Corn Ethanol: The Thermodynamics and Environmental and Political Realities

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Abstract

The goal of this project was to explore the ethanol industry in the US. In this report we detail the energy balance of producing ethanol; the impact ethanol can have on the economy as a substitute for gasoline, as well as ethanol's environmental impacts. This report shows that although the net energy balance of producing ethanol is positive, the industry would not survive without huge government subsidies. We hope that this report will cause people to question government subsidies being paid out to a small group of producers, and to encourage legislature to remove or reduce current ethanol subsidies.

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Introduction

Ethanol is a simple, clean burning alcohol with an energy content comparable to, but slightly less than, that of gasoline. Many people view ethanol as a possible solution to the energy crisis the world is facing as natural fossil fuel supplies are quickly being used up. Pure ethanol as a fuel as well as ethanol gasoline blends seems to have several advantages over pure gasoline. Price at the pump is a big factor right now. Currently the cost of E85, a blend of 85% ethanol, and 15% gasoline, hovers around $2.00 per gallon[1]while the cost of pure gasoline is about $2.15 (as of this writing). This price difference means very little to most drivers, but there can be up to a 4% fuel efficiency loss when using the ethanol blend E10 as compared to gasoline.[2] This loss is due to poor combustion in engines not designed for ethanol use, as well as a lower energy content of ethanol (1.15 kg of ethanol has the energy content of about 1 kg of gasoline)[3]. However, for flexible fuel vehicles designed to run on ethanol blended gasoline the fuel efficiency difference is much smaller, with the difference resulting only from the difference in energy content. In early September 2005 the price difference was much greater, as average gasoline prices were over $3.00 per gallon, with E85 prices staying closer to $2.00 per gallon depending on location. In the Midwest where ethanol is produced in the largest quantities and flexible fuel vehicles are most abundant, the difference in price between the two fuels averages about $0.50 cents per gallon with E85 the cheaper of the two[4].

Another perceived benefit of ethanol as a fuel is that every atom of carbon in the carbon dioxide produced during combustion originally came from the atmosphere so there is no net addition of carbon, which helps to prevent greenhouse gas buildup. About 90% of all ethanol produced for use as a fuel comes from corn crops.[5]

Many politicians believe ethanol is a way to reduce dependence on foreign oil[6]. Having a renewable source of energy that can be produced in the US, and provide jobs to people in the Midwest where ethanol plants are most abundant would be a huge step towards securing energy supplies for future generations.

E85 also removes the need for antifreeze in cold climates. Pure gasoline has no ability to absorb water, and in cold weather water can build up in fuel lines and freeze. Ethanol blends have a much better interaction with water, and can absorb excess moisture in fuel lines and displace it, preventing fuel lines from freezing.

Literature Review

Ethanol production

Most ethanol used as a fuel in the US is produced from corn[7]. Two methods of converting the corn to ethanol are used, wet milling and dry milling. Dry milling starts with whole corn ground up in a hammer mill to form a fine powder called meal. The meal is mixed with recycled water and alpha-amylase. This mixture is passed through a jet cooker heated by steam (often recycled from other plant processes[8]), and passed to a liquefaction tank. In the liquefaction process, the mixture is passed through cookers where heat is applied to liquefy the starch. Enzymes (commonly gluco-amylase) are added after the mixture has been passed through mash cooling to convert the starch to fermentable sugars (mainly dextrose). Yeast is then added to ferment the sugars to ethanol typically over 48 hours. This step releases carbon dioxide which can either be used as a coproduct or released. The product of this step, called beer, contains roughly 10% alcohol by volume. The beer from the fermentation tanks is passed through a distillation system where it is separated into 190 proof (95%) ethanol, water, and whole stillage. The whole stillage is processed by centrifuge, and converted into the coproduct DDGS (distillers' dried grains with solubles). DDGS is often sold as livestock feed. The steam or hot water is often recycled to earlier plant processes, either used for it's heat, or directly added to the liquefaction step. The 190 proof ethanol is passed through molecular sieves to remove the remaining water, and then mixed with gasoline or other hydrocarbons to denature it, rendering it unfit for human consumption, ending in the final product 200 proof denatured ethanol.[9] Wet milling is mainly the same process but without first grinding up the dry grain to include the whole kernel. Instead of grinding, the corn is added to water and sulfurous acid and steeped for 24-48 hours. The mixture is ground to separate out the corn germ, and centrifugal, screen, and hydroclonic separators separate remaining fiber, gluten, and starch. The starch and water mixture is fermented into ethanol following the same process as dry milling.[10] Many plants choose dry milling because of its lower capital and operating costs, and the lack of sulfurous acid makes it a much safer process.

Energy balance

Many studies have been done on the energy balance of producing ethanol. To gain some perspective on the reported energy values, it's necessary to know how much energy you can get out of ethanol for various purposes. The energy content in a gallon of ethanol burned for fuel is about 76,000 BTU, the LHV (low heat value; all water produced during combustion is in vapor form). Many studies use 80,000 BTU per gallon as the energy content of ethanol, which is an average of the HHV (high heat value; all water produced during combustion is condensed into a liquid) and LHV of ethanol, perhaps an unfair estimate since it is impossible to gain any useful energy from the

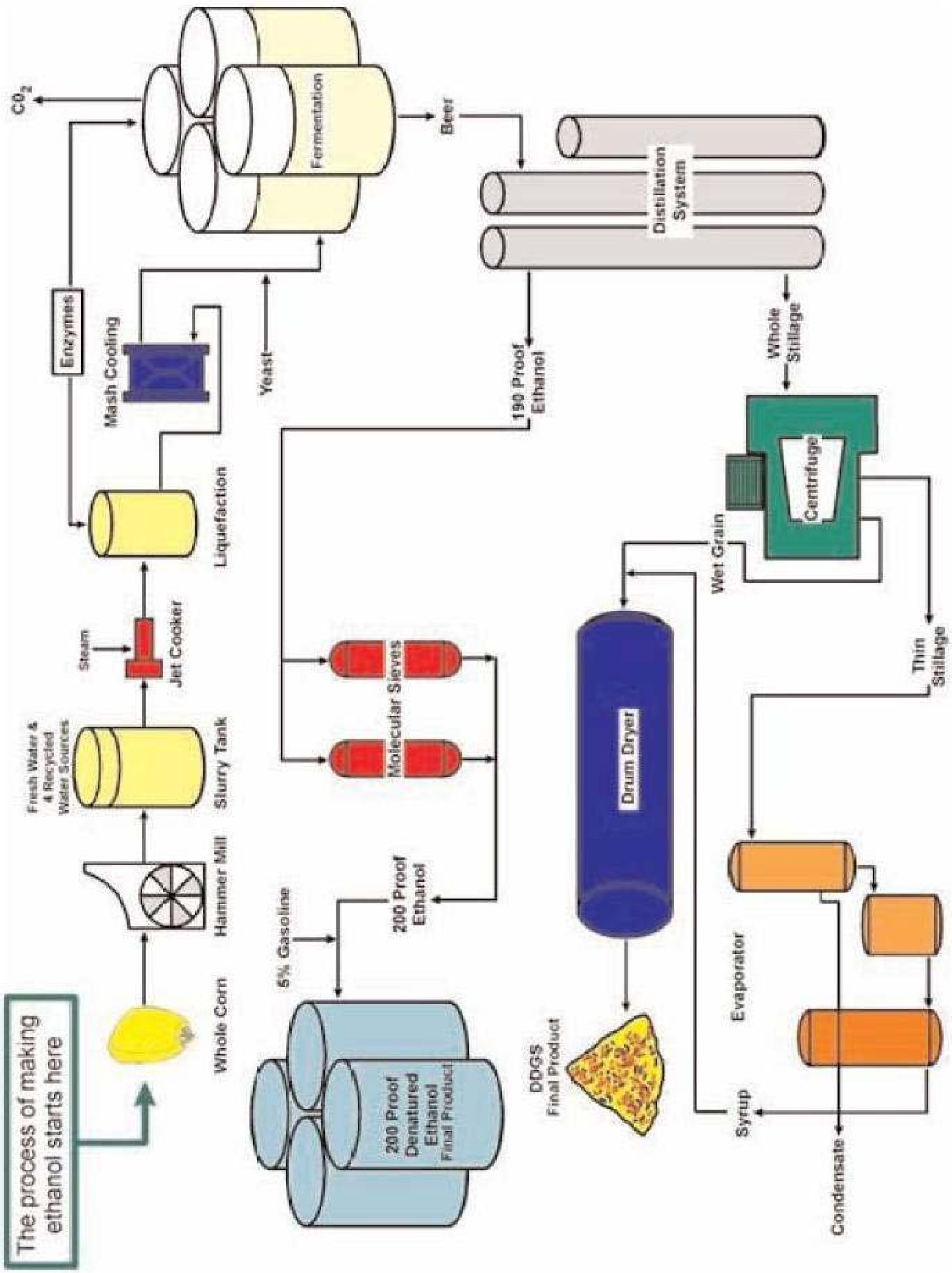

Figure 1: Ethanol Plant Flow Chart[11]

condensation of water in an automobile engine. If ethanol were being used in a process where all energy is conserved, as in heating, the HHV would be applicable, the energy content would be 84,000 BTU per gallon.

In Pimentel's 1991 paper on the ethanol energy balance, he showed a net loss of over 33,000 BTU per gallon of ethanol produced[12]. Keeny and Delucia showed a net loss of 8,000 BTU per gallon[13], and Ho showed a net loss of 4,000 BTU per gallon[14]. On the positive side, Shapouri, Duffield and Graboski showed a gain of 16,000 BTU per gallon[15], Marland and Turhollow showed a gain of 18,000 BTU per gallon[16], and Morris and Ahmed showed a gain of over 25,000 BTU per gallon[17]. The major difference in these figures arises from different assessments of the energy required for distillation, and the energy gained from co-products produced along with ethanol. Pimentel by far assumed the highest energy cost estimating 73,687 BTU per gallon are used in the conversion process alone. Keeny and Delucia estimated a much lower 48,434 BTU for the conversion process. Ho assumed the second highest energy required for the conversion process, 57,000 BTU per gallon. Shapouri, Duffield and Graboski estimated 53,277 BTU per gallon. Marland and Turhollow had the lowest value for this process, 40,105 BTUper gallon, and Morris and Ahmed estimate 46,297 BTU per gallon. One major point of difference that sets Pimentel's energy requirement much higher than any of the other studies is his inclusion of the energy required to construct the ethanol plant in this figure. He includes such factors as the energy involved in the steel, cement, and construction equipment that represent a one time energy cost to start up the plant, but play no part in requiring more energy for the actual distillation process. However, these factors add up to only about 7,000 BTU per gallon, and by leaving these out Pimentel still estimates the highest energy requirement of all of the studies. A second point of disagreement is the ethanol conversion rate. Surprisingly, both the high and low energy estimates (Pimentel vs. Marland and Turhollow) use the same low ethanol conversion rate. They assume that ethanol can be distilled from corn at a rate of about 2.5 gallons per bushel. This is at the lowest end of the conversion spectrum, assuming that the outer fibrous layers of the corn kernels are unusable, and this value generally does not agree with the outputs described by state of the art ethanol plants. Dry grind plants produce 2.7 to 2.8 gallons of ethanol per bushel without a significant difference in energy input.[18] Pimentel also uses low estimates of corn yield per acre.

Corn crop yield may not seem like a big factor in the energy balance of ethanol, but a good amount of the energy expense is seen in fertilizer applications and farm equipment. Increasing, crop yield without increasing the amount of fertilizer used would make ethanol production more energy efficient. Modern farms produce closer to an average of 120 bushels per acre instead of the 110 bushels per acre used in Pimentel's study. This value obviously depends on numerous factors including weather patterns and can change from year to year. Averages are calculated on a 3 year basis, Pimentel appears to be using the average corn yield from 1980-1982, which was 109 bushels of corn per acre. More recent technology has allowed the average to climb over the years and in 1998-2000 reaching an average 140 bushels of corn per acre while using nearly 20% less fertilizer per bushel[19]. This low estimate of crop yields combined with his high estimate of 136 lb per acre of nitrogen fertilizers show why Pimentel's estimate of the energy expense used to produce corn crops and corn ethanol is higher than other studies using more reasonable up to date data.

Coproduct energy is another point of dissent among studies. Pimentel uses only the energy recovered from DDGS (distillers' dried grains with solubles) which is a dry milling coproduct. Corn oil, corn gluten meal (CGM), and corn gluten feed (CGF) are coproducts derived from wet milling. Both dry and wet milling emit carbon dioxide but Morris and Ahmed are the only authors to include it in their analysis.

Coproducts also can be used in unconventional ways to gain more of their energy than expressed in these reports. For example, the Permolex ethanol plant in Alberta Canada is exploring the possibility of using waste heat and carbon dioxide produced to run a year round greenhouse. A feasibility study concluded that the plant could sustain a greenhouse complex spanning up to six acres where they would grow cucumbers. Other plants already have innovative uses for waste heat. The EcoGenics research center in Tennessee operates a small ethanol plant (26,000 gal/year) and operates a biosphere for tilapia fish and production of spirulina algae by keeping the temperature between 75 and 85 degrees Fahrenheit year round with waste heat. In Iowa, the Department of Natural Resources developed an energy farm concept in which a small ethanol plant served as an aquaculture facility heater used for raising fish commercially.

Subsidies

Corn growers and ethanol plants receive billions of dollars in subsidies each year. One main point that needs to be addressed in the assessment of ethanol as a fuel is whether or not it would be economically sustainable without grants from the government. On the consumer end, we see government subsidies in effect in excise taxes. In 2001, excise taxes on gasoline were $0.184 per gallon, but 10% ethanol blended gasoline enjoyed a $0.053 exemption per gallon.

To encourage ethanol production a “small producer’s credit” is given to ethanol plants producing 30 MGPY or less[20]. This credit was given as an income tax credit of up to $0.10 per gallon, up to 15 million gallons a year. This credit can only be given if tax is due, but can be a pass-through credit for individual investors in small ethanol plants.

An incentive offered by the USDA in 2001-2002 has been $300 million biofuels effort to increase production of ethanol and other renewable fuels such as biodiesel.[21] This incentive offered payment to any plant increasing it's ethanol production over the previous year.

State subsidies, specifically in the Midwest, provide a large portion of the money used to fund ethanol production. For example, Minnesota offers a $0.13 per gallon payment for the first 15 MMGY (million gallons per year) per facility per year for eligible plants until July2007. Minnesota also offers a $0.058 excise tax exemption on E85. They have also passed laws requiring all gasoline sold in the state to be blended with 10 percent ethanol, and all state owned flexible fuel vehicles must use E85. Montana provides a huge $0.30 per gallon payment (not to exceed $3 million per year per producer) for plants using state resources, and a proportionately reduced payment for plants using out of state resources.

Energy demand

The United States consumes a huge amount of energy for transportation. Approximately 20 million barrels of oil per day are consumed in the US alone, which translates to about 300 billion gallons of gasoline per year.[22] Depending on the temperature of combustion, ethanol contains from 75,700 BTU to 84,000 BTU per gallon. Assuming combustion at an average of 25 degrees Celsius, a gallon of ethanol used as fuel will give off 80,000 BTU of energy.[23] One gallon of gasoline contains approximately 120,000 BTU. With this difference in energy content, it would take 450 billion gallons of ethanol to completely replace gasoline as a transportation fuel in the US.

The US produced 9 billion bushels of corn in 2002. 900 million of these were used to produce ethanol. Modern ethanol plants produce an average of 2.5 gallons of ethanol per bushel of corn[24]. Technologically advanced plants which use whole kernels including the outer fibrous layer can achieve up to 2.8 gallons of ethanol per bushel of corn. If every ethanol plant achieved this larger value, and if every bushel of corn grown in the country was used for ethanol production, a total of only 25.2 billion gallons of ethanol could be produced. Compared to the 450 billion gallons of ethanol that would be needed to satisfy the country's transportation fuel demands, the total impact corn ethanol production could have is a mere 5.6%.

New technologies could push this figure higher, new yeasts with modified genetics secrete cellulolytic enzymes that can break down cellulose into simpler sugars that the yeast can convert to ethanol[25]. With a similar achievement, cellulase hyperproducing F3 strains of fusarium oxysporum will ferment cellulose directly to ethanol[26]. These technologies have yet to be used on a large scale, and even if efficient means for fermenting large quantities of cellulose were available there would still be a huge gap in fuel demand and ethanol production capacity.

An Analysis of Ethanol Production in the US

Ethanol Plant Energy Balance

A modern ethanol plant using current technologies for the production and separation of ethanol from water uses less energy to create a gallon of ethanol than one gets out of the ethanol[27]. Although many ethanol plants are hesitant to share their energy expenses, The Gildred/Butterfield Fuel Alcohol Plant in California has provided its performance data in great detail. This plant was constructed after winning an ethanol fuel plant design competition sponsored by the California Department of Food and Agriculture and the California Waste Management Board. This plant reports 22,235 BTU of energy is used to produce 1 gallon of ethanol. (See table 1). This is much lower than the 80,000 BTU of energy contained in a gallon of ethanol[28] burned at room temperature. However, this plant uses no molecular sieves or other separations technology to dry the ethanol after distillation. The purity of ethanol needed to be able to blend with gasoline is 99.5%[29]. Surprisingly, drying ethanol to 99.5% takes a very small amount of energy compared to the distillation process, accounting for another 135 BTU per gallon[30], bringing the total for in-plant energy use to 22,370 BTU per gallon of ethanol produced.

Table 1: Energy Demand of Gildred/Butterfield Ethanol Plant[31]

Energy Using Process	BTU/gallon
Cooking	2,441
Distillation	18,436
	KWh/day
Cook Tank Mixer	17.9
Utility Pump	3
Sweco	2.2
Screw Press	9
Beer Pump	5.9
Bottoms 1 Pump	5.9
Bottoms 2 Pump	5.9
Reflux Pump	5.9
Condenser Fan	1.5
Compressor	22.4
Other utilities	15.9
TOTAL:	95.5
TOTAL FOR DISTILLATION:	**25.1**
KWh per gallon of ethanol:	0.398
KWh per gallon of ethanol from distillation:	**0.105**
1 kilowatt hour = 3 412.14163 BTU	BTU/gal
From plant electricity use	1358
From distillation electricity use	**358**
TOTAL ENERGY USE/GAL WITHIN THE PLANT	22235
TOTAL ENERGY USE/GAL FOR DISTILLATION	**18794**

Many authors will grant a co-product energy credit per gallon of ethanol. Dry milling produces 2 main co-products, carbon dioxide, and DDG (dry distillers' grains). Carbon dioxide is often collected, compressed, and sold to other industries, but is generally not included as an energy credit because of the amount of energy used in collection and compression of the gas. DDG is sold as a feedstock for cattle, but cannot be used for many other forms of livestock because of it's low protein content (27%)[32]. For every 10 kg of corn that is used for ethanol, 3.3 kg of DDG are produced[33]. This does not add to the energy balance of operating the plant, it's only contribution to energy requirements at all is in lowering the price per gallon of ethanol.

Cellulose

Cellulose is one of the most prominent organic molecules on the planet, as it is a key component to plant life. Cellulose is a sturdy material that weaves together to form the strong, fibrous backbones of cell walls in plants, giving them their robust stalks and tough nature. Cellulose, however, also has a high energy content, but isn't digestible to humans, so its other uses are being explored. It can be found in almost pure form as cotton, and it is also a major constituent of most agricultural wastes.

The nature of cellulose is of a strong chain, which has countless links in the chain connected by oxygen atoms. Cellulose is a carbohydrate, like sugar and starch, but cellulose isn't utilized directly for energy. The monomer of cellulose, or the individual links in the chain, is a six membered ring called beta-glucose. The reason why glucose binds so tightly is because the chains it exists as will hydrogen bond with other chains that are parallel to it, creating a fibrous sheet. Other sheets will stack on top of one another, and create a sturdy material. The strong material can't be digested directly by humans, but animals with more complex digestion systems and many types of bacteria can get energy from cellulose directly.

Using chemical processes, the cellulose can be broken down and converted into glucose. From there, the same types of processes that are used in converting corn sugar into ethanol are applicable. This is done by breaking down the long cellulose chains into five and six carbon ringed sugars. The prospect of turning these agricultural wastes into ethanol could put a positive spin on ethanol, if, in fact, the energy balance is positive.

One of the most frequently cited sources of cellulose would be the agricultural wastes of growing corn. The majority of the corn plant is the stalk, the leaves, the cob, and the husk. These are high in cellulose, but very low in sugar. The residue, or the part of the corn plant that remains after the harvest, is often left on the field after the harvest until spring to return nutrients to the soil and to prevent erosion during the winter.

This cellulose residue is not specifically waste, but only a small portion of it (enough for 30% ground cover) needs to be left to regenerate the soil. The remaining residue can be grazed on by cattle. The amount of residue left for a 100 bushel/acre grain yield should result in 6000 lbs of field residue, which can sustain a 1000 lb animal for 60 days. This procedure allows for a large number of livestock to graze a limited area for a short period of time, and is available as soon as the corn is harvested in the fall. This source of 'waste' is actually well recycled. If the residue is overgrazed, or if the residue itself is harvested, a rye or wheat crop must be seeded to protect the soil from erosion during the winter months.[34]

The corn residue can be stacked or baled in order to maintain it as a crop after the main corn grain has already been harvested, but like above there must be another crop planted to preserve the soil quality until the spring. Stacking or baling is simply collecting the residue using machinery, and compacting it into large stacks or bales that are tight enough to resist weather, so it can be left on the field. Stacking or bailing forces the grain harvest to be delayed due to moisture tolerances, as moisture must drop to under 30% before the residue won't spoil when stacked. This process can result in soil compaction, as it requires heavy machinery to cross and recross the fields.[34]

Another method of retrieving the residue is to harvest it as silage, or putting it in an air tight container such as a silo and allowing it to ferment to become a viable animal fodder. This allows for a higher moisture content than stacking or bailing, as the fermentation in a silo is expected, so harvesting the residue immediately after the grain is appropriate. The water content should be greater than 50 or 60%, and water must be added if the content drops too low.

The silage must be chopped fine and packed tight, which makes for more energy use in processing the residue. Like stacking, this will remove nearly all of the corn residue, so it is important to plant another crop immediately thereafter to maintain the soil.

This residue is commonly used as feed for animals after it has been processed conventionally, but it is not a high quality feed. It is low in energy and protein, and difficult for cattle to digest. It does not have the nutrients to sustain cattle year round, especially when a cow is pregnant. The harvest of this limited feed is well established to have varying effects on the corn crop, but the residue is still a crop that can be harvested while maintaining the corn fields.

The Corn Stover Collection Project[35] was operated between 1996 and 1998 to assess the costs involved in collecting the excess corn residue (stover, the dried stalks and leaves of a cereal crop, in this case corn, sometimes used as animal feed after the grain has been harvested.) created by the US corn production in Iowa. The collection method used was to bale the corn stover, and a second operation to collect the bales and delivering them to the processor. After two separate attempts after the 1996 and 1997 corn harvesting season, there were predictions that corn stover could be collected and transported for less than $33 per dry Mkg (1.1 dry ton) of baled corn residue. This would be a theoretical cost of $0.10 of starting material for each gallon of ethanol, and the corn residue available in the US is estimated to be between 80 and 120 million dry tons. In

1998, the ethanol produced could have theoretically accounted for up to 10% of US gasoline consumption without endangering the current corn crops.[35]

Another source of cellulose often cited is wood wastes, in the form of prunings, wood chips, and sawdust. Many sawmills already produce large quantities of residue that are recycled, but many smaller sawmills do not produce enough waste to warrant a large scale operation such as an ethanol plant. The amount of wood wastes from multiple saw mills may be collected and communized into one ethanol plant, but the transportation costs would have to be considered in the energy balance of the ethanol production. This would put ethanol plants of this nature at a natural disadvantage, because they would necessarily be using more energy to produce ethanol than an on-site plant.

Cass Lake, Minnesota, was considered to be a prime location for an ethanol plant due to the local lumber mills that were putting their wood wastes into landfills at a cost to the plants. In order to sustain a 20 million gallon per year ethanol production, the plant would have to collect the communal wood wastes from every sawmill within a radius of at least 100 miles.[36]

Urban wood wastes include wood hauled with trash, municipal yard waste, utility tree trimming, and private tree trimming. The industrial sector also produces a substantial amount of wood waste, from pallet companies, truss companies, wholesale and retail lumber companies, and woodworking companies.

North Dakota, a large source of wood waste, was surveyed[37] for wood waste by city. These findings show that no city produced enough wood waste to sustain a viable ethanol plant, but if transportation costs were minimal, a collective plant could produce over 15 million gallons of ethanol per year. [37]

Some crops can be grown for their cellulose content alone, as switchgrass is currently being studied for its viability as an ethanol crop. The tallgrass is a common species that flourishes naturally. It is found naturally in the northern Great Plains area, and grows on much Canadian soil with ease. The Canadian government is heading up the Ecological Agriculture Projects[38] program, which is investigating growing switchgrass en mass to replace Canadian dependence on gasoline, and help reduce their CO_2 emissions.

The Ecological Agriculture Project refers to 35 million acres of land that can be used for growing switchgrass, and using statistics of switchgrass production is the US, they estimate that 2.8 tons of switchgrass can be produced per acre annually. As one ton of switchgrass can be converted into approximately 400 liters of ethanol, the EAP believes that it can produce 39.2 billion liters of ethanol per year at full production, which would be 2 billion more liters than Canada's equivalent gasoline consumption.[39]

A recent report[40] compiled the findings of four prominent cellulosic ethanol research teams to compare their varying calculations. It concludes that the gross energy inputs for cellulosic ethanol is much lower than that of corn ethanol, with the majority of experts agreeing on a substantial return.

So how does this ethanol conversion work? There are three distinct methods of converting cellulose into a usable fuel. These are Concentrated Acid Cellulose Conversion, Dilute Acid Cellulose Conversion, and Enzymatic Cellulose Hydrolysis. Concentrated Acid Cellulose is a process that has been patented by Arkenol and Masada Resource Group, but is touted as a cost effective method for converting cellulosic material into ethanol. The four processes begin the same, with 'pretreatment', or separation of the various components of the raw biomass collected. This is usually done by a mechanical process that physically grinds down the mixture of biomass, and steam processing. Chemical pretreatment consists of dilute mixtures of acids, organics solvents, and other chemicals. This is to make the biomass more digestible.

Then, the cellulose is treated with a hydrolysis step, by introducing concentrated acids to dissolve it, and then dilution with water hydrolyzes it, which changes the beta-glucose into glucose. At this point, the long chains of cellulose have been broken down into small chains of five or six glucose molecules, which are easily digestible by living organisms. After this stage, the fermentation and separation processes are similar to those of ethanol, except with the additional hurdle of removing the concentrated acid. However, as the original biomass contains lignin, and this byproduct can be used to fuel the hydrolysis, fermentation, and distillation processes.

This process is the one that the Canadian EAP is basing the numbers calculated from their switchgrass operations off of. It is the most efficient of the modern cellulosic ethanol conversion methods that have been extensively tested.

The second, older method of converting cellulose into ethanol is Dilute Acid Cellulose Conversion[41]. This process is more complicated, as it requires two stages as it needs to differentiate between cellulose, and hemicellulose, which is structurally similar to cellulose. This process uses excess cellulose and lignin from the hydrolysis reactors to produce energy to power the operation, and this technique is still viable today.

Enzymatic Cellulose Hydrolysis[42] uses enzymes to accomplish the step of hydrolysis rather than acid water mixtures. Recent technology has allowed for the hydrolysis and cofermentation of cellulose, which means the same microbes can break down and then ferment cellulose in one step, converting it directly into ethanol in one step. The Ecological Agriculture Projects program calculated their numbers by using this form of cellulosic ethanol conversion for switchgrass. They also believe that lignin will be utilized to drive the energy of the reactions of the conversion processes. This process is believed to be more efficient than Concentrated Acid Cellulose Conversion, but it is still technically an experimental method. There are only two ethanol plants (the oldest of which was established in 2004) believed to use this method.

Another form of biomass conversion to a gasoline equivalent is through a rising company called Changing World Technologies, Inc. Their vision is to take almost any carbon based waste, and put it through the same kind heat and pressure that would naturally occur to buried organic deposits in the creation of crude oil. The “Thermal Conversion Process” they use claims to produce a substance identical to crude oil. Their tagline, "Turkey Oil"[43], refers to using the remnants of turkey factory farms that would normally be discarded to create this oil. This technology is claimed to be useful not only on discarded animal products, but a wide range of carbon based organic materials, from tires to municipal waste. The thermodynamics behind their methods are not yet published, so no further analysis can be conducted at this time, but recently a plant met in Missouri met a negative fate when the mayor of the town of Springfield shut down the plant due to failing to comply with emissions standards, specifically, a foul odor.[44]

The true impact of such technologies has yet to be seen. The Canadian Ecological Agriculture Projects program believes in the feasibility of the switchgrass as a source of ethanol to power the Canadian economy, and the corn stover that is wasted every year from the current corn crop shows more promise in the ethanol market than corn does. But the jealous guarding of techniques and processes to create a more potent cellulose or biomass to ethanol process makes further scientific pursuit of this impossible to judge how realistically the industry can supplement current gasoline consumption. The current condition of the cellulose to ethanol market is so small, a mere six plants as of 2004, that true scrutiny of their practices would be unrealistic to base expectations for major global changes on.

Environmental Impact

Ethanol is often considered an environmentally friendly fuel because most of the carbon released as CO_2 during it's burning came originally from the atmosphere, and the great majority of it's energy contact was originally solar energy. This seems like good news compared to gasoline. However, taking a closer look at ethanol is necessary to see if it is indeed as environmentally friendly as it seems.

Most ethanol plants use coal as well as other fossil fuels and electricity to power the conversion of corn to ethanol. Transportation, and production and application of fertilizers also contribute a great deal of fossil fuel resources to the overall production of ethanol. Patzek calculates the equivalent CO_2 emissions to be 7475 kg of CO_2 per hectare of corn[45]. Based on his estimate of 2294 kg of ethanol per hectare, and the energy ratio of one kilogram of gasoline to 1 kilogram of ethanol being 1.15:1, we calculate that it would be necessary to burn 1995 kg of gasoline to get the same energy content as 1 hectare of corn. Gasoline emits 0.067 kg of CO_2 per MJ of energy.[46] Gasoline contains 44 MJ of energy per kg (http://hypertextbook.com/facts/2003/ArthurGolnik.shtml), and so burning an equivalent energy content of gasoline would emit about 5800 kg of CO_2. This poses an interesting question. If ethanol emits 1675 kg more net CO_2 per hectare of corn than it's energy equivalent in gasoline, where is the carbon coming from?

Fertilizers are a big source of greenhouse gases. First we must consider that in Patzek's calculations, he considered CO_2 equivalents, so the numbers are a little misleading. Patzek reports that 1.25% of nitrogen fertilizers applied to a corn field escape into the atmosphere as N_2O; 30% of nitrogen fertilizers escape from the field and 2.5% of that amount is converted to N_2O in surface water; 10% of nitrogen fertilizer escapes into the air as NH_3 and 1% of that becomes N_2O; and an average ammonia plant emits .03 kg N_2O per kg of nitrogen in nitric acid used to make ammonium nitrate. This doesn't seem to add up to much until we consider that N_2O is 300 times more potent as a greenhouse gas than CO_2. In total, using these numbers, fertilizers alone contribute 1950 kg of CO_2 equivalents per hectare. This number is somewhat unfair, considering that not all corn crops use ammonium nitrate as a fertilizer, and the amount of other nitrogen fertilizers varies greatly from farm to farm.

Subsidies and Economic Impact

The question of whether the ethanol industry would survive without subsidies depends on how much consumers are willing to pay for ethanol. Federal and state governments have invested billions into the corn ethanol industry. Even excluding start up costs, many ethanol plants are payed on a per gallon basis. State payments, which can be as high as 40 cents/gallon, can be seen in table 2. Federally, there is a 54 cent/gallon tax credit for ethanol plants that blend ethanol with gasoline to form gasohol.[47] For consumers, there is a 5.4 cent federal excise tax exemption for E10 (10% ethanol, 90% gasoline blend). States further promote the sale of ethanol blended gasoline by providing tax exemptions up to 8 cents per gallon (see table 2). Subsidies of ethanol alone, not including corn farm subsidies can subtract as much as $1.08 from the price of a gallon of ethanol. Senator McCain reported the price of a gallon of ethanol in 2003 as $3 per gallon after subsidies[48]. If ethanol was not subsidized by state governments, the cost to consumers could be $4 per gallon or more.

Table 2: State subsidies available to ethanol plants and consumers

State	Consumer Tax Exemptions/Credits	Plant Incentives
Alaska	6 cent/gallon exemption for E10 8 cent/gallon for biomass ethanol	x
Colorado	Tax credit for purchase of alternative fuel vehicles	x
Connecticut	1 cent/gallon exemption for E10	x
Hawaii	4% excise tax exemption for E10 or higher	30 cent/gallon capacity credit for plants with at least 15 mmgy capacity up to $4.5 million
Idaho	2.5 cent/gallon exemption for E10	x
Illinois	Sales tax exemption for E70 and higher; 20% sales tax exemption for E10-E70; tax credit for purchase of flexible fuel vehicles	Up to $15 million in grants for new and expanding ethanol plants with 30 mmgy capacity or higher
Indiana	Grants for purchase of alternative fuel vehicles	12.5 cent/gallon income tax credit for new plants
Iowa	1.3 cent/gallon exemption for ethanol blended fuel; 2.5 cent/gallon credit for stations with 60% or higher of total sales being ethanol blended	No interest loans available for plant production
Kansas	40% tax credit for additional costs of alternative fuel vehicles	7.5 cent/gallon payment up to 15 mmgy for no more than 7 years
Louisiana	Income tax credit for purchase of alternative fuel vehicles	x
Maine	6.4 cent/gallon tax exemption for E85; sales tax exemption for purchase of alternative fuel vehicles	x
Michigan	x	Grants and property tax exemptions for alternative fuels production
Minnesota	5.8 cent/gallon exemption for E85	13 cent/gallon payment up to 15 mmgy until 6/30/07
Mississippi	x	Up to $30 million/year payments to ethanol plants using in-state feedstock
Missouri	x	20 cent/gallon payment for fist 12.5 mmgy; 5 cent/gallon for second 12.5 mmgy for up to 5 years
Montana	x	30 cent/gallon payment up to $6 total (no more than $3 million per plant) for ethanol plants using in-state resources
Nebraska	x	18 cent/gallon tax credit up to 15.625 mmgy, up to 8 years

New York	Tax credits and exemptions for costs associated with alternative fuel vehicles	x
North Carolina	35% tax credit for renewable energy for business or industry up to $250,000	25% state income tax credit on facilities and equipment
North Dakota	x	Per gallon payment based on ethanol and corn market values
Ohio	Tax credit of 50% up to $5,000 per year for investments in eligible ethanol plants	Grants and loans available for new plants; exemptions from property, use, and sales tax for plants
Oklahoma	x	20 cent/gallon tax credit up to 25 mmgy per plant until 2010
Oregon	x	10% tax credit for first 2 years, and 5% credit for next 3 years for costs of building an ethanol plant; 50% property tax exemption for plants up to 5 years
Pennsylvania	Grants for up to 20% of additional costs of purchasing alternative fuel vehicles	5 cent/gallon payment up to 12.5 mmgy
Rhode Island	50% tax credit for alternative fuel vehicles	x
South Dakota	2 cent/gallon tax reduction for E10; 12 cent/gallon tax reduction for E85	20 cent/gallon payment up to $1 million per year
Texas	x	20 cent/gallon payment up to 18 mmgy for 10 years
Utah	50% state income tax credit for additional costs of altenative fuel vehicles	x
Washington	x	Property, sales, and use tax exemptions for qualified ethanol plants
West Virginia	Income tax credit for alternative fuel vehicles	x
Wisconsin	x	20 cent/gallon payment up to 15 mmgy after first 10 million gallons
Wyoming	x	40 cent/gallon tax credit up to $4 million per year

*values taken from Ethanol Producer Magazine, and confirmed with state government legislature.

The main source of ethanol produced in the US is corn. Corn growers receive billions of dollars in subsidies each year, further subtracting from the price per gallon of ethanol.

From 1995-2004 corn farms received 41.8 billion dollars in subsidies.[49] Most of these subsidies do not add to the cost of ethanol, because 70% of corn grown in the US is used as livestock feed.[50] From 2003-2004 the US produced 10.2 billion bushels of corn. Of this, 1.2 billion bushels, or 17% were used to produce ethanol[51]. The amount of corn subsidies used to grow corn that would eventually be sold to ethanol plants comes out to be $7.1 billion from 1995-2004, an average of $710 million per year. Total US capacity for producing ethanol is 6.48 billion gallons per year (see table 3). This means that the contribution of corn subsidies to the price of ethanol is a reduction of about 11 cents/gallon. So in total, without federal or state subsidies, the price of ethanol could be as high as $4.11 per gallon in some states unless corn growers and ethanol plants are willing to take a reduction in profits.

Table 3. Ethanol Production by State [52]

State	Ethanol Production Capacity (Million Gallons Per Year)
Iowa	1,809.5
Nebraska	1,048.5
Illinois	881.0
South Dakota	603.0
Minnesota	593.6
Indiana	282.0
Wisconsin	228.0
Kansas	212.5
Michigan	207.0
Missouri	155.0
Colorado	85.0
North Dakota	83.5
California	68.0
Tennessee	67.0
Arizona	55.0
Kentucky	35.4
New Mexico	30.0

Texas	30.0
Wyoming	5.0
Ohio	3.0
Georgia	0.4
United States Total	6,482.4

*Values are for maximum possible capacity including plants under construction, actual US total is 4381.4 million gallons per year.

The cost of ethanol doesn't stop at federal and state subsidies. The impact that making ethanol from corn crops has on other markets is surprisingly large. The National Center for Policy Analysis reports that ethanol production from corn is increasing the cost of feeding livestock up to $1 billion per year[53]. The demand from ethanol plants for corn increases the cost of corn to livestock producers, subsequently increasing the cost of meat and dairy products across the country. The National Center for Policy Analysis also reports that the byproducts from ethanol, mainly DDG produced from dry milling, directly compete with soybeans, a crop that is mostly unsubsidized. This costs soy farmers $300 million per year in lost revenue. This cost is not directly passed on to consumers, rather, it affects the economy as a whole by reducing the amount of soy farming jobs available in states that produce the most ethanol.

If the inflation to meat and dairy prices is included as another hidden cost of producing ethanol, and distributed among consumers, it could add another 15 cents/gallon. If lost revenue to soybean producers is included, it bumps the price up another 5 cents/gallon. In total, ethanol production without subsidies and compensating for the increase in other consumer costs can be estimated as high as $4.31 per gallon.

Most ethanol produced is intended to be used as a fuel to be mixed with or used instead of gasoline. However, it takes about 1.5 gallons of ethanol to replace 1 gallon of gasoline in terms of energy content. This means that consumers would have to pay up to $6.46 for every gallon of gasoline they replace with ethanol. Even without including a correction for the difference in meat and dairy products, the price is still very high, amounting to a high of $6.16 per gallon. This figure alone shows that the ethanol industry would not survive without federal and state subsidies. Pimentel and Patzek estimate an even higher true cost of ethanol, arguing that it would cost $7.12 for an amount equivalent to 1 gallon of gasoline.[54]

If that still isn't enough to pay for ethanol, there's also the fact that many states don't charge property and sales taxes to ethanol plants. It would be impossible to calculate just how much these tax benefits could add to the price per gallon of ethanol, but it's worth noting that it does make a difference.

If corn ethanol's true cost is over $4 a gallon, who is paying the difference? Every tax payer is. Ethanol produced in the US is mainly used in the US and not exported. Contrary to government hopes that ethanol could reduce dependence of foreign oil, the total impact on the consumption of gasoline has been merely 1%[55]. Consumers are getting very little benefit by the way of energy security, while paying extraordinary prices to keep the ethanol industry alive.

A recent publication in the *Wall Street Journal*[56] mirrors these fears that the US taxpayer is picking up the tab for a market that gets overrepresentation in the federal government. The claims, however, are that the US tax payer is not at the greatest risk because of the money lost from their pockets, but instead because of the false sense of security that the citizens of the United States have been given due to the parasitic relationship between the agriculture businesses and the US government through subsidies.

There are some people making money off of this, although the number of those benefiting from corn ethanol is quite few. The main producer of ethanol is Archer

Daniels Midland Corporation, 10 times the size of it's next biggest competitor.[57] It has been estimated that ADM has collected more than $10 billion in subsidies from excise tax exemptions alone. Small farmers and farm owned ethanol plants can't compete with the capacity of ADM, cutting into their profits so that even with subsidies their profits are minimal.[58] Large corporations like ADM are the only people greatly benefiting from ethanol subsidies.

Total Impact

The push for increasing the ethanol production in the US comes from the fragile state of the world energy economy. In President Bush's 2005 State of the Union address, he said plainly that the US is "Addicted to Oil", and proposed a plan to reduce the US energy reliance on foreign energy sources, specifically Middle Eastern oil. His proposition was to use local energy sources for upwards of 75% of the energy needs of the country.

This daunting task was not defined to come from a specific fuel source, but the need for the country's energy independence is becoming more exaggerated every year. This initiative is expected to increase the existing subsidies for corporations that embark into the field of renewable energy sources, such as wind, solar, or locally grown ethanol, and increase the tax cuts for the individuals who are patrons of items and services that are more efficient; specifically, to use renewable fuels. President Bush has referred to the $10 billion spent since 2001 toward developing cleaner and more reliable fuel sources that the US can exploit to feed its energy hungry economy.[59]

This initiative, which aims to change the infrastructure of the United States, is so bold only because of the position of the US on the world energy stage. The proven oil reserves of the planet exceeded one trillion barrels in a January 2002 estimate, of which the US only contains about 2%. The majority of the world's oil resides in the Middle East, with Saudi Arabia accounting for over 25% of the world's total supply.[a]

The war torn Iraq and the politically dangerous Iran together constitute 23.98%[b] of the world's proven oil reserves, but both of these countries are broken by political unrest and US presence in both has been met with opposition on a global scale. The US's current military occupation of Iraq has been contested by the UN and the Iraqi citizens, despite the intention of helping Iraq rebuild an infrastructure to sustain itself on. Further Western tampering with the economic or political constitution of the Middle East to vie for the oil reserves contained therein would be unfeasible, and unsupported on a domestic and international scale.

However, the US absolutely requires access to the quantities of energy that only the consistent flow of fossil fuels has been able to provide. The US's oil driven economy is based on the consumption of huge amounts of oil: 20.03 million barrels of oil a day for the year 2003.[60] This amount increased again in 2004 and reached a peak of 20.7 million barrels a day average in 2005[61]. The second largest oil consumer since 2003 has been China,[62] which used 6.4 million barrels of oil in 2003, and increased their oil consumption by 15% in 2004, but still remained at firmly less than half of the US's oil use.

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[a]US oil reserves:
22,450,000,000 US barrels of oil / 1,025,000,000,000 Global Barrels of oil = 2.19%
Saudi Arabia oil reserves:
262,700,000,000 Saudi Barrels of oil / 1,025,000,000,000 Global barrels of oil = 25.63%
CIA, "Rank Order – Oil – Proved Reserves", The World Factbook;
http://www.cia.gov/cia/publications/factbook/rankorder/2178rank.html

[b] Iraq + Iran:
(133300000000 Iranian Barrels of Oil + 112500000000 Iraqi barrels of oil)
1025000000000 Global Barrels of Oil = 23.98%
CIA, "Rank Order – Oil – Proved Reserves", The World Factbook;
http://www.cia.gov/cia/publications/factbook/rankorder/2178rank.html

The growth of the Chinese economy in recent years has lead to a prediction that the Chinese may someday rival the US in terms of oil consumption, and tensions between the two nations could occur over the limited oil supplies that exist on the planet. They still do require less than one third of the energy that the US consumes, but their growth has many politicians demanding that the US find a secure source for the oil it uses, or turn to local renewable sources.

The US is known to have substantial oil fields in Texas and Alaska, which are currently being exploited for the gains of large corporations. The amount of oil that has been extracted in the US was averaged at 7.61 million barrels per day of the year 2005. This vast amount of oil produced is not nearly as vast as how much oil the US uses. If all the oil produced in the US was put toward the US oil consumption, the US would still use more oil than the combined second and third most oil hungry countries, China and Japan (respectively) [63]. Table 3 describes the amount of proven oil reserves of the ten most oil rich nations, along with other facts, and Table 4 shows the ten top oil producing nations:

Table 3: Oil Consumption by Country[64]

Country	Oil Consumption (barrels/day)	Date of Oil Consumption Estimate	Popluation (Millions)	GDP
United States	20700000	2005	295	$41,800.00
China	6391000	2004	1306	$6,200.00
Japan	5578000	2003	127	$30,400.00
Russia	2800000	2005	143	$10,700.00
Germany	2677000	2003	82	$29,700.00

Table 4 Oil Production by Country[65]		
Country	**Oil Production (Barrels/day)**	**GDP – per capita**
Saudi Arabia	9,475,000	$12,900.00
Russia	9,150,000	$10,700.00
United States	7,610,000	$41,800.00
Iran	3,979,000	$8,100.00
China	3,504,000	$6,200.00

This energy consumption brings moral issues into question. The US has the third largest population of any country in the world, trailing behind China and India. The population of the US was estimated as of July 2005 as 295 million people, who manage to account for over one quarter of the world's oil consumption. The distributed consumption of a US citizen is approximately 2.94 gallons of oil a day.[c] China, with the greatest population in the world, has approximately 1.3 billion residents. Considering their oil consumption, Chinese citizens use 0.2 gallons of oil a day[d]. In India, the third

[c] 20.7 million barrels of oil a day * 42 gallons per barrel / 295,734,134 US citizens = 2.94 gallons of oil a day

[d] 6.39 million barrels of oil a day * 42 gallons per barrel / 1,306,313,812 Chinese Citizens = 0.21 gallons per day.

CIA, "Rank Order – Oil – Consumption", "Rank Order – Population", The World Factbook; http://www.cia.gov/cia/publications/factbook/rankorder/2174rank.html http://www.cia.gov/cia/publications/factbook/rankorder/2119rank.html largest nation on the planet, citizens on average use less than a tenth of a gallon a day.[e] The question of how to fix the US's oil dependence may altogether be the wrong question. The right question is why the US is content hording so much energy from the planets exhaustible reserves for the lifestyle it promotes, and how to change the excessive nature that exists within the culture the country currently embraces.

The crude oil imported is much more complicated than gasoline itself. It is most commonly measured in barrels, which are each 42 gallons. 'Crude' just refers to how the oil is unrefined, and cannot be used by most common processes. The crude oil must first be converted into a plethora products, only two of which are used in automobiles. The refining process is actually simple, and can use a small fraction of the crude to fuel the process.

Crude oil is refined by fractional distillation, which produces many more products than gasoline and diesel, as seen below:

- Petroleum gas
- Naphtha, or Ligroin
- Gasoline
- Kerosene
- Diesel
- Lubricating oil
- Heavy gas
- Coke, asphalt, tar, waxes, and other minor constituents

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[e] $\frac{\text{2.32 million barrels of oil a day * 42 gallons per barrel}}{\text{1,080,264,388 Indian Citizens}}$ = 0.090 gallons of oil a day.
CIA, "Rank Order – Oil – Consumption", "Rank Order – Population", The World Factbook; http://www.cia.gov/cia/publications/factbook/rankorder/2174rank.html
http://www.cia.gov/cia/publications/factbook/rankorder/2119rank.html

About a third of the products that are created from crude oil, including the asphalt, road oil, kerosene, lubricants, and starting materials for plastics are all not replaceable by ethanol in any form. The US's dependence on oil goes much deeper than the problem of consumer automobiles, which is the problem that most corn subsidies are trying to fix with the American tax dollars.

Over half of the volume of every barrel of oil can be used directly in modern automobiles. The most prominent form of auto fuel used today is gasoline, which accounts for 45% of the oil consumed in the US. The total amount of gasoline consumed in the US in 2004 was 136 billion gallons[66]. The number of total highway registered vehicles in the US in 2005 was 243,023,486[67], and new cars sold in the US was over 17 million in 2005.[68] The US president was right when he stated the country was addicted to oil, but not the companies and the government of the country, the citizens themselves are an excessively gasoline hungry population.

During recent years, the use of alternative fuels has been on the rise in the commercial sector, with the use of ethanol blends in commercial vehicles increasing dramatically. In 2003, the use of 85% ethanol-gasoline blends was up 12 percent from 2002, and in 2004 the use increased again by 10 percent[f]. However, this pales in comparison to the amount of gasoline it replaced. In 2004, ethanol blends made up two hundredths of one percent[g] of the total auto fuel consumed in the US. Biodiesel was

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[f] 17783000 Ethanol blends consumed in 2002 (gal. Gas equiv.)
20092000 Ethanol blends consumed in 2003 (gal gas. Equiv) = 12% and 1-(20092/22405)= 10%
[g] 22405000 Ethanol Blends in 2004 (gas gas. Equiv)
136374000000 Gasoline = 0.01643%
Bureau of Transportation Statistics, "Table 4-10: Estimated Consumption of Alternative and Replacement Fuels for Highway Vehicles", 2005; http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_04_10.html

estimated to have replaced less than one tenth of a percent[h] of the diesel consumed in the country.

The only solution to this problem would be to upscale the production of corn ethanol, to further supplement the market for liquid fuels with a renewable source of energy.

The United States is estimated to have 440 million acres of cropland, of which approximately 70 million acres are devoted to corn. The Midwest is the most prominent grower of corn, with four states containing more than 50% of the corn production in the US.

The greatest corn producing state is Iowa, with Illinois at a near second. Both of these states have over ten million acres of farmland devoted to corn each. Their crops average about 125 bushels of corn per acre, and they have the highest yield in the country. Nebraska and Minnesota are the third and forth greatest producers of corn, having about 8 and 6 million acres worth respectively. Almost every state has a yield of corn annually, with the yields ranging between about 200 and 80 bushels per acre, but the national average is just under 120.[69] Corn is found in either Southern corner, of Florida and California, and also up in the northern corners of Washington, Oregon, and in New England. The greatest production, however, resides right around Iowa in the Midwest.

According to the Renewable Fuels Association (RFA)[70], the current US ethanol plants are owned by 106 different companies, some with multiple plants in a number of states, and some with individual facilities. In total, their current combined capacity is

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[h] $\frac{\text{36599000 Biodiesel in 2004 (gal gas equiv)}}{\text{40740760000 Diesel Consumed 2004 (gal gas equiv)}} = 0.0898\%$

Data Cited From:
Bureau of Transportation Statistics, "Table 4-10: Estimated Consumption of Alternative and Replacement Fuels for Highway Vehicles", 2005;
http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_04_10.html

4,381.4 million gallons of ethanol annually, of which the vast majority is produced from corn. The planned and under construction expansions to these plants are attributed an additional 2,101 million gallons of ethanol annually, or a sum of 6,582.4 million gallons of ethanol per year in the future.

This is a staggering number, but needs to be compared to the current gasoline usage in the US. As stated by the Bureau of Transportation statistics, ethanol replaced only 2,052 million gallons worth of gasoline in 2004. This is obfuscated by the lower energy content of ethanol: it takes 3,348 million gallons of ethanol[i] to replace 2,052 million gallons of gasoline.

The amount of ethanol production planned for future use would have to be scaled up enormously. Currently, the industry is citing that it will one day be able to produce 6,482.4 million gallons of ethanol a year. This would replace only 3,973 million gallons of gasoline annually.[j] Optimistically assuming that 4 billion gallons of gasoline are replaced annually, surpassing the expectations of the plants in the field and any expansions currently under construction, at most the ethanol industry could replace just under 3%[k] of the gasoline consumed in 2004, and only 2.26%[l] of the gasoline and diesel fuel consumed in this country by highway vehicles.

Obviously this is not a viable solution in the short term to the country's energy demands, but it has been offered as a plan for future generations to reap the rewards of current policymakers' foresight. If such is the case, a severe upscale of the number of ethanol plants must occur. Trying to equate the amount of ethanol produced by one plant

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[i] $\frac{\text{\{(124000 BTUs per gallon of gasoline) * 2,052 million gallons of gasoline}}{\text{(76000 BTUs per gallon of ethanol)}} = \text{3,348 million gallons of ethanol}$

[j] $\frac{\text{\{(76000 BTUs per gallon of ethanol) * 6482.4 million gallons of ethanol}}{\text{(124000 BTUs per gallon of gasoline)}} = \text{3973 million gallons of gasoline}$

[k] $\frac{\text{4,000,000 Thousand Gallon of Gasoline Ethanol Equiv. * 100}}{\text{136,374,000 Thousand Gallons of Gasoline}} = 2.933\%$

[l] $\frac{\text{4,000,000 Thousand Gallon of Gasoline Ethanol Equiv. * 100}}{\text{177,114,760 Thousand Gallon of Gasoline Commercial Fuel Equiv.}} = 2.258\%$

would be a ridiculous comparison, as ethanol plants are often placed into varying categories based on the age of the technology they use to ferment and separate the ethanol, and also based on the scale of their production. Averaging even plants only using the newest technology would fail to give an appropriate estimate of the scale of change necessary to fuel the US's automobiles with ethanol. What would provide insight into this matter, however, would be to look at how much corn we can grow.

The amount of ethanol produced per acre of corn varies greatly from state to state, but the major corn producers all have slightly higher than average yields. Currently the nationwide average corn yield hovers between 110 bushels per acre and 130, but this number depends on a great many factors. Corn yields can drop dramatically due to inclement weather, as they dropped 29% in the 1988 drought[71]. However, for the purposes of this report, accepting the generous 120 bushels per acre yield is a relatively insignificant concession.

The number of gallons of ethanol per bushel of corn has been argued between the ratios of 2.50[72] and 2.66[73]. For the purposes of this paper, the optimistic estimate of current technologies producing 2.66 gallons of ethanol for every bushel of corn will be used. The net energy balance has been estimated as only as high as 30,000 BTU per gallon[74], expecting the other 50,000 BTU per gallon to be used in growing and harvesting the corn, and in refining the corn into ethanol.

The current ethanol produced in the United States would, according to these optimistic figures, corresponds to 13 million acres of cropland, if all the ethanol was to be created via corn.[m]. As noted earlier, only about 70 million acres of US cropland is used

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[m] $$\frac{\text{4,336.4 million gallons of ethanol}}{\text{(2.66 gallons /bushel * 120 bushels/acre)}} = \text{13 million acres of cropland}$$

for corn, so the US is currently sacrificing nearly 20% of the corn it grows to the ethanol industry.

If all the ethanol produced in corn ethanol plants today was used for the explicit purpose of fueling highway vehicles, this would account for about 2.5 billion gallons of the 136 billion gallons of gasoline consumed annually. The ethanol industry would need to expand to 51[n] times their current acreage to support the remaining energy needs. That means just to power the gasoline run cars on the roads today, it would require the US farm 667[o] million acres of farmland, or 150% of the farmland the country currently cultivates overall. If the amount of energy spent on the production of ethanol is taken into account, even the most optimistic estimates conclude that the corn necessary to fuel the highway vehicles in the US is an awesome 395%[p] of the US farmland utilized today.

The current ethanol industry boasts large numbers for the record ethanol production and the record ethanol demand, but the nation requires more fuel than the country's corn could ever satisfy.

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[n] (136374 million gallons of gasoline used in the US in 2004) * 124 kBTUs per gallon of gasoline
4336.4 gallons of ethanol per year current ethanol production * 76 kBTUs per gallon of ethanol = 51.3x

[o] [(136374 million gallons of gasoline used in the US in 2004) * 124 kBTUs per gallon of gasoline
{76 kBTUs per gallon of ethanol}] *{ (2.7 gallons /bushel * 120 bushels/acre)}
= 686 million acres of corn crops

667 million acres necessary
440 million acres current cultivated* 100 = 152%

[p] [(136374 million gallons of gasoline used in the US in 2004) * 124 kBTUs per gallon of gasoline
{30 kBTUs per gallon of ethanol}] *{ (2.7 gallons /bushel * 120 bushels/acre)} * 440 million acres
= 395%

Conclusions

In today's economy, the ethanol industry would not survive without government subsidies. Even though the energy balance of creating a gallon of ethanol from corn is positive, the high cost associated with it's production would keep the industry from being able to sustain a profit. The true cost of replacing one gallon of gasoline with ethanol has been shown to be over $6, an amount consumers are unknowingly paying through taxes and inflated meat and dairy prices.

Even if somehow through new technologies the cost of ethanol could be lowered to one comparable to gasoline, it still could not make a large impact on US energy demands. An optimistic estimate is a 3% reduction in gasoline consumption using the maximum capacity of current ethanol plants. This figure does not include other energy demands of the US, only the impact on gasoline used for transportation. As 20% of US corn is now used for ethanol, if all US grown corn were processed into ethanol, this number could reach al high as 15%.

The federal government should rethink it's current status of spending billions of dollars per year on ethanol subsidies, perhaps instead devoting the money to increasing the fuel efficiency of cars, or other renewable energy sources such as solar cells.

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