

# **Corn Ethanol Viability: An Analysis of Corn Ethanol as an Alternative to Petroleum Based Fuel in the United States**

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## 1) Introduction

When it comes to ethanol, there is no disagreement about its potential and viability as an alternate fuel source for the future. Due to heightened concern and fears of an American nation dependent upon foreign oil, our government has been promoting ethanol for decades now as an alternative to gasoline. However, is ethanol truly the grand solution to the problem? Ethanol is a form of alcohol, derived from the fermentation of glucose, which can be used as a combustible fuel source for cars. Although ethanol can be produced from a number of sources, the primary fountain for ethanol production in the United States is the corn crop. Dating back to 1908, with the first Model-T car, developed by Henry Ford, we can see early attempts of ethanol as a fuel source. In fact, the engine of the Model-T was originally developed and designed to be capable to run on gasoline, kerosene, and ethanol.<sup>1</sup> However, ethanol production never reached fruition as gasoline prices declined and the era of prohibition retarded the production of ethanol.<sup>2</sup> As a fuel source, ethanol has come a long way since then. In the current state of alternative fuels, ethanol is one of the front-runners, as it has begun to be integrated into the fuel infrastructure of the United States. Specifically, car engines are being developed more widely to be “flex fuel engines,” which are able to use a gasoline-ethanol mixture as fuel. In this paper, we will make a cost benefit analysis on the feasibility of shifting our primary fuel source for ground transportation to e85 using corn ethanol, e85 being a blend of 85% ethanol and 15% gasoline.

There are numerous advantages of ethanol fuel. It can be produced on a large-scale basis domestically, thus reducing use of imported petroleum, and it requires relatively few technological breakthroughs.<sup>3</sup> However, using a food crop as the primary resource in fuel production comes with certain notable drawbacks. Specifically, the negative impact on food prices, the poorer fuel efficiency compared to gasoline, and the environmental impact of ethanol pollution. The debate rests on the argument of whether or not the advantages outweigh the disadvantages and costs of converting to e85 for ground transportation

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<sup>1</sup> Ethanol Fuel History, [http://www.fuel-testers.com/ethanol\\_fuel\\_history.html](http://www.fuel-testers.com/ethanol_fuel_history.html), (December 9<sup>th</sup> 2012)

<sup>2</sup> Ethanol Fuel History, [http://www.fuel-testers.com/ethanol\\_fuel\\_history.html](http://www.fuel-testers.com/ethanol_fuel_history.html), (December 9<sup>th</sup> 2012)

<sup>3</sup> Ethanol Fuel History, [http://www.fuel-testers.com/ethanol\\_fuel\\_history.html](http://www.fuel-testers.com/ethanol_fuel_history.html), (December 9<sup>th</sup> 2012)

purposes. But first, it is important to gain a clear understanding of the production cycle and chemical process in creating ethanol to further support our argument.

Ethanol is created through two distinct yet similar processes: dry milling and wet milling. Although ethanol can be derived from several different sources, corn is the primary source due to its abundance in the United States. The majority of US ethanol is produced through dry milling, as it has a higher efficiency and lower capital and operating costs than wet milling, specifically when producing ethanol.<sup>4</sup> As a result, dry milling is by far the most popular method, and it will be the method focused on during this paper. The process of producing ethanol from corn on a small scale is fairly simple, but in order to produce on a large-scale basis, there must be a rigid step-by-step system in place.

#### *a) Milling*

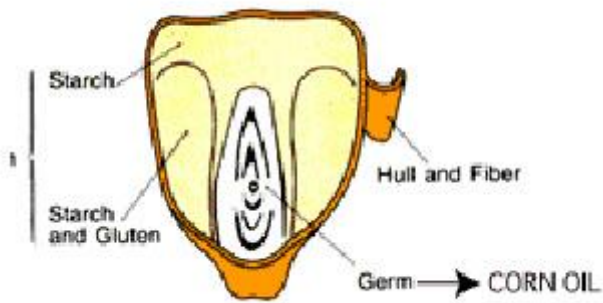
To obtain the end product of ethanol from corn, a series of steps must be taken to convert the starch present in the corn kernel into the simple sugar glucose. More specifically, the corn kernel must first be broken down to allow for the conversion of starch into glucose. Starch is found in nature as “insoluble, non-dispersant granules resistant to enzymatic breakdown.”<sup>5</sup> The starch is protected within the biological makeup of a corn kernel; it is difficult to break down due to its protective barrier. (See diagram below).

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<sup>4</sup> Cole Gustafson, Ethanol Production – Dry versus Wet Grind Processing, <http://www.ag.ndsu.edu/energy/biofuels/energy-briefs/ethanol-production-dry-versus-wet-grind-processing>, (December 9<sup>th</sup> 2012)

<sup>5</sup> Gerald B. Borglum, Starch Hydrolysis for Ethanol Production, [http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25\\_4\\_SAN%20FRANCISCO\\_08-80\\_0264.pdf](http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20FRANCISCO_08-80_0264.pdf), (December 9<sup>th</sup> 2012)

## A KERNEL OF CORN



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Therefore, the starch must first be separated from its counterparts in order to expose it to enzymatic breakdown. This presents the initial step in the production cycle: “milling.”

Once the corn kernels have reached the factory, are offloaded from the trucks, and have gone through the necessary inspection procedures, they travel through grain lines to the “hammer mills.” As the name suggests, the hammer mills grind down the corn kernels into a fine powder referred to as “corn flour.” Within the mill, the kernels are struck by several hammers attached to a shaft which rotates at high speeds, and, as a result, are crushed by the repeated impact.<sup>7</sup> A various alignment of screens allows the separation of the finished corn flour from the oversized materials which repeat another cycle in the mill.<sup>8</sup> This step is a crucial because it exposes the starch from its protective barrier. Now, enzymes are able to attack the starch and break it down further and into the eventual end product of glucose.

### *b) Hydrolysis*

From the hammer mills, the corn flour is transported via conveyer belts to the “cook area,” where the corn flour is soaked in a mixture of water and enzymes to break down the

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<sup>6</sup> The Corn Kernel ,[http://t1.gstatic.com/images?q=tbn:ANd9GcQesmiObsFga8wl-g27e\\_n6PR71GMxYOEdYDbjtmv0EMwhuPd49FLC0D4YpGw](http://t1.gstatic.com/images?q=tbn:ANd9GcQesmiObsFga8wl-g27e_n6PR71GMxYOEdYDbjtmv0EMwhuPd49FLC0D4YpGw), (December 9<sup>th</sup> 2012)

<sup>7</sup> How Does a Hammer Mill Work?, <http://www.hammermills.com/how-does-a-hammer-mill-work>, (December 9<sup>th</sup> 2012)

<sup>8</sup> How Does a Hammer Mill Work?, <http://www.hammermills.com/how-does-a-hammer-mill-work>, (December 9<sup>th</sup> 2012)

starch into sugar (this is the same process used to ferment alcohol). Starch is insoluble at room temperature; therefore, the water is briefly heated in order to weaken the hydrogen bonds of the starch<sup>9</sup>. When the hydrogen bonds are broken, water is absorbed and the starch molecules swell in a process known as gelatinization.<sup>10</sup> The starch is now a gel-like substance which is vulnerable to enzymatic breakdown. With the addition of water, however, another problem arises which must be addressed: the increased viscosity of the substance. The gel-like mash is difficult to work with and process; therefore, the enzyme “alpha amylase” must be added. This enzyme is essential in the production of ethanol because it works against the viscosity by breaking down the long starch molecules into smaller chains. In order to attain the energy from starch molecules, the glucose polymers must first be broken down into smaller sugars, which can then convert to glucose. Alpha amylase breaks down long starch molecules into smaller and shorter polymers, known as dextrans. The breakdown of starch molecules into dextrans reduces the viscosity of the substance. This is referred to as “liquefacing” the solution.<sup>11</sup>

Following liquefaction, the corn mash undergoes temperature changes once more and an additional enzyme must be included. The temperature is cooled to 30 degrees Celsius and the enzyme, glucoamylase, is added to the equation. This enzyme is necessary in order to complete the breakdown of dextrans into the fermentable sugar glucose. Glucoamylase hydrolyzes both alpha-1,4 and alpha-1,6 bonds to “completely degrade the

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<sup>9</sup> Alcohol Production by Yeasts, <http://dwb4.unl.edu/Chem/CHEM869P/CHEM869PLinks/www-dept.usm.edu/~bsclabs/380/yeasts.htm>, (December 9<sup>th</sup> 2012)

<sup>10</sup> Gerald B. Borglum, Starch Hydrolysis for Ethanol Production, [http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25\\_4\\_SAN%20FRANCISCO\\_08-80\\_0264.pdf](http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20FRANCISCO_08-80_0264.pdf), (December 9<sup>th</sup> 2012)

<sup>11</sup> Gerald B. Borglum, Starch Hydrolysis for Ethanol Production, [http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25\\_4\\_SAN%20FRANCISCO\\_08-80\\_0264.pdf](http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20FRANCISCO_08-80_0264.pdf), (December 9<sup>th</sup> 2012)

dextrins to glucose.”<sup>12</sup> The hydrolyzation of dextrins to glucose with glucoamylase is a process known as “saacharification.”

### *c) Fermentation*

Once the starch has been broken down by alpha amylase and glucoamylase enzymes, it is transported to a fermentation tank where yeast is added. Starch, through the addition of water and enzymes, has been successfully reduced to the fermentable simple sugar glucose. In order to tap into the energy of glucose, it must undergo a fermentation process which results in the end products of ethanol and carbon dioxide. Fermentation, simply put, is the process in which yeast “converts glucose to ethyl alcohol and carbon dioxide.”<sup>13</sup> When glucose comes into contact with the yeast, it enters the yeast and is broken down through a process called glycolysis.<sup>14</sup> This is the initial step in converting sugar to ethanol and is the method humans use to produce energy anaerobically. The process of glycolysis requires a minimal input of energy, but results in a positive net gain. The end product of glycolysis is the creation of two 3-carbon pyruvate molecules from one 6-carbon glucose. The yeast then converts the two pyruvate molecules into ethanol and carbon dioxide.<sup>15</sup>

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<sup>12</sup> Gerald B. Borglum, Starch Hydrolysis for Ethanol Production, [http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25\\_4\\_SAN%20FRANCISCO\\_08-80\\_0264.pdf](http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20FRANCISCO_08-80_0264.pdf), (December 9<sup>th</sup> 2012)

<sup>13</sup> Making Ethanol, <http://e85.whipnet.net/ethanol.faq/make.ethanol.html>, (December 9<sup>th</sup> 2012)

<sup>14</sup> Gerald B. Borglum, Starch Hydrolysis for Ethanol Production, [http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25\\_4\\_SAN%20FRANCISCO\\_08-80\\_0264.pdf](http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20FRANCISCO_08-80_0264.pdf), (December 9<sup>th</sup> 2012)

<sup>15</sup> Making Ethanol, <http://e85.whipnet.net/ethanol.faq/make.ethanol.html>, (December 9<sup>th</sup> 2012)





final step moves the ethanol and water vapors to a molecular sieve in which the vapors are separated from one another.<sup>19</sup> The sieve contains thousands of small clay pellets; these pellets absorb the water vapors, thus isolating the ethanol vapor.<sup>20</sup> The final product being 200 proof alcohol and yielding a total return on energy of 3.65:1.

## **2) Consequences of Corn Ethanol on the Economy**

Despite the possible gains on energy return and ecological impact, including the reduction of greenhouse gasses, other factors need to be looked at as well, chiefly the ancillary effects of job growth and food production and scarcity. During the 2005 Energy Policy Act ethanol was established as a fuel additive which replaced the oxygenate requirement with the Renewable Fuel Standard (RFS) which was developed to increase the volume of renewable fuel that is blended into transportation fuels<sup>21</sup>. The mandates and incentives of the Energy Policy Act of 2005 accelerated ethanol production at an alarming rate. Under the renewable fuels standard, gasoline was mandated to contain 7.5 billion gallons of renewable fuel annually by 2012, with almost all of this being met with ethanol<sup>22</sup>. Such a rapid growth in the ethanol industry causes a substantial diversion of grain out of the food system. Given the fact that almost 40 percent of America's corn production goes toward the creation of ethanol it is important to consider the potential impact ethanol has had on the prices of corn<sup>23</sup>.

### *a) Prices of agricultural products*

Just like corn is used in the production of ethanol, it is also used in the production of various types of food such as bread, juice, yogurt, cereal, meat and many more. According to Corn Refiners Association, more than 4,000 food items in a typical grocery store contain

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<sup>19</sup> The Dry Mill Ethanol Process, <http://www.ethanol.org/index.php?id=73>, (December 9<sup>th</sup> 2012)

<sup>20</sup> The Dry Mill Ethanol Process, <http://www.ethanol.org/index.php?id=73>, (December 9<sup>th</sup> 2012)

<sup>21</sup> Cushman, John. "In Drought, a Debate Over Quota for Ethanol." *Nytimes.com*. New York Times, 16th Aug. 2012. Web. 22 Oct. 2012

<sup>22</sup> "Corn Has Deep Economic Roots as High Prices Create Ripple Effect - *USATODAY.com*." *Corn Has Deep Economic Roots as High Prices Create Ripple Effect*. *Usatoday.com*, 24 Jan. 2007. Web. 08 Nov. 2012.

<sup>23</sup> "Corn as Food." *SDCorn.org*. N.p., 2012. Web. 08 Dec. 2012.

corn products<sup>24</sup>. This begs the question; does the use of corn ethanol affect food prices? If so, to which degree does the use of corn ethanol affect food prices? Unfortunately, this issue has been lingering in the minds of both of opponents and supporters of ethanol for the past decade without a clear answer. Opponents of ethanol often argue that the existence of corn ethanol increases the price of corn which results in the direct rise of food prices since corn is an important food ingredient for many different types of foods. In addition, it is the main product used for livestock feed. On the other hand, ethanol supporters argue that an increase in corn prices have a very small impact on food prices because the value of corn makes up such a small share of the final consumer food dollar.

It is clear that there is a relationship between ethanol production and corn prices. The real question is to what degree the production of ethanol affects corn prices. There is a direct link between higher corn prices and food costs because higher corn prices translate directly into livestock feed costs, which eventually translate into higher prices for meat, eggs, and dairy products<sup>25</sup>. However, the extent to which higher corn prices are caused by ethanol production is difficult to calculate considering that it's nearly impossible to know how much corn products are in all the foods we eat today. The demand for ethanol, particularly within the past decade, has always fluctuated due to things such new blending mandates and constantly changing oil prices. Additionally, the price of corn is not only dependent on ethanol. One major factor that has a large impact on the price of corn is the supply and demand for livestock feed within the United States and abroad. The livestock feed demand usually depends on the population and incomes levels since it sets how much people can spend on food during a certain time of the year. On the other hand, livestock feed supply is heavily dependent on the weather and the quality of the soil<sup>26</sup>. Additionally,

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<sup>24</sup> Carter, Colin, Gordon Rausser, and Aaron Smith. "The Effect of the U.S. Ethanol Mandate on Corn Prices." Egecon.com. Colin Carter, 22 July 2007. Web

<sup>25</sup> McDonald, Kay, and The Opinions Expressed in This Commentary Are Solely Those of Kay McDonald. "Paying More for Food? Blame the Ethanol Mandate." CNN. Cable News Network, 20 Aug. 2012. Web. 20 Nov. 2012.

<sup>26</sup> Weiss, Elizebeth. "USA TODAY." USATODAY.COM. Elizebeth Weiss, 14 Feb. 2011. Web. 27 Nov. 2012.

ethanol is impacted by the price of gas since more than 70 percent of ethanol is used toward transportation<sup>27</sup>.

#### *b) Job creation*

The United States currently produces 700 billion lbs. of corn, which takes up a total of 32,900,000 hectares of land, or approximately 2 states the size of Illinois. Based on our analysis, it would take about 4.9 trillion lbs. of corn to produce enough corn to convert all the gasoline in the United States to e85 which takes up 188,700,000 hectares of land, or approximately ten more states the size of Illinois. From this we can see that it would be economically and geographically inefficient to convert gasoline into e85. However, this is not to say that the current amount of ethanol that is used is not efficient<sup>28</sup>. Ethanol production directly benefits U.S. agriculture and leads rural economic development. Because ethanol is primarily made up of corn, ethanol greatly increases demand for corn which in turn increases the amount of money farmers receive for corn. Rural areas that have an opportunity to develop ethanol see large financial gains. Over the past decade, farmer-owned and locally-owned ethanol plants have driven the dramatic growth in the U.S. ethanol industry. Although many different private companies are currently producing ethanol, at least 22 percent of the industry is still owned by local owners and farmers<sup>29</sup>. The ethanol industry within the United States has increased demand for corn and has played a significant role in raising the prices of corn from historically low prices. The first result of this is that it has allowed farmers to earn a higher income since corn is the most heavily grown crop. Independent studies that have analyzed the prices of corn around areas with an ethanol plant has shown that the local price of corn increases by at least 5-10 per bushel in the area around an ethanol plant, evidence of ethanol significantly adding to the farmer's income within that area<sup>30</sup>. However, not everyone benefits from the price

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<sup>27</sup> "American Coalition for Ethanol : Home." American Coalition for Ethanol : Home. N.p., 2012. Web. 03 Dec. 2012.

<sup>28</sup> Neimeyer, Garry, and Rick Tolman. "2012 World of Corn." Ncga.com. N.p., 2012. Web. 15 Nov. 2012.

<sup>29</sup> "Bankers: Ethanol at Heart of Corn, Farm Pricing Structure." Chicago Tribune. N.p., 05 Sept. 2012. Web. 03 Dec. 2012

<sup>30</sup> Plumer, Brad. "Study: U.S. Could Put a Big Dent in Food Prices by Relaxing Ethanol Rules." Washingtonpost.com. Washingtonpost.com, 21 Aug. 2012. Web. 02 Dec. 2012.

increase of corn. Given the fact that livestock producers use corn as their main feed source and increase in the price of corn has negative impacts. Producers are already reducing some feeding as evidenced by lower reported weights for hogs and chickens being sold in current market.

The creation of ethanol plants has had a very positive impact on the economy in terms of job production. In 2011, the production of nearly 14 billion gallons of ethanol helped support more than 401,000 jobs in all sectors of the economy<sup>31</sup>. It is important to note that the production of ethanol is not a labor-intensive industry considering the fact that there only 12,500 full time ethanol manufacturing. The majority of the jobs come from agriculture, research and development. The reason why the majority of the jobs come from these fields is because the production of ethanol is more capital than labor intensive, the number of direct jobs supported by the ethanol industry is relatively small and is concentrated primarily in manufacturing and agriculture. The majority of the agricultural jobs supported by the ethanol industry are farm workers and laborers associated with grain production. However, a wide range of jobs in support activities related to crop production ranging from farm managers and bookkeepers to farm equipment operators are supported by ethanol production. As the impact of the direct spending by the ethanol industry expands throughout the economy, the employment impact expands significantly and is spread over a large number of sectors.

### ***3) Government Intervention and Prices Concerning Ethanol***

#### *i) Government subsidies*

Subsidies directly impact the feasibility of ethanol and as such they need to be examined. Currently Corn farmers in the United States have been benefiting from annual federal subsidies of around \$6 billion in the past few years, all due to the ethanol being used as an additive for the nation's vehicles. That ended January 1<sup>st</sup> of this year, however,

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<sup>31</sup> Urbanchuk, John. "Contribution of the Ethanol Industry." Cardnoentrix.com. Renewable Fuel Association, Feb. 2011. Web. 22 Nov. 2012.

when the companies making ethanol lost a tax credit of 46 cents per gallon.<sup>32</sup> This was particularly due to high oil prices, which makes ethanol a very competitive commodity. An outcome the industry does not want to see is an end to a separate tax credit for ethanol made not from corn but non-foodstuffs such as switchgrass, wood chips, and even the leaves and stalks of corn.<sup>33</sup> This is known as cellulosic ethanol, but no one is selling it just yet because of its higher research and development demands as well as production costs.

ii) *Government tax benefits*

To elaborate further on the government tax benefits towards ethanol, from the 1980s to 2011, domestic ethanol producers were protected by a 54-cent per gallon import tariff as well, mainly intended to curb the Brazilian sugarcane importation of ethanol.<sup>34</sup> Starting in 2004, transportation fuel blenders received a tax credit for each gallon of ethanol they mix with gasoline.<sup>35</sup> Originally, the tariff was intended to offset the federal tax credit that applied to ethanol without regard to country of origin.<sup>36</sup> Several countries in the Caribbean Basin imported and reprocessed Brazilian ethanol, typically converting hydrated ethanol into anhydrous ethanol for re-exportation into the United States. They bypassed the 2.5% duty and tariff, mainly due to the Caribbean Basin Initiative (CBI) and free trade agreements. This process was limited to 7% of U.S. ethanol consumption.<sup>37</sup>

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<sup>32</sup> Llanos, Miguel. "\$6 Billion-a-year Ethanol Subsidy Dies -- but Wait There's More." *NBC News*. N.p., 29 Dec. 2011. Web. 3 Dec. 2012.

<sup>33</sup> Llanos, Miguel. "\$6 Billion-a-year Ethanol Subsidy Dies -- but Wait There's More." *NBC News*. N.p., 29 Dec. 2011. Web. 3 Dec. 2012.

<sup>34</sup> "Ethanol Subsidies: Fiscal Sobriety." *The Economics*. N.p., 23 June 2011. Web. 3 Dec. 2012.

<sup>35</sup> Krauss, Clifford. "Ethanol Industry Is Unruffled by Senate Vote Against Tax Breaks." *The New York Times*. N.p., 17 Jan. 2011. Web. 3 Dec. 2012.

<sup>36</sup> Rohter, Larry. "With Big Boost From Sugar Cane, Brazil Is Satisfying Its Fuel Needs." *The New York Times*. The New York Times, 10 Apr. 2006. Web. 06 Dec. 2012

<sup>37</sup> Austin, Anna. "Brazil Launches Campaign to Remove Ethanol Tariff." *Ethanol Producer Magazine*. N.p., 04 Aug. 2008. Web. 5 Dec. 2012.

As previously mentioned, blenders received a 46-cent per gallon tax credit as of 2011 regardless of feedstock; in addition, small producers received an additional 10-cents on the first 15 million U.S. gallons while producers of cellulosic ethanol received credits up to \$1.01. Tax credits to promote the production and consumption of biofuels date back to the 1970s.<sup>38</sup> A study in 2010 conducted by the Congressional Budget Office (CBO) found that in fiscal year 2009, biofuel tax credits reduced federal revenues by around \$6 billion, of which corn and cellulosic ethanol accounted for \$5.16 billion and \$50 million, respectively. Another study in the same year conducted by the Environmental Working Group estimated that the total ethanol subsidies between 2005 and 2009 were \$17 billion. The same study estimated the future cost to taxpayers at \$53.59 billion if these tax credits were extended until 2015, yielding 15 billion US gallons.<sup>39</sup>

Also in 2010, CBO estimated that the strain on taxpayers to reduce gasoline consumption by one gallon was \$1.78 for corn ethanol and \$3.00 for cellulosic ethanol. The costs to taxpayers of lowering greenhouse gas emissions through the tax credits were roughly \$750 per metric ton of CO<sub>2</sub>, equivalent for ethanol and around \$275 per metric ton for cellulosic ethanol.<sup>40</sup> On June 16, 2011, the U.S. Congress approved an amendment to an economic development bill to repeal both the tax credit and the tariff, but it did not move forward.<sup>41</sup> Nonetheless, the U.S. Congress did not extend the tariff and the tax credit, allowing both to end on December 31, 2011. Since 1980 the ethanol industry was awarded an estimated \$45 billion in subsidies.<sup>42</sup>

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<sup>38</sup> Elmendorf, Douglas W. "Using Biofuel Tax Credits to Achieve Energy and Environmental Policy Goals." Congressional Budget Office, July 2010. Web. 6 Dec. 2012.

<sup>39</sup> Cox, Craig, and Hug, Andrew. "Driving Under The Influence: Corn Ethanol & Energy Security". Environmental Working Group. June 2010. Web 27 July 2010.

<sup>40</sup> Elmendorf, Douglas W. "Using Biofuel Tax Credits to Achieve Energy and Environmental Policy Goals." Congressional Budget Office, July 2010. Web. 6 Dec. 2012.

<sup>41</sup> Krauss, Clifford. "Ethanol Industry Is Unruffled by Senate Vote Against Tax Breaks." *The New York Times*. N.p., 17 Jan. 2011. Web. 3 Dec. 2012.

<sup>42</sup> Pear, Robert. "After Three Decades, Tax Credit for Ethanol Expires." *The New York Times*. N.p., 1 Jan. 2012. Web. 6 Dec. 2012.

### *iii) Price of ethanol*

Since 2007 ethanol prices in the U.S. have traded in a wide and erratic price range. The average price of gasoline was \$2.97, while the average price of E85 ethanol was \$2.41.<sup>43</sup> A good illustration of the ethanol price variance is to observe the price changes in the state of Iowa in 2008. The ethanol price high was \$2.82 per gallon, which occurred in early July 2008, while the low of \$1.40 per gallon occurred in mid-December 2008.<sup>44</sup> The prices of ethanol in Iowa declined approximately 51% during this 6-month span. Since the market low in late 2008, Iowa ethanol prices have been trending slightly higher through early June 2009, closing at \$1.69 per gallon on June 5, 2009,<sup>45</sup> with the U.S. following suit. Given the relative strength of corn prices during this period, low ethanol prices have severely narrowed if not completely eliminated the profitability of operating ethanol plants in some areas of Iowa, Kansas, and various other locations in the Midwestern United States.<sup>46</sup> Other regulatory and environmentally oriented mandates by the U.S. Federal government have a smaller, yet pronounced impact on the market supply-demand and prices of ethanol.

President Bush and other politicians have pushed for ethanol as a possible long-term solution for the American addiction to fossil fuels, mainly with the intention of substituting high-priced gasoline.<sup>47</sup> At this moment, however, it is actually pushing gas prices higher because the U.S. demand for ethanol (as an additive to gasoline at the pump) has caused its price to soar about 65 percent since early May to around \$4.50 a gallon in

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<sup>43</sup> *E85 Prices*. Web. 6 Dec. 2012. <<http://e85prices.com/>>.

<sup>44</sup> O'Brien, Daniel, and Mike Woolverton. "The Relationship of Ethanol, Gasoline and Oil Prices." *AGManager*. N.p., n.d. Web. 6 Dec. 2012.

<sup>45</sup> O'Brien, Daniel, and Mike Woolverton. "The Relationship of Ethanol, Gasoline and Oil Prices." *AGManager*. N.p., n.d. Web. 6 Dec. 2012.

<sup>46</sup> O'Brien, Daniel, and Mike Woolverton. "The Relationship of Ethanol, Gasoline and Oil Prices." *AGManager*. N.p., n.d. Web. 6 Dec. 2012.

<sup>47</sup> McKay, Peter A. "Ethanol Pushes Gas Prices Higher: Demand for Ethanol Aggravates Pain at the Pump." *Energy Refuge*. N.p., 2009. Web. 6 Dec. 2012.



U.S. spot markets, according to the Oil Price Information Service.<sup>48</sup> That makes it far more expensive than pure gasoline, which costs about \$2.90 a gallon at the pump on average, according to the AAA driving club. Amazingly, this price is higher than the retail price of gas, which includes taxes, transportation costs, additives, etc.<sup>49</sup>

Currently, at gas stations across the U.S., the gasoline that drivers use to fuel their cars is up to 15 percent ethanol. The source of this can be seen easily enough: If you mix something into a product that is more expensive than the product itself, as a result, the overall price of the product will rise as well.

#### *iv) Other factors contributing to gasoline prices*

Other factors that are contributing to high pump prices are hefty crude oil prices and a tight global refining capacity. The ethanol squeeze has gradually become yet another catalyst in gasoline's recent climb, becoming counterproductive to many consumers' perception of ethanol as a source of relief.<sup>50</sup> Many people think of ethanol and gasoline as competitors, or substitutes when they are actually complements of each other. Ethanol is used as an additive to gasoline, so when the price ethanol increases, the price of gasoline moves in tandem. Despite widespread anxiety about gas prices, fuel additives such as ethanol are not essential, still they are an important part of the process of refining crude oil into gasoline.

#### *v) Effects of the 2012 drought on price of ethanol and gasoline*

This past year the United States has experienced a drought that had a significant impact on the price of ethanol and consequently gasoline. The everyday citizen filling up at

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<sup>48</sup> McKay, Peter A. "Ethanol Pushes Gas Prices Higher: Demand for Ethanol Aggravates Pain at the Pump." *Energy Refuge*. N.p., 2009. Web. 6 Dec. 2012.

<sup>49</sup> McKay, Peter A. "Ethanol Pushes Gas Prices Higher: Demand for Ethanol Aggravates Pain at the Pump." *Energy Refuge*. N.p., 2009. Web. 6 Dec. 2012.

<sup>50</sup> McKay, Peter A. "Ethanol Pushes Gas Prices Higher: Demand for Ethanol Aggravates Pain at the Pump." *Energy Refuge*. N.p., 2009. Web. 6 Dec. 2012.

the gas pump has seen the effects of falling corn production first-hand, which has also negatively impacted the U.S. economy. Prices for ethanol in the U.S., largely derived from corn and accounting for some 10% of volume of gasoline consumed by U.S. drivers, have jumped by nearly one-third to \$2.60 per gallon since May of this year due to uncertainties relating to hot, dry weather that has baked most of the country since June.<sup>51</sup> Nearly all of the ethanol consumed in the U.S. comes from corn, of which the production will fall to the lowest level in nearly two decades due to this drought, as circulated by the U.S. Department of Agriculture.

*vi) Economic efficiency of E85*

For the overall economy, the increases in prices of ethanol and gasoline come at a bad time for a nation tunneling its way out of an economic slump. The average American household spends roughly 4% of its income on gasoline and fuel, according to federal Bureau of Economic Analysis.<sup>52</sup> Whenever the prices increases, over time it will add up until the few extra cents spent on gasoline is money not spent in the wider economy, said Richard Hastings, macroeconomic analyst at Global Hunter Securities.<sup>53</sup>

A hot topic of debated is whether or not switching from the current blend of gasoline to one of which is composed of 85% ethanol would be economically efficient. E85 ethanol contains a higher ethanol concentration than current blends such as E10 and E15, mixing 85 percent ethanol with 15 percent regular gasoline. As of October 2012, regular gasoline averaged \$3.80 per gallon across the U.S. whereas E85 was cheaper at \$3.39 per gallon at the time.<sup>54</sup> This means that E85 was roughly the same price that gasoline was one

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<sup>51</sup> LEFEBVRE, Ben. "Midwest Drought Hits Gas Pump." *The Wall Street Journal*. The Wall Street Journal, 10 Aug. 2012. Web. 7 Dec. 2012.

<sup>52</sup> LEFEBVRE, Ben. "Midwest Drought Hits Gas Pump." *The Wall Street Journal*. The Wall Street Journal, 10 Aug. 2012. Web. 7 Dec. 2012.

<sup>53</sup> LEFEBVRE, Ben. "Midwest Drought Hits Gas Pump." *The Wall Street Journal*. The Wall Street Journal, 10 Aug. 2012. Web. 7 Dec. 2012.

<sup>54</sup> Ingram, Anthony. "Is E85 Ethanol The Solution To High Gas Prices?" *Green Car Reports*. N.p., 8 Oct. 2012. Web. 6 Dec. 2012.

year before; but as E85 contains less energy than regular gasoline, which means that the fuel efficiency is lower, making the overall advantage much smaller.

Ethanol producers, especially those in favor of the E85 system, argue that in October the wholesale price of the fuel was about 70 cents per gallon less than standard gas, instead of the estimated 40 cents, which presents E85 as the much more cost-effective choice.<sup>55</sup> An example is the Chevrolet Tahoe. It comes in a FlexFuel model, meaning that it runs on E85, but only gets 13 miles per gallon, compared to 17 mpg its gasoline model gets, which is 23% lower mileage. At this level, E85 would have to be lower than \$3 per gallon for Tahoe drivers to see any benefit. Another factor is availability.<sup>56</sup> There are only 3,000 listed E85 stations currently in the U.S.<sup>57</sup>, the majority of which are in the Midwest. As a point of contrast, there are about 168,000 gas stations in the U.S.<sup>58</sup> Simply put, E85 is not very likely to be a widely-used fuel in the near future without a significant reduction in price and increase in availability.

#### *vii) What the Future Holds For Ethanol Prices*

Looking ahead, most analysts believe ethanol prices will eventually pull back from their current highs, but it could also take much longer before supply and demand really stabilize, a process that will also require refiners and energy companies to invest in facilities to produce and deliver ethanol. It is very difficult to project future prices of gasoline and E85 due to the fact that global current events and macroeconomic supply and demand levels, which we cannot currently account for, determine many of the influencing factors of price. For Example, gasoline prices rely heavily on the price of crude oil, which have been fairly high in the past year because experts believed the global oil demand was

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<sup>55</sup> Ingram, Anthony. "Is E85 Ethanol The Solution To High Gas Prices?" *Green Car Reports*. N.p., 8 Oct. 2012. Web. 6 Dec. 2012.

<sup>56</sup> Ingram, Anthony. "Is E85 Ethanol The Solution To High Gas Prices?" *Green Car Reports*. N.p., 8 Oct. 2012. Web. 6 Dec. 2012.

<sup>57</sup> *E85 Prices*. Web. 6 Dec. 2012. <<http://e85prices.com/>>.

<sup>58</sup> "How Many Gas Stations Are There in the U.S.?" *FuelEconomy.gov*. N.p., n.d. Web. 09 Dec. 2012.

going to reach a record high as the developing nations of Asia, Latin America and the Middle East increase their need for oil to further their growing industries.<sup>59</sup> There have also been a few small supply interferences in South Sudan, Syria and Nigeria. In addition, oil prices have been pushed higher by commodity traders worried that nuclear tensions with Iran, the world's third largest exporter of oil, could lead to more intense supply disruptions.<sup>60</sup>

#### **4) Cost Benefit Analysis**

##### *a) Energy efficiency*

In the following section, we will take a look at the energy efficiency and energy balance of the two aforementioned fuel sources in question in this study. In the end, we will produce a final energy balance or net energy value figure for both corn ethanol and gasoline.

##### *i) Energy efficiency of corn ethanol*

According to the United States Department of Energy, in order to successfully evaluate the net energy of ethanol, four variables must be considered:

- I. The amount of energy contained in the final ethanol product
- II. The amount of energy directly consumed to make the ethanol product (such as the diesel used in tractors, refinery energy sources etc.)
- III. The quality of the resulting ethanol compared to the quality of refined gasoline
- IV. The energy indirectly consumed (in order to make the ethanol processing plant, etc.)

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<sup>59</sup> Fahey, Jonathan. "What -and Who - Make Gasoline Prices Rise." *USATODAY.COM*. Associated Press, 23 Mar. 2012. Web. 07 Dec. 2012.

<sup>60</sup> Fahey, Jonathan. "What -and Who - Make Gasoline Prices Rise." *USATODAY.COM*. Associated Press, 23 Mar. 2012. Web. 07 Dec. 2012.

Much of the current discussion regarding ethanol revolves around system borders. This refers to how complete of a picture is drawn when evaluating energy inputs. For example, there is academic debate on whether to include items like the energy required to feed the people processing the corn, to maintain the equipment, or even the amount of energy a tractor represents. Also, there is no consensus as to what energy value to give the rest of the corn (that which is not used for ethanol refining, i.e.: the stalk), commonly known as the *co-product*. Depending on the ethanol study in question, these issues result in a net energy return variation of 0.7-1.5 units of ethanol per unit of fossil fuel energy consumed.

*ii) A negative look at corn ethanol efficiency*

Opponents of corn ethanol often point to the 2005-research paper of David Pimentel, a retired Entomologist, and Tadeusz Patzek, a Geological Engineer from UC Berkeley. In their study of corn ethanol energy efficiency, they boldly concluded that corn ethanol was not only more inefficient than petroleum-based gasoline, but that it in fact had a negative energy balance. The following calculations and analysis refers to their findings.

The conversion of corn and other food/feed crops into ethanol by fermentation is a well-established technology. The ethanol yield from a large production plant is about 1 liter of ethanol from 2.69 kilograms of corn grain.

The production of corn in the United States requires a significant amount of energy and dollar investment. To produce an average corn yield of 8,655 kg/ha of corn using average production technology requires the expenditure of about 8.1 million kcal for the large number of inputs listed in Table 1. This includes about 271 gallons of gasoline or equivalents/ha. The production costs end up being about \$917/ha for the 8,655 kg/ha, which translates to about \$0.11/kg of corn produced.

It should be noted that the corn feedstock alone requires about 50% of the energy input. Also, the mean energy input associated with irrigation is 320,000 kcal per ha as seen in Table 1.

The average costs in terms of energy and dollars for a large (produces around 245-285 million liters/year), modern ethanol plant are listed in Table 2. Note that the largest energy inputs are for the corn feedstock, the steam energy, and the electricity used in the fermentation/distillation process. The total energy input to produce a liter of ethanol is 6,597 kcal (Table 2). However a liter of ethanol has an energy value of only 5,130 kcal. Thus, there is an energy loss of 1,467 kcal of ethanol produced.

**This results in an energy balance, or net energy value of only 0.77x.**

To produce a liter of ethanol requires 29% more fossil fuel energy that is produced by the ethanol and it ends up costing \$0.42 per liter or \$1.59 per gallon to produce.

Note that not included in this analysis was the distribution energy to transport the actual physical ethanol. The DOE estimates this to cost about \$0.02 per liter, or approximately more than 331 kcal/liter of ethanol.<sup>61</sup>

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<sup>61</sup> Pimentel, Patzek. Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. Diss. Natural Resources Research, 2005. Web. <[http://www.sehn.org/tccpdf/Energy-biofuel outputs &inputs.pdf](http://www.sehn.org/tccpdf/Energy-biofuel%20outputs%20&inputs.pdf)>.

**Table 1.** Energy Inputs and Costs of Corn Production Per Hectare in the United States

Inputs	Quantity	kcal × 1000	Costs \$
Labor	11.4 hrs <sup>a</sup>	462 <sup>b</sup>	148.20 <sup>c</sup>
Machinery	55 kg <sup>d</sup>	1,018 <sup>e</sup>	103.21 <sup>f</sup>
Diesel	88 L <sup>g</sup>	1,003 <sup>h</sup>	34.76
Gasoline	40 L <sup>i</sup>	405 <sup>j</sup>	20.80
Nitrogen	153 kg <sup>k</sup>	2,448 <sup>l</sup>	94.86 <sup>m</sup>
Phosphorus	65 kg <sup>n</sup>	270 <sup>o</sup>	40.30 <sup>p</sup>
Potassium	77 kg <sup>q</sup>	251 <sup>r</sup>	23.87 <sup>s</sup>
Lime	1,120 kg <sup>t</sup>	315 <sup>u</sup>	11.00
Seeds	21 kg <sup>v</sup>	520 <sup>w</sup>	74.81 <sup>x</sup>
Irrigation	8.1 cm <sup>y</sup>	320 <sup>z</sup>	123.00 <sup>aa</sup>
Herbicides	6.2 kg <sup>bb</sup>	620 <sup>cc</sup>	124.00
Insecticides	2.8 kg <sup>cc</sup>	280 <sup>ee</sup>	56.00
Electricity	13.2 kWh <sup>dd</sup>	34 <sup>ff</sup>	0.92
Transport	204 kg <sup>gg</sup>	169 <sup>hh</sup>	61.20
Total		8,115	\$916.93
Corn yield 8,655 kg/ha <sup>ii</sup>		31,158	kcal input: output 1:3.84

**Table 2.** Inputs Per 1000 l of 99.5% Ethanol Produced From Corn<sup>a</sup>

Inputs	Quantity	kcal × 1000	Dollars \$
Corn grain	2,690 kg <sup>b</sup>	2,522 <sup>b</sup>	284.25 <sup>b</sup>
Corn transport	2,690 kg <sup>b</sup>	322 <sup>c</sup>	21.40 <sup>d</sup>
Water	40,000 L <sup>e</sup>	90 <sup>f</sup>	21.16 <sup>g</sup>
Stainless steel	3 kg <sup>i</sup>	12 <sup>i</sup>	10.60 <sup>d</sup>
Steel	4 kg <sup>i</sup>	12 <sup>i</sup>	10.60 <sup>d</sup>
Cement	8 kg <sup>i</sup>	8 <sup>i</sup>	10.60 <sup>d</sup>
Steam	2,546,000 kcal <sup>j</sup>	2,546 <sup>j</sup>	21.16 <sup>k</sup>
Electricity	392 kWh <sup>j</sup>	1,011 <sup>j</sup>	27.44 <sup>l</sup>
95% ethanol to 99.5%	9 kcal/L <sup>m</sup>	9 <sup>m</sup>	40.00
Sewage effluent	20 kg BOD <sup>n</sup>	69 <sup>h</sup>	6.0
Total		6,597	\$453.21

*iii) A more positive look at corn ethanol*

Pimentel's assessment of corn ethanol concluded that corn ethanol achieved a negative energy balance (which is usually defined as the energy in a product minus the energy used to produce it). However, it is possible to argue that this assessment took into consideration variables that were present in the 70's and 80's, and thus failed to take into account technological improvements over the last 20 years and their impacts on energy requirements of corn farming and ethanol production.

Michael Wang and Dan Santini from the Argonne National Laboratory claim that corn-based ethanol does indeed achieve positive energy benefits. The following analysis and calculations refer to their findings.

Technological advancements have undoubtedly helped increase productivity and product performance and reduce input energy requirements in almost every U.S. sector. Problems with Pimentel's 2005 assessment are found in three key areas: energy use of corn farming, energy use of ethanol production, and failure to credit co-products from ethanol plants.

The most controversial issue on corn ethanol efficiency analysis is how to deal with co-products from corn plants. Ethanol is not the only product created during production. Co-products also have energy content. Corn is typically 66% starch and the remaining 33% is not fermented. This unfermented component must be accounted for somehow.

Dry milling ethanol plants produce distiller's grains and soluble together with ethanol, while wet milling plants produce corn gluten feed, corn gluten meal, corn oil, and other high-value products together with ethanol. These products are currently sold in the marketplace as animal feeds or for other uses.

While there are several ways of estimating energy and emission credits of co-products, most researchers agree that the *displacement method* should be used to estimate the credits. This method assigns a co-product credit based on the input energy



requirement of the feed product or good that the ethanol co-product displaces. With the method, it is necessary to estimate an energy credit of 15,440 BTU per gallon of ethanol.

The following table shows energy inputs for a gallon of ethanol. We'll refer to this as Table 3. The units mentioned are in BTUs.

### Energy Inputs for a Gallon of Ethanol

Item	Argonne	Pimentel
Corn Farming	26,700	55,300
Ethanol Production	44,300	74,300
Co-Product Credit	-15,400	0
Total	55,600	129,600
Net Energy Balance	20,400	-53,600

As we can see, after factoring in the co-product credit, we indeed have a positive energy balance for corn ethanol.

It is worth noting that the displacement method gives the least energy and emission credits to ethanol co-products. If other methods are to be used, co-product credits will be higher than presented in Table 3.

**Thus, after accounting for the co-products, we end up with a positive net energy value or balance of roughly 1.06x up to 1.67x depending on the credit method utilized.** <sup>62</sup>

A 2006 paper by MIT researcher Tiffany Groode produced similar findings.

#### *iv) Energy efficiency of petroleum-based gasoline*

Depending on the study utilized, net energy returns vary from approximately 0.7-1.5 units of ethanol per unit of fossil fuel energy consumed. It is important to realize that for petroleum-based gasoline, the same one unit of fossil fuel invested in oil and gas

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<sup>62</sup> Wang, Santini. Corn-Based Ethanol Does Indeed Achieve Energy Benefits. Diss. Argonne National Laboratory. Web. <<http://www.transportation.anl.gov/pdfs/TA/267.pdf>>.

extraction will yield approximately 15 units of gasoline, a yield significantly higher than current ethanol production technologies. However, this is ignoring energy quality arguments and the fact that this yield is both declining and not carbon neutral.

Energy return on investment can be derived from the biophysical model of resource scarcity, meaning the use of increasing amounts of natural capital to deliver a unit of resource to society. Energy is commonly used to reflect and measure the costs associated with such process. In general, there is an evident inverse relation between the quality of the resource and energy costs. A decline in the quality of the natural resource due to cumulative depletion, an increase in the rate of exploitation, or an increase in the scale of extraction, all increase the amount of energy used to extract a unit of a natural resource.

It is evident that there has been a decline in the energy return on investment (EROI) over the last decades, suggesting that depletion of the resource has raised the energy costs of extraction. We do not have a single measure of the quality of the oil or gas resource, but a number of such measurements point towards physical deterioration. Also, on the discovery side, an important indicator is the average size of new discoveries. We find that the average oil field has declined in size roughly 20-40 million barrels in the 1930's to less than 1 million today. The average depth of exploratory oil wells has also increased by an average of 3,000 ft over the past 80 years.

Opposing these effects that have reduced the EROI of petroleum, technological, organizational and institutional changes have worked to reduce the costs of oil extraction in the industry. On the technological side, 3D seismology, horizontal drilling, and deepwater production systems have worked to reduce costs over the past 15 years. However, on energy balance, the effects of these changes on the energy cost of extraction have been outweighed by the depletion effects and thus producing a decline in EROI.<sup>63</sup>

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<sup>63</sup> Cleveland, Cutler J. Net Energy From the Extraction of Oil and Gas in the United States, 1954-1997. Diss. Boston University, 2000. Center for Energy and Environmental Studies and Department of Geography, Print.

Although the energy balance or net energy value of petroleum-based gasoline has been declining, it is important to realize that this figure is still significantly higher than that of corn-based ethanol. Without taking into account the quality of the energy, it is clear that on a purely efficiency-based argument, gasoline is the superior fuel source.

*b) Infrastructure cost of a transition to corn ethanol*

In addition to the costs of actually growing corn, converting it to ethanol, increased food prices and environmental effects, there remain the costs of retooling our infrastructure in order to make pure ethanol a true viable alternative to gasoline. Converting cars to run on pure ethanol costs about as much as it does to run it on an e85 blend; on an individual basis this runs some \$250-700 depending on the car and engine type.<sup>64</sup> People not wanting to convert their entire car to ethanol can see gasoline fuel savings of some 30 percent with a \$1000 investment into an ethanol turbo and a few gallons of ethanol a month; this would pay for itself in some 4 years at current gasoline prices.<sup>65</sup> However for an industrial move to ethanol as a fuel it would only cost some \$70-100 more than a traditional direct fuel injected gasoline motor.<sup>66</sup> With greater possible power output and increased fuel efficiency the industry is heading towards direct fuel injection anyways and many cars already utilize it. In addition advances in the direct fuel injection technology have helped lead the resurgence of diesel power vehicles. With this shift to direct fuel injection already occurring, the problem of cold-starting with an ethanol motor would be a thing of the past and range issues due to the lower volume efficiency of ethanol would be partly alleviated. With about 247 million registered vehicles on the road in the United States, excluding heavy trucks and busses, the total cost to have each passenger vehicle eventually running on ethanol would total some 24.7 billion dollars<sup>67</sup> at the higher range for ethanol engine production costs.

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<sup>64</sup> Mongers, Inc. "E85 Conversion Kits." *E85 Conversion Kits Change2E85.com*. Mongers, June 2012. Web.

<sup>65</sup> Stauffer, Nancy. "The MIT Energy Research Council." *MIT Energy Research Council : Research Spotlight*. MIT, n.d. Web.

<sup>66</sup> Lang, Jim. "E100 Engines and Vision." *E100ethanolgroup*. N.p., n.d. Web.

<sup>67</sup> (247 million \* \$100)

*i) Trucking transportation conversion costs*

Trucking as well would have to be converted to run on ethanol. Production costs wouldn't be significantly more and in fact some countries like Sweden, without a large ethanol fuel base, have begun employing light and heavy trucks without detriment.<sup>68</sup> However there is a major cost involved with operating trucks that work on ethanol versus diesel. According to a government case study, the fuel injector requires replacing every 60,000 miles on average for ethanol trucks to the cost of some \$1000 apiece.<sup>69</sup> With the shipment of goods by trucks returning to pre-recession levels representing some 140 billion miles per year,<sup>70</sup> the cost here could be some \$2.33 billion yearly. Finding the present value for the next 50 years of costs running semi trucks on ethanol vs. diesel and discounting by the average US inflation rate since 1913 (3.23%) gives us some \$58.2 billion.<sup>71</sup> This combined with the cost to convert the passenger vehicles gives us a present day cost of some \$82.9 billion that would be paid gradually as new vehicles are produced at rates that continue to match demand and fuel injectors wear out in semi trucks.

*ii) Distribution infrastructure conversion costs*

Beyond the extra costs of producing and running vehicles on e85 ethanol on an industrial scale are the costs associated with the retrofitting of fueling stations across the United States. Currently there are some 168,000 gas stations located in the United States.<sup>72</sup> With a cost of \$23,000 to have a fuel dispenser dispense ethanol and \$102,000 to have a tank that can store it, if each gas station were to only install 4 e85 capable dispensers and 2

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<sup>68</sup> Scania. "Green Light for Ethanol Trucks." *Scania.com*. N.p., n.d. Web

<sup>69</sup> United States. Illinois DCCA. By Paul Norton, Kenny J. Kelley, and Norman J. Marek. N.p.: n.p., n.d. Web. p.5

<sup>70</sup> "Truck Stats." *Trucking Statistics*. N.p., n.d. Web.

<sup>71</sup>  $(2.33(1-.0323)^{50})/(.0323)$

<sup>72</sup> "How Many Gas Stations Are There in the U.S?" *How Many Gas Stations Are There in the U.S?* N.p., n.d.

tanks (below the level of current gas storage tanks and dispensers) that would cost some \$49.7 billion dollars.<sup>73</sup>

Rather than convert all gas stations in the country to use ethanol, a viable alternative to start spurring more ethanol use as a main fuel could be convert only 12,000 gas stations in the most crucial and highly populated places. This would be enough for 1 every 2 miles in each of America's 100 most populated cities, as well as one every 25 miles along it's highway system. The total cost of this would be \$3.552 billion using the same assumptions on ethanol storage tanks and dispensers built per gas station.<sup>74</sup>

After the cost of the actual corn, the next largest portion of ethanol costs goes to its transportation. Currently in the United States 40% of the ethanol is transported by rail, another 40% by truck, and the remaining 20% by barge. Ethanol shipped via pipeline is possible but it isn't a very probable occurrence.<sup>75</sup> The primary reason for this is ethanol's affinity for water. It is water soluble and as such it absorbs water lowering the fuel grade, and often water finds its way into pipelines. As well ethanol has more issues with corrosion in pipelines when it is at high concentrations and pressures.<sup>76</sup> However this does not mean ethanol pipelines are impossible. The US Department of Energy did a feasibility study of a large pipeline from producers in the Midwest to the Northeast and came to the conclusion that it would cost some \$4.25 billion and be able to transport some 2.8 billion gallons of ethanol a year.<sup>77</sup> About 134 billion gallons of gasoline was consumed in the US last year with 10% of that being ethanol. This represents a total of some 4,764.5 billion kwh worth of energy. To make that equivalent amount of energy would take some 180.67 billion

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<sup>73</sup>  $(168,000)*((23,000*4)+(102,000*2))$

<sup>74</sup>  $(12,000)*((23,000*4)+(102,000*2))$

<sup>75</sup> Roger Brown, Erin Orwig, Jefferey Nemeth, and Carolos S. Rocha, "The Economic Potential for Ethanol Expansion in Illinois", (Illinois Institute for Rural Affairs at Western Illinois University)

<sup>76</sup> "In The Pipe: Increased Ethanol Use Creates Challenges." *In The Pipe: Increased Ethanol Use Creates Challenges*. N.p., n.d. Web.

<sup>77</sup> "DOE Finds Ethanol Pipeline Feasible, with Conditions." *Ethanol Producer Magazine*. N.p., n.d. Web.

gallons of e85, 153.6 billion gallons of which is ethanol, taking into account of course of energy densities and holding the energy for ground transportation needs constant. To do this by building new pipelines (converting old ones doesn't really help as petrol production locations differ from those of ethanol), even at the generous price to gallons transported yearly ratio found by the DOE for that large project which would be tough to replicate in smaller projects, would amount to a total cost of some \$233.1 billion.<sup>78</sup>

*iii) Total potential E85 ethanol usage costs*

Due to some of the issues previously stated, it is likely that the majority of transportation for this new ethanol would be by truck, barge, and rail. The total amount of gallons needed at e85 by current energy used to drive is some 180.9 billion gallons (calculated using current gallons of gasoline used a year and dividing it by .7186 which represents the lower energy density of e85 compared to gasoline)<sup>7980</sup>. This would represent an increase of some 27.3 billion gallons of liquid needing to be transported, equivalent to 179.907 billion lbs, or approximately some 90 million tons. Considering that ethanol refining is mostly located in the Midwest far from most of the population centers, the distance travelled from the refinery to the station would have to average at least some 200 miles. At the average freight prices of \$.27, \$.2, and \$.1 per mile-ton freight transportation by truck, rail, and barge respectively,<sup>81</sup> the weighted cost by transportation type breakdown currently would be \$.208 per mile-ton shipped on average. That would cost some \$3.75 billion a year currently, with the discounted present value of that for the next including price increase that match inflation 50 years would cost some \$187 billion.<sup>82</sup>

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<sup>78</sup>  $(153.6/2.8)*4.25$

<sup>79</sup> <http://www.epa.gov/oms/rfgecon.html>, N.p. Nnd. Web.

<sup>80</sup><http://alternativefuels.about.com/od/resources/a/gge.html>, N.p. n.d. Web.

<sup>81</sup> "Freight Transportation." *Center for Climate and Energy Solutions*. N.p., n.d. Web.

<sup>82</sup>  $(3.75*50)$ , assuming the price increase matches inflation)

The costs to convert the system to run on e85 would come chiefly from the conversion of engines and the replacement of fuel injector in semi-trucks, the creation of an e85 compatible fuel delivery infrastructure, and a delivery system for all ethanol, whether by a new pipeline network or by more traditional means of truck, rail, and barge transportation. The total present value cost for the next 50 years under the pipeline scenario is estimated to be some \$390.4 billion. Under the other means of transportation scenario it would only be \$344.3; however this only takes into account the transportation costs for the next 50 years and none after that, so in the longer term this would be much costlier.

c) Emissions and environmental concerns from production process of ethanol

As well as the monetary costs of converting our infrastructure on e85, the emissions from the production process also have to be taken into account as part of the total costs of conversion. According to the Congressional Budget Office of the United States (CBO) and research conducted by Argonne National Laboratory (ANL) it has been suggested that in the short run, the processes of production, distribution, and consumption of ethanol will create 20% less greenhouse gas emissions than the same processes create for gasoline.<sup>83</sup> This creates a reduction of about 14 million metric tons of carbon dioxide and other equivalent gases, which are known to be the main causes of greenhouse gases.<sup>84</sup> In choosing to convert all of the gasoline used for ground transportation into e85 we would end up emitting 1,277 billion lbs. of CO<sub>2</sub> into the atmosphere during the production process, compared to the 91 billion lbs. we produce today.

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<sup>83</sup> Elmendorf, Douglas W. "The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions." Congressional Budget Office. Congress of the United States Congressional Budget Office, Apr. 2009. Web. 6 Dec. 2012.

<sup>84</sup> Elmendorf, Douglas W. "The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions." Congressional Budget Office. Congress of the United States Congressional Budget Office, Apr. 2009. Web. 6 Dec. 2012.

*i) Calculation for total extra CO2 emissions in lbs. to achieve 100% E85 efficiency in ground transportation*

In order to calculate total extra CO2 emissions from the extra ethanol production needed to fuel America's ground transportation, a few calculations need to be done. Today, all energy needed for transportation is 4,343.3 billion kWh. To make that much energy in e85 we would need to make 180.67 billion gallons of e85 (4,343.3 billion kWh/2.404 kWh per gallon of e85). 85% of e85 is ethanol, which results in 153.6 billion of the total 180.67 billion gallons of e85. 153.6 billion gallons of ethanol x 22.27 kWh per gallon of pure ethanol is equivalent to 3,420.69 billion kWh worth of ethanol. For every 3.65 kWh of ethanol produced it costs us 1 kWh<sup>85</sup>. Taking the 3,420.69 billion kWh worth of ethanol and dividing it by 3.65 kWh we come up with 937.18 billion kwh, which is the amount of energy used to convert all gasoline into ethanol. On average the amount of CO2 produced per kWh is 1.363 lbs. When we take into consideration all the kWh of energy used to convert all gasoline into e85 and multiply it by the lbs. of CO2 produced per kWh, we get a total of 1,277 billion lbs. of CO2, approximately 14x the amount of CO2 produced today.

*ii) Calculation for total cost of CO2 emissions to achieve 100% E85 efficiency in ground transportation*

According to the Environmental Protection Agency, one ton of CO2 released into the atmosphere led up to \$35 in economic damage according to a social cost of carbon discount rate of 2.5% which estimates the monetized damage associated with the incremental increase in carbon emissions.<sup>86</sup> This means that currently in the United States 45,500,000 tons of CO2 are produced from ethanol production, which costs \$1,592,500,000. If we were to switch to 100% e85 in our pumps, the total cost of CO2 emissions from production

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<sup>85</sup> Pimentel, David. "Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts Are Negative." Natural Resources Research. Washington University St. Louis, June 2003. Web. 5 Dec. 2012.

<sup>86</sup> Environmental Protection Agency, "Social Cost of Carbon for Regulatory Impact Analysis" (Washington D.C., 2010), 2.



would come out to be 638,500,000 million tons of CO<sub>2</sub> produced x \$35 per ton = \$22,347,500,000. This results in a total change of \$20,755,000,000.

*iii) Environmental concerns from ethanol production process*

As well as the total costs of CO<sub>2</sub> emissions, the release of harmful toxins and greenhouse gases are also a major concern in the production process of ethanol. Land conversion has been a topic of discussion recently in regards to the environmental concerns that ethanol has created. Producing ethanol for use in motor fuels increases the demand for corn, which increases the demand for land conversion across the United States. To produce more ethanol, farmers can engage in deforestation practices, which releases a significant amount of carbon to the atmosphere that was previously stored in plants and soil.<sup>87</sup> Deforestation and the removal of conservation lands also forego ongoing carbon sequestration as plants continue to grow each year. The foregone carbon sequestration needs to be considered and is the equivalent of additional emissions.<sup>88</sup> Also, with these large increases in the use of nitrogen fertilizer as a result of land conversion in order to keep up with the growing demand for corn, the fertilizer in fact has increased nitrous oxide emissions, thus leading to more Greenhouse gas emission problems as well.

In a study conducted by the University of Nebraska an ethanol biorefinery's Greenhouse gas emissions were documented and publicized. Ethanol biorefineries are the other major contributor to the Greenhouse gas emission process. Further studies showed that at this ethanol biorefinery, which can be representative of other Midwest ethanol biorefineries, natural gas contributed to about 2/3 of the emissions that were produced.<sup>89</sup>

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<sup>87</sup> Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simia Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science Magazine*. N.p., 7 Feb. 2008. Web. 06 Dec. 2012.

<sup>88</sup> Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simia Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science Magazine*. N.p., 7 Feb. 2008. Web. 06 Dec. 2012.

<sup>89</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." *Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter*, Aug. 2009. Web. 05 Dec. 2012.

Electricity combined with the natural gas contributed to 90% of the Greenhouse gas emissions.<sup>90</sup> According to the study, “The distillers grains co-product provides a 29 percent GHG emission credit. Most of the credit is due to the reduction in emissions resulting from substituting distillers grains for other feeds (that emit GHG in their production) in cattle rations.”<sup>91</sup> From the results displayed below, it can clearly be seen that the net emissions from the production process of ethanol come out to be 42 units of emissions per unit of energy produced.<sup>92</sup> The energy produced is measured in grams of CO<sub>2</sub> equivalent emissions per megajoule of energy produced. Compared to gasoline, which net emissions are 92 units; this represents a 54 percent reduction in Greenhouse gas emissions when it is compared to gasoline.

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<sup>90</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<sup>91</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<sup>92</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<b>Table 1. Greenhouse Gas Emissions from Ethanol Production (Iowa natural gas biorefinery) (emissions expressed as CO2 equivalents)</b>		
	<b>Emissions per Unit of Energy Produced *</b>	<b>Percent</b>
<b>Corn Production</b>		
Fertilizer and Lime	8.6	15%
N <sub>2</sub> O Emissions	14.1	25%
Seed and Pesticides	1.7	3%
Fuel	2.1	4%
LP Gas and Electricity	1.6	3%
Depreciation Capital	0.3	0%
<b>Total</b>	<b>28.3</b>	<b>50%</b>
<b>Biorefinery</b>		
Natural Gas	19.7	34%
Electricity	6.5	11%
Depreciation Capital	0.5	1%
Grain Transport	2.1	4%
<b>Total</b>	<b>28.8</b>	<b>50%</b>
<b>Grand Total</b>	<b>57.1</b>	<b>100%</b>
<b>Co-product Credit</b>	<b>-16.5</b>	<b>-29%</b>
Ethanol Transportation	1.4	
<b>Net Emissions</b>	<b>42.0</b>	
Gasoline	92	
<b>Reduction Relative to Gasoline</b>	<b>50</b>	<b>54%</b>
* Grams of CO <sub>2</sub> equivalent emissions per megajoule of energy produced.		
Source: <a href="#">University of Nebraska</a> .		

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The production process of ethanol, although less harmful than the production process of gasoline in regards to net emissions as described previously, is accountable for the release of harmful toxins and other greenhouse gases. “Crop production accounts for 50 percent of the total emissions from ethanol production. One-half of these emissions are in the form of nitrous oxide (N<sub>2</sub>O.)”<sup>94</sup> Nitrous oxide proves to be an extremely powerful Greenhouse gas as it is recorded as being 289x more powerful than carbon dioxide<sup>95</sup> is, thus creating a powerful impact for Greenhouse gas concerns, even in small doses. N<sub>2</sub>O is

<sup>93</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<sup>94</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<sup>95</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

found in the soil and produced from the processes of nitrification and de-nitrification. According to Dan Hofstrand in his 2009 renewable energy newsletter, “during nitrification, ammonium (NH<sub>4</sub>) produces nitrates (NO<sub>3</sub>.) During de-nitrification, nitrates (NO<sub>3</sub>) are reduced to nitrogen gas (N<sub>2</sub>). An intermediate step in both of these processes is the creation of nitrous oxide (N<sub>2</sub>O).”<sup>96</sup>

Separate from the greenhouse gases are the harmful toxins (VOCs) produced by the ethanol production process. Upon the arrival of corn to the production plant, tiny particles from the corn are released into the air. These same particles are released into the air during the drying process of production. These small, invisible particles are known as particulates and can be harmful if inhaled. Results from a study performed by the Minnesota Pollution control agency concerning ethanol production in Minnesota, showed that “during fermentation, distillation and drying, volatile organic compounds (VOCs) are released. Some of these VOCs are known as ‘hazardous’ or ‘toxic’ at certain levels. These include some or all of the following: acetaldehyde, acrolein, ethanol, formaldehyde, 2-furaldehyde, methanol, acetic acid and lactic acid.”<sup>97</sup> Besides the VOC’s released, other toxic gases such as carbon monoxide and nitrogen oxide are generated from the combustion in the boilers of the plant.

*iv) Percent increase in CO<sub>2</sub> emissions to achieve 100% E85 efficiency in ground transportation*

The economic costs in CO<sub>2</sub> pollution if we were to convert entirely to e85, would be, according to self conducted calculations, the percentage difference between 1,592,500,000 and 22,347,500,000 which equals 173.39%, and the 20,755,000,000 rise (from 1,592,500,000 to 22,347,500,000) equates to a 1303.30% increase in CO<sub>2</sub> emissions. This

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<sup>96</sup> Hofstrand, Don. "Greenhouse Gas Emissions of Corn Ethanol Production." Agricultural Marketing Resource Center. AgMRC Renewable Energy Newsletter, Aug. 2009. Web. 05 Dec. 2012.

<sup>97</sup> "Ethanol Production in Minnesota." Minnesota Pollution Control Agency. Ed. Rhonda Land. N.p., 20 Oct. 2002. Web. 04 Dec. 2012.

can be accompanied by the environmental concerns in regards to greenhouse gas emissions and the emission of other harmful toxins into the atmosphere.

*d) Emissions and Environmental Concerns from the Consumption of Ethanol*

To examine the use of ethanol on the consumption level, it should be stated that ethanol is considered a cleaner burning alternative to using gasoline. The amount of greenhouse gas emissions released by ethanol is considerably lower. This has led many to believe that ethanol is a viable replacement for gasoline, as gasoline has had a detrimental effect on the environment. However, it has been shown that ethanol is less efficient than gasoline in terms of fuel economy.<sup>98</sup> What that means is that the output of energy for ethanol is less than that of gasoline giving cars less miles per gallon. So, while ethanol burns cleaner than gasoline, cars must use more ethanol in order to travel the same distance, and thus releasing more pollutants like carbon dioxide. When comparing the two inputs on the consumption level, the relative amount of pollution per equivalent energy output must be realized in order to judge whether or not ethanol would be a viable replacement of gasoline.

Ethanol has been developed to be used in automobiles as an alternative motor fuel source to help prevent air pollution. It contains 35% oxygen which results in a more complete fuel combustion that reduces tailpipe emissions. Ethanol is biodegradable in nature, non toxic, and also reduces the amount of greenhouse gases and tailpipe emissions. This is compared to fossil fuels which are a major contribution to the emissions of carbon dioxide among other pollutants. According to the EPA, CO<sub>2</sub> emissions through fossil fuel combustion by commercial means totaled to 224.2 metric tons in 2010.<sup>99</sup> Ethanol in the United States is currently used as additive to gasoline, with cars slowly developing the technology to handle higher concentrations of ethanol blends. The idea behind this is that

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<sup>98</sup> *The Truth About Ethanol*, [http://www.ucsusa.org/clean\\_vehicles/smart-transportation-solutions/cleaner\\_fuels/ethanol-and-other-biofuels/the-truth-about-ethanol.html](http://www.ucsusa.org/clean_vehicles/smart-transportation-solutions/cleaner_fuels/ethanol-and-other-biofuels/the-truth-about-ethanol.html) (July 2007).

<sup>99</sup> Environmental Protection Agency, "US GHG Inventory 2012 Executive Summary" (Washington D.C., 2012), 5.

the more ethanol is being used as fuel in motor vehicles, the less gasoline will be used, and these numbers of CO<sub>2</sub> emissions from commercial vehicles will go down.

The efficiency of Ethanol burning must first be examined in order to determine if it is a viable replacement to gasoline. Ethanol contains less energy than gasoline when being burned, thus leading to worse fuel economy. In addition, most cars have not been designed to handle higher blends of ethanol into gasoline, thus leading to worse fuel efficiency. The E10, or gasohol, blend of 10% ethanol and 90% gasoline has become more commonly available in the United States where 10 states have sanctioned it as mandatory. In terms of efficiency, the E10 blend will generally run about 3-4% fewer miles per gallon on an automobile than straight gasoline would.<sup>100</sup> E85 blends contain much higher concentrations of ethanol as fuel and are used in Flexible Fuel vehicles (FFVs). E85 blends will typically experience a 25-30% drop in the miles per gallon of a vehicle due to the lower energy content.<sup>101</sup> Even with replacing most common gasoline stations in the United States with E10 gas, it is uncertain if ethanol will have a significant impact on the reduction of CO<sub>2</sub> emissions given its less efficient nature compared to gasoline.

To approach the question of pollution by ethanol on the consumption level and whether it is or is not a viable replacement of gasoline, carbon dioxide levels must be measured. This will determine which releases more based on the same level of usage, gasoline or ethanol. The burning of fossil fuels has largely contributed to the increase in carbon dioxide in the Earth's atmosphere, and the introduction of ethanol sought to reduce the levels of carbon dioxide being released into the atmosphere. While other greenhouse gases being released into the atmosphere are prevalent, this analysis will focus on carbon dioxide because it has irreversibly long term effects in the atmosphere. This is due to the

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<sup>100</sup> Knoll, Keith, Brian West, Wendy Clark, Ronald Graves, John Orban, Steve Przesmitzki, and Timothy Theiss, "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 - Updated" Prepared by the National Renewable Energy Laboratory, February 2009. P. 3-3.

<sup>101</sup> West, Brian H., Alberto J. Lopez, Timothy J. Theiss, Ronald L. Graves, John M. Storey, and Samuel A. Lewis, "Fuel Economy and Emissions of the Ethanol-Optimized Saab 9-5 Biopower" Prepared for SAE International, January 2007.

greenhouse gas effect, where gases like carbon dioxide will raise the temperature of the Earth.

To measure the amount of CO<sub>2</sub> released into the atmosphere by the different types of automobiles, this analysis will determine the average miles per gallon of the different fuel types and with this find the amount of CO<sub>2</sub> that is released per mile. With these numbers we will be able to compare gasoline with the E10 and E85 fuel blends to see what will release more CO<sub>2</sub> per mile.

*i) Average ethanol miles per gallon*

The change in miles per gallon by blend will first be taken into account. Given findings found that were mentioned earlier in this paper, 28% will be used for the change in E85 miles per gallon.

$$\Delta \text{E85 MPG} = \mathbf{28\%}$$

The average fuel efficiency for light duty vehicles with short wheel bases is 23.8 mpg.<sup>102</sup> Given the average fuel efficiency we can find the average mpg of the different blends of ethanol by using the change of mpg from the different ethanol blends.

$$\text{Avg E85 MPG} = 23.8 * .75 = \mathbf{17.1}$$

Using the amount of CO<sub>2</sub> release from gasoline, E10, and E85, the CO<sub>2</sub> emissions per mile can be calculated given the average mpg determined above. The CO<sub>2</sub> emissions from a gallon of gasoline are 8,887 grams CO<sub>2</sub>/gallon.<sup>103</sup>

*ii) CO<sub>2</sub> emissions comparison on a per mile basis*

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<sup>102</sup> Bureau of Transportation Statistics, "Average Fuel Efficiency of U.S. Light Duty Vehicles" (Washington D.C., 2011).

<sup>103</sup> Environmental Protection Agency, "Greenhouse Gas Emissions from a Typical Passenger Vehicle" (Washington D.C., 2011), 1.

CO2 emissions per mile gasoline= CO2 emissions per gallon / MPG = 8887/23.8 = **373.4 grams**

Given that we converted the average miles per gallon of each ethanol blend on the basis of gasoline, we can use the same carbon dioxide emissions per mile number as we used when calculating gasoline.

CO2 emissions per mile E85= CO2 emissions per gallon / MPG = 8887/17.1 = **519.7 grams**

*iii) CO2 emissions comparison on a total consumption basis*

In addition, earlier in our analysis, we found that if the United States were to switch from gasoline transportation to only E85 fuel for transportation, we would be using 159 billion gallons of E85 blend. Also, we must find the total amount of gasoline consumption.

Total E85 transportation consumption = 159 billion \* 17.1 = **2,719 billion miles**

Total gasoline consumption = Total fuel consumption (1- % Ethanol Additives) Avg mpg

Total fuel consumption = 134 billion gallons

Total ethanol additives = 10%

Total gasoline consumption = 134 (1-.1)(23.8) = **2,870 billion miles**

Comparing these two numbers, we see that total miles driven from E85 fuel blends would be 2,719 billion. The total miles driven from using gasoline fuel would be 2,870 billion miles. This shows that with the same relative amount of fuel necessary to supply the United States, gasoline would provide more overall miles. Now, applying the CO2 emissions per mile for E85, we can see the amount of CO2 a switch from gasoline to E85 would yield.

Total CO2 yield E85 = 2,719 billion \* 519.7 = **1,413 billion kilograms CO2 released**

Total CO2 yield gasoline = 2,870 billion \* 373.4 = **1,071 billion kilograms CO2 released**



*iv) Total CO2 emissions on an economic cost basis*

Given this analysis, we see that there are in fact more carbon dioxide emissions per mile and in total consumption by E85 blends compared to gasoline given the increase in miles driven due to the lower energy content of ethanol. Next, the amount of CO2 released must be assessed from a cost basis. From an economic stand point, the amount of CO2 emissions leads to a cost of damages that is incurred from climate behavior and the related physical damages that go along with environmental change. According to the Environmental Protection Agency, one ton of CO2 released into the atmosphere led up to \$35 in economic damage according to a social cost of carbon discount rate of 2.5% which estimates the monetized damage associated with the incremental increase in carbon emissions.<sup>104</sup> Analyzing our results from a cost benefit standpoint, we can compare the total cost of E85 versus the total cost of gasoline and compare the change. The total cost of gasoline will be the benefit that will be gained because the United States will no longer suffer from the CO2 emissions from gasoline. The total cost of E85 would be the cost of the United States because by transitioning to purely E85, the United States would be taking on new economic costs from the emissions resulting from the use of ethanol.

1 ton = 907 kilograms

Total Cost E85 = (1,413 billion/907) \* 35 = \$54 billion

Total Cost gasoline = (1,071 billion/907) \* 35 = \$41 billion

Cost Benefit Analysis:

Total Cost = \$54 billion

Total Benefits = \$41 billion

Total change = \$13 billion in cost

*v) Consumption level pollution cost benefit analysis summary*

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<sup>104</sup> Environmental Protection Agency, "Social Cost of Carbon for Regulatory Impact Analysis" (Washington D.C., 2010), 2.

From our cost benefit analysis of ethanol from a consumption pollution standpoint, we can see that it is currently not a viable solution. The economic costs in CO2 pollution outweigh the benefits by \$13 billion. In order to become a viable pollution reduction replacement on the consumption level to motor fuel, ethanol first needs to become more fuel efficient. This can be done when better technology is created and distributed. More advanced fuel efficient engines that are better designed to operate using ethanol as fuel would lead to higher potential miles per gallon with ethanol. Better designs would mean more ethanol would not have to be used by cars in order to consume the same number of miles that results from gasoline. Until then, ethanol cannot be considered a viable replacement to gasoline on the consumption level from the basis of pollution.

## **5) Conclusion**

Converting corn to ethanol is an expensive and time consuming process, whose costs seem to far outweigh its benefits in terms of transportation needs. E85 itself is not as energy dense as gasoline, the net energy gain isn't that great or necessarily apparent, and the process has some negative externalities such as increased pollution. Estimates for the NEV of ethanol compared to gasoline range a fair bit but average about a 1:1 ratio meaning there is a net sum of zero benefits there. Furthermore, much of the progress made towards ethanol as a main fuel for ground transportation was made possible only with generous government subsidies that come at a cost to taxpayers. Infrastructure changes to accommodate the transition to e85 are a major cost and reason to forego this conversion and they sum to at least \$390.4 billion under the long term solution of a pipeline network. The greenhouse emissions differences total to 970 million extra tons of CO2 from the consumption and production side when comparing going to e85 versus now. Monetized, this amounts to some \$33.9 billion. However, it is clear from the sheer amount of extra corn needed that it is unfeasible to grow this amount of corn in the United States. Currently some 700 billion lbs. are grown yearly and we would need some 4 trillion lbs a year to satisfy the transportation needs as well as keep other corn consumption constant. Assuming a similar corn to acre efficiencies as now, there would have to be the equivalent of some 10 Illinois set aside to grown all the extra corn. Clearly that cannot be done and to buy this much corn on the market would send prices skyrocketing, further endangering

those who already are already struggle to feed themselves. As such for the reasons summarized above we find it unfeasible to try to run the nations ground transportation on e85.

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