7.4	13.95	12.6	1.35	0.006[d]	0.80	0.54
2012	7.5	15.20	13.2	2.00	0.00[e]	1.00	1.00
2013	7.6 (est.)	16.55	13.8	2.75	0.014[f]	1.28[f]	1.46
2014	7.7 (est.)	18.15	14.4	3.75	1.75	[g]	1.00
2015	7.8 (est.)	20.50	15.0	5.50	3.00	[g]	1.50
2016	7.9 (est.)	22.25	15.0	7.25	4.25	[g]	2.00
2017	8.1 (est.)	24.00	15.0	9.00	5.50	[g]	2.50
2018	8.2 (est.)	26.00	15.0	11.00	7.00	[g]	3.00
2019	8.3 (est.)	28.00	15.0	13.00	8.50	[g]	3.50
2020	8.4 (est.)	30.00	15.0	15.00	10.50	[g]	3.50
2021	8.5 (est.)	33.00	15.0	18.00	13.50	[g]	3.50
2022	8.6 (est.)	36.00	15.0	21.00	16.00	[g]	4.00
2023	—	[h]	[h]	[h]	[h]	[h]	[h]

Source: RFS1 is from EPAct (P.L. 109-58), Section 1501; RFS2 is from EISA (P.L. 110-140), Section 202.

a. "Other" advanced biofuels is a residual category left over after the ethanol-equivalent gallons of cellulosic and biodiesel biofuels are subtracted from the "Total" advanced biofuels mandate.

b. The initial EISA cellulosic biofuels mandate for 2010 was for 100 million gallons. On February 3, 2010, EPA revised this mandate downward to 6.5 million ethanol-equivalent gallons.

c. The biomass-based diesel mandate for 2010 combines the original EISA mandate of 0.65 billion gallons (bgals) with the 2009 mandate of 0.5 bgals.

d. The initial RFS for cellulosic biofuels for 2011 was 250 million gallons. In November 2010 EPA revised this mandate downward to 6.0 million ethanol-equivalent gallons.

e. The initial RFS for cellulosic biofuels for 2012 was 500 million gallons. In December 2011 EPA revised this mandate downward to 10.45 million ethanol-equivalent gallons. In January 2013, the U.S. Court of Appeals for D.C. vacated EPA's initial cellulosic mandate for 2012 and remanded EPA to replace it with a revised mandate. On February 28, 2013, EPA dropped the 2012 RFS for cellulosic biofuels to zero.

f. The initial 2013 cellulosic RFS was 1 bgals. In January 2013, EPA revised this mandate to 14 million ethanol-equivalent gals. The 2013 biodiesel mandate was revised upwards from 1 bgals to 1.28 bgals actual volume.

g. To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.

h. To be determined by EPA through a future rulemaking.

Appendix 2: Summary of Debate on the Impact of Ethanol on Gasoline Prices between Hayes & Du and Knittel & Smith

Date	Article	Abstract
May 2012	The Impact of Ethanol Production on US and Regional Gasoline Markets: An Update to 2012 (Hayes & Du, The Impact of Ethanol Production on U.S. and Regional Gasoline Markets: An Update to 2012, May 2012)	Due to the increase in ethanol and using a 2009 economic model by Du & Hayes with price data from 2000-2011, gasoline prices were reduced by $.29/gallon. Using data from 2011 only, it showed prices were lower on average by $1.09.
July 2012	Ethanol Production and Gasoline Prices: A Spurious Correlation (Knittel & Smith, July 2012)	The economic model published by Du & Hayes contains false assumptions and incorrect statistical correlations.
Aug 2012	Response to "Ethanol Production and Gasoline Prices: A Spurious Correlation" by Knittel and Smith (Hayes, 2012)	Rebut the arguments contained in Knittel & Smith: should have used crack spread (average of gas price & distillates produced by a barrel of crude minus cost of the crude) not crack ratio (gas to crude oil price), accepting industry funding for their study, the effect on prices in 2013 from limiting ethanol supply if RFS2 mandates were relaxed resulting in ethanol plants to suddenly shut down, decrease in ethanol supply would spike prices and others
	Response to Professor Hayes' Response (Knittel & Smith, Response to Professor Hayes Response, 2012)	Rebuts the 21 claims in previous Hayes' first response as to why their argument is credible. Highlights Hayes own statement that some of their claims may be questionable due to some of their assumptions in the model. Presents alternative models.
Sept 2012	Second Response to Knittel and Smith (Hayes, 2012)	Rebuts the 7 alternative models that Knittel and Smith present.
Late 2012	Knittel's Final response (Knittel C. , Response to Hayes' Second Response)	Posts a fake exam question for an undergraduate economics class used to illustrate the assumptions Hayes uses are false.

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