First Honorable Mention Team Prize: $2,500
Wheeler School, Providence, RI

Coach: George Lewis
Team:
Brett Musco
Cameron Musco
Christopher Musco
Christopher Shaw
Karan Takhar

Ethanol – Too Good To Be True?

Team # 175

Ethanol – Too good to be true?

It's likely that this isn't the first ethanol article you've read in the past month, or even week. Recently, publicity around the issue has exploded as the U.S. faces growing problems with energy supply and the environment. Consumers are seeing continuously rising gasoline prices, and oil has recently surpassed $100 a barrel. In addition, it is hard to ignore our growing reliance on foreign nations for energy, especially as conflict and relations complicate in the oil rich Middle East. On top of these issues, concerns about global warming due to increased levels of CO2 in the atmosphere seem increasing real and problematic.

To many, the answer to all these problems seems to lie in ethanol - a transportable fuel that can be produced from domestically grown corn. Our investigative team set out to evaluate the feasibility of this "miracle cure."

We started our investigation by assessing the amount of ethanol the U.S. would need to significantly decrease our reliance on traditional oil based gasoline. After researching ethanol fuels, we determined that if the U.S. would most likely begin using a combination of E10, a fuel made from 10% ethanol and 90% traditional gasoline, and E85, which contains 85% ethanol and can be used by "flex-fuel" vehicles. Using a mathematical model to predict how much E10 and E85 we would need to consume in order to reduce gasoline consumption by 10%, we calculated that we would need to produce an additional 23 billion gallons of ethanol each year. This massive number represents four times our current ethanol!

Even if that level of production is possible, replacing 10% of gasoline consumption with ethanol may not significantly affect CO2 emissions. Massive amounts of fuel would be necessary to grow the corn needed for ethanol, and producing ethanol from crops requires additional energy. Modeling the fossil fuel inputs of ethanol production, we constructed a mathematical model to calculate the change in CO2 emissions that would result if we began using more ethanol-based fuels. Because corn does take CO2 out of the atmosphere during photosynthesis, emissions would decrease by 32,570,916 metric tons per year. However, this number seems much less impressive when compared to the 7 billion metric tons of CO2 that the U.S. produces each year.

Considering the facts above, it is not surprising that our cost-benefit analysis of increased ethanol production demonstrates its economic disadvantages. Increased production costs, which are absorbed by heavy subsidies, overshadow the benefits, even accounting for the economic value in reducing CO2 emissions. Additionally, by using so much corn to produce fuel, we would drive up the cost of crops, seriously jeopardizing the wellbeing of third world citizens who rely on these important food sources. The U.S. could not justify a massive shift to ethanol reliance until technology and research significantly increases in this area.

We concluded our study by examining possible alternatives to ethanol fuel use, especially in vehicles. In the end, we focused mostly on two notable alternatives, namely hydrogen fuel cells and cellulose-based ethanol, which comes from the structural parts of plants. While these energy solutions might be more expensive to implement in the short term, we believe that they will provide better long-term energy solutions for the U.S.

Unfortunately, the cure-all solution of ethanol fuel seems to falter under detailed scrutiny. Although this doesn't necessarily spell the end of the ethanol movement, we hope our results will encourage a broader view on the need to address the energy and environmental concerns that are facing the U.S. today.

Assumptions

Assumption #1: Ethanol production and corn prices/subsidies can be predicted by simple curves fitted in Excel from Internet data.

Reason: We need a way to stably determine the full cost of ethanol in order to do a full cost-benefit analysis, which takes into account corn prices and subsidies. We also need to determine the effects of the plan outlined in Problem #1 on emissions and developing countries based on a predictable increase in ethanol production.

Assumption #2: The data we obtained from our sources is accurate.

Reason: The sources we use are from large organizations that either are required to report the truth (the EIA) or do not have an incentive to distort the facts and academic studies that are non-biased in viewpoint.

Assumption #3: The change in ethanol production and environmental benefits will be insignificant during the time period assumed in our calculations.

Reason: Technology discoveries progress at an extremely volatile rate that makes it impossible to factor into any calculations, and, with a possible looming global recession, we would not predict a large increase in new investments in ethanol research and development.

Assumption #4: We do not expect large economic fluctuations such as rapid inflation.

Reason: Any event that would cause such a large fluctuation would be inherently unpredictable in nature and unreasonable to include in our models of such a new commodity.

Assumption #5: E10 and E85 will continue to be the dominant ethanol containing fuel forms in the future.

Reason: There are a variety of reasons that are explained in Problem #1 including the economic feasibility of these forms of ethanol.

Problem #1: How Much Ethanol Is Needed to Replace 10% of Annual U.S. Gasoline Usage?

First we define the term "gasoline" as the portion of fuel (as used in cars, motorcycles, etc.) not including any preexisting ethanol additives. We feel that this definition is appropriate since this problem focuses on U.S. energy independence and the emission of CO2 due to burning nonrenewable fossil fuels. Thus, in reducing gasoline usage by 10%, our goal is to reduce our reliance on non-ethanol-based fuel.

As an additionally note, we have decided to base our calculations off data for the year 2007 because this is the most recent information readily available.

Following the above definition, we start by calculating the amount of gasoline used in the U.S. in 2007:

GasolineConsumption = TotalFuelConsumption – TotalEthanolAdditives

TotalFuelConsumption = 142,421,076,000 gallons/year (U.S. Energy Information Administration)

As stated by the EIA, this figure, termed "finished motor gasoline," "includes all ethanol blended gasoline (e.g., E10, E85)," so it incorporates the volume of TotalEthanolAdditives.

The Energy Information Administration also states that "nearly all ethanol [consumed] is blended into gasoline" and this fact can be confirmed when examining ethanol fuel use in previous years. In 2003, 2004, and 2005, nearly all imported and domestically produced ethanol was blended into fuels, so we assume that this fact would stand in 2007.

As a result:

TotalEthanolAdditives = TotalEthanolProduced + TotalEthanolImports = 6,846,647,000 gallons/year (Renewable Fuels Association, Ethanol Industry Statistics).

It is important to note that TotalEthanolAdditives represents only approximately 5% of TotalFuelConsumption, despite the fact that the U.S. Congress allows up to a 10% blend in standard gasoline. We see this disparity because ethanol's current price ensures that it is not always economically beneficial to replace traditional additives, like methyl tertiary butyl ether, with ethanol.

GasolineConsumption = TotalFuelConsumption – TotalEthanolAdditives
= 142,421,076,000 - 6,846,647,000
= 135,575,857,000 gallons/year

Our goal is to reduce this figure by 10%, so we multiply by .90 to calculate the target consumption of gasoline after increased ethanol consumption.

TargetGasolineConsumption = .9 * 135,575,857,000 = **122,018,271,300 gallons/year**

To reduce U.S. gasoline consumption while maintaining an equal supply of energy (stored in fuel) for vehicles, the U.S. will either need to produce or import more ethanol. Here, we make an important assumption:
All additional ethanol produced will be incorporated into gasoline blends of 10% or 85% ethanol, namely, E10 and E85 ethanol fuel.
We make this assumption because of the following:
1. As the U.S. government drives down the price of ethanol with large subsidies, it is becoming cheaper for gas companies to blend fuel with 10% ethanol in lieu of other additives, like MTBE (Gasohol, wikipedia.org). As a result, flooding the market with a surplus of ethanol will first affect the gas supply by increasing the amount of E10 sold. Eventually, the entire gas supply will contain at least 10% ethanol when the price of ethanol drops enough to exclude MTBE from the fuel additive market.
2. Converting all non-ethanol blended fuel to E10 will obviously not reduce the gas supply by 10% because a significant portion of our fuel is already E10 blended.
3. In the U.S., increased ethanol production will next be absorbed by increased production of E85 fuel. This fuel will develop slower than E10 because automotive manufacturers will have to produce "flex-fuel" vehicles that can burn E-85 before it can be consumed extensively. Fortunately, many automotive manufacturures are already capable of mass-producing these vehicles.
4. Although there are alternative ethanol/gasoline blends, beside E85 and E10, no other ethanol fuel is consumed in a large quantity in the U.S. This stems from the fact that regular vehicles can only burn fuel that contains up to 10% ethanol. Additionally, current American "flex-fuel" vehicles burn up only to an 85% blend because some gasoline is necessary for ignition in colder weather (despite the fact that warmer countries, like Brazil, sometimes use up to 100% ethanol blends). We can assume that, to increase the consumption of ethanol, the price would have to drop below the price of gasoline. As a result, consumers will always purchase fuel with the highest blend of ethanol possible to save money.

Based off this assumption, we can derive a few equations that describe a future ethanol market.

Variables: Q_{E10} = quantity of E10 produced, Q_{E85} = quantity of E85 produced
Constants: .90 = the fraction of E10 composed of gasoline
.15 = the fraction of E85 composed of gasoline
1/1.33 = this fraction will be used to scale the calculated production of E85 because 1.33 gallons of E85 provide a vehicle with the same energy as 1 gallon of gasoline (Energy Information Association). We assume that the efficiency of E10 is negligibly different than that of regular fuel. Additionally, we assume that the current quantity of E85 produced negligibly affects the efficiency of TotalFuelConsumption.
Equations:
$(Q_{E10}*.9) + (Q_{E85}*.15)$ = TargetGasolineConsumption = 122,018,271,300 gallons/year

$(Q_{E10}) + (Q_{E85}*(1/1.33))$ = TotalFuelConsumption = 142,421,076,000 gallons/year (Note: this equation reflects the fact that, although we can change the make-up of fuel consumed, we cannot change the real quantity consumed. However, the nominal quantity of fuel consumed will appear to increase because more E85 fuel is needed to power the same number of vehicles as gasoline.)

Solving this system in a matrix, we find that
Q_{E10} = 133,626,362,081 gallons/year
Q_{E15} = 11,696,969,511.8 gallons/year

The total amount of ethanol needed to produce this combination of fuel would be
(Q_{E10}*.10) + (Q_{E85}*.85) = **23,305,060,293.1 gallons per year**

Problem #2: What Effect Will This Fuel Substitution Have on Carbon Dioxide Emissions?

In order to calculate the change in carbon emissions due to the proposed increase in ethanol we must take into account both the change in the amount of ethanol and the amount of gasoline used. To do this we had to also calculate the amount of CO_2 produced in the burning of these substances. Thus we use the following equation:

Δ CO_2 emissions =(Δ usage of gasoline)*(kg of CO_2 emitted per gallon gasoline) + (Δ usage of ethanol)*(kg of CO_2 emitted per gallon ethanol)

In order to calculate the kilograms of CO_2 created when combusting one gallon of gas we used the following equation:

CO_2 emission per gallon of gas = 2,421 grams x 0.99 x (44/12) = 8,788 grams = **8.8 kg/gallon**

2,421 grams is the carbon content in one gallon of gasoline, .99 is the oxidation factor of gasoline (the percent of carbon in the gasoline actually combusted and combined into CO2), and 44/12 is the ratio of the molecular weight of CO_2 to the molecular weight of Carbon (Environmental Protection Agency).

To calculate the net amount of CO_2 emitted per gallon of ethanol we have to take into account several factors, including the amount of CO_2 produced when burning ethanol, emission from the production and transportation of the corn (e.g., harvesting, pesticides, herbicides, and fertilizer), emissions from the refining and transportation of ethanol, and negative emissions from the absorption of CO_2 by corn crops. Based on these predictions one can accurately estimate that between 1392 – 1459 kg of CO_2 are produced for every cubic meter of ethanol (Dias De Oliveira et al.). Converting these units we get
($1392\ kg/m^3$)*(m^3/264.172052 gal) = **5.27 kg/gal**
(1459 kg/m3)*(m^3/264.172052 gal) = **5.52 kg/gal**

Our data was obtained by a paper called *Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint*, which contained these charts:

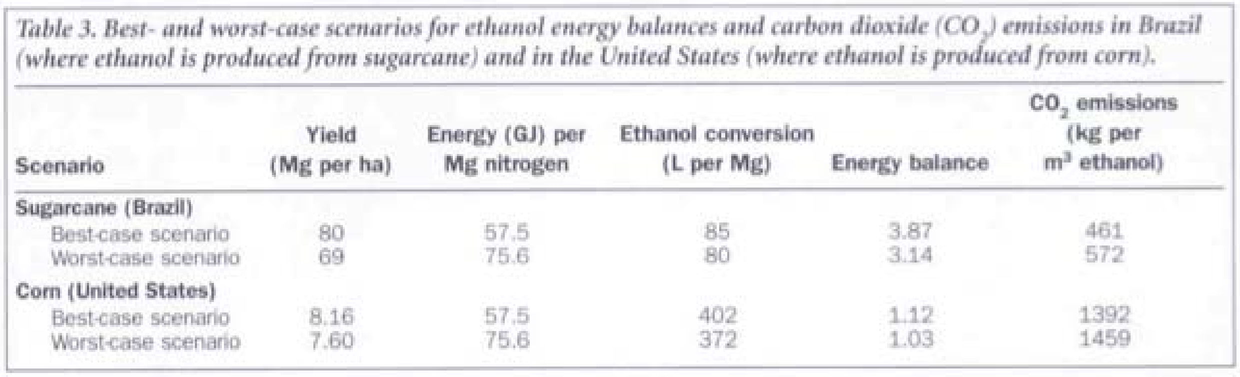


Table 3. Best- and worst-case scenarios for ethanol energy balances and carbon dioxide (CO_2) emissions in Brazil (where ethanol is produced from sugarcane) and in the United States (where ethanol is produced from corn).

Scenario	Yield (Mg per ha)	Energy (GJ) per Mg nitrogen	Ethanol conversion (L per Mg)	Energy balance	CO_2 emissions (kg per m^3 ethanol)
Sugarcane (Brazil)					
Best-case scenario	80	57.5	85	3.87	461
Worst-case scenario	69	75.6	80	3.14	572
Corn (United States)					
Best-case scenario	8.16	57.5	402	1.12	1392
Worst-case scenario	7.60	75.6	372	1.03	1459

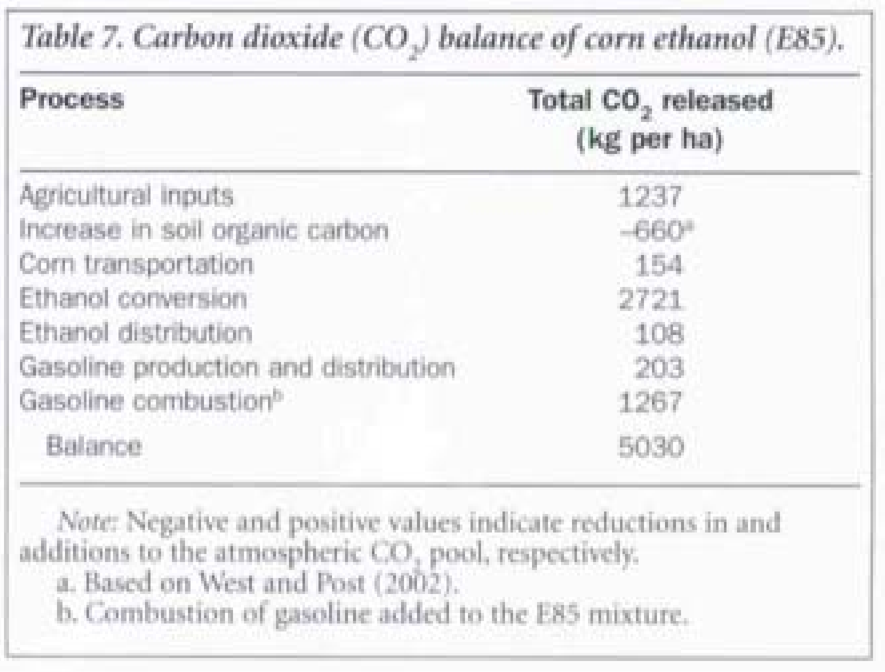


Table 7. Carbon dioxide (CO_2) balance of corn ethanol (E85).

Process	Total CO_2 released (kg per ha)
Agricultural inputs	1237
Increase in soil organic carbon	-660[a]
Corn transportation	154
Ethanol conversion	2721
Ethanol distribution	108
Gasoline production and distribution	203
Gasoline combustion[b]	1267
Balance	5030

Note: Negative and positive values indicate reductions in and additions to the atmospheric CO_2 pool, respectively.

a. Based on West and Post (2002).

b. Combustion of gasoline added to the E85 mixture.

Using these values and values obtained in Problem #1, we can go back to our original equation.

Δ CO_2 emissions =(Δ usage of gasoline)*(kg of CO_2 emitted per gallon gasoline) + (Δ usage of ethanol)*(kg of CO_2 emitted per gallon ethanol)

Δ CO_2 emissions = (135,575,857,000*.9 – 135,575,857,000)*(8.8) + (23,305,060,293.1 – 6,846,647,000)*(5.27) = - 32570916100 kg = **-32570916.1 metric tons**

Δ CO_2 emissions = (135,575,857,000*.9 – 135,575,857,000)*(8.8) + (23,305,060,293.1 – 6,846,647,000)*(5.52) = -28456312800 kg = **-28456312.8 metric tons**

CO_2 emissions will decrease between 28,456,312.8 – 32,570,916.1 metric tons per year.

Problem #3: Is Corn-Derived Ethanol a Cost Efficient Way of Producing Fuel?

In order to assess this question, we decided to list the costs and benefits of using pure ethanol fuel and assign values to these costs and benefits. If costs are greater than benefits, then ethanol is a cost-efficient fuel source that should be used. Because there was no time frame or specific quantity of ethanol given in the problem, we chose to assess the costs and benefits of ethanol production given the changes proposed in Problem #1. These results might not accurately reflect future results as technology and industry develops further. However, they will assess the feasibility of a large scale move to ethanol, as proposed in Problem #1.

Note: All costs and benefits are calculated on a per gallon basis.

Costs (most important)	Benefits (most important)
-Price of ethanol -Direct ethanol subsidies from U.S. gov't -Subsidies for corn used to produce ethanol	-Energy -Lower CO2 emissions -Energy independence and other non-quantifiable benefits

__Costs:__

Price: It is important to note that, by assuming that corn is produced in a competitive market (domestically), we can assume that the price of ethanol incorporates all production costs, inputs such as corn, and costs that result from the diversion of corn from food production, distribution, sales, storage, etc.

We used the April, 2008 futures price of ethanol, which was **$2.350** per gallon, as a reasonable estimate for the current price of ethanol (Chicago Board of Trade).

Direct Ethanol Subsidies:
The U.S. federal government offers a **$0.51** direct subsidy per gallon of ethanol (Foreign Affairs – How Biofuels Could Starve the Poor by C. Ford Runge and Benjamin Senaurer).

Subsidies for Corn Used to Produce Ethanol:
We could not obtain data on the total corn subsidies paid out by the U.S. government in 2006 and 2007, so we used past data to model a sinusoidal prediction curve S(t) for the subsidies (based on the fact that the market will correct itself at periodic rate due to

supply and demand fluctuations, with the oscillations increasing with each period from a base low). This curve gave us the following equation:

$S(t) = A(t) * [5.00*10^9 + 3.40*10^9 * \sin([2*\pi/6.3]*t + 3.6)]$

where $A(t) = 1 + t/(16*\pi)$ for $2*\pi*k < [(2*\pi*t)/6.3] + 3.6 < 2*\pi*(k+0.5)$ and $t > 8$
(k is a positive integer)
= 1 at all other values

from which we predicted the 2007 total subsidies level to be
$6,781,337,969.05.

The historical data used to make this prediction was obtained from
http://farm.ewg.org/farm/progdetail.php?fips=00000&progcode=corn - The Farm Subsidy Database.

The equation for the corn subsidy per gallon of ethanol is

PercentCornMadeIntoEthanol * TotalCornSubsidies / TotalGallonsEthanolProduction

PercentCornMadeIntoEthanol = 18% (in 2007)
(http://ww.ethanolrfa.org/resource/facts/agriculture/)

TotalGallonsEthanolProduction: 6,485,472,000
(http://ww.ethanolrfa.org/industry/statistics/#DFirefoxHTML\Shell\Open\Command)

So, subsidies/ gallon = .18 * 6,781,337,969.05/6,485,472,000 = **$0.19/gallon**

Total Costs (per year):

$\text{TotalCost} = (\text{Price} + \text{Subsidies})*Q_{\text{EthanolProduced}}$
= (2.35+.51+.19)*23,305,060,293.1 (from Problem #1)
= **$71,080,433,894**

<u>Benefits:</u>

Energy: We will calculate the value of the energy obtained from our increased production of ethanol by calculating the value of the gasoline we effectively replaced.

$\text{TotalEnergyValue} = \text{Price}_{\text{Gasoline}}*(\text{GasolineConsumption}*10\%)$

$\text{Price}_{\text{Gasoline}}$ = $3.162 (national average as of 3/3/2008 according to the Energy Information Association)

GasolineConsumption = 135,575,857,000 (calculated in Problem #1)

TotalEnergyValue = $42,869,085,983.4

Lower CO2 Emissions:
Although it can be hard to put a price on CO2 emissions, we believe that Europe's well developed carbon credit trading market provides the best estimates available. This market, which allows companies to buy and sell rights to emit carbon into the atmosphere, should ideally determine the current value of reducing CO2 emissions.

We calculate the total value of the reduced emissions that would result from making the proposed changes in Problem #1 with the following equation:

ValueReducedEmissions = ReductionInCO2*PrevailingPricePerUnitCO2 (as determined by the European Climate Exchange®)

Reduction in CO2 = between 28,456,312.8 – 32,570,916.1 metric tons
PrevailingPricePerUnitCO2 = 21.5 euros/metric ton = $33.15/metric ton (This value was obtained by looking at the value of carbon futures for Dec. 2008, which is the most recent data available considering the annual duration of carbon credits)

ValueReducedEmissions = **up to $1,079,725,868.72**

Total Benefits (per year):
TotalBenefit = EnergyBenefits + EmissionsBenefits
= 42,869,085,983.4 + 1,079,725,868.72 = **$43,948,811,852.1**

Energy Independence and Other Non-quantitative Benefits:
Politicians have often argued that the U.S. would benefit significantly from developing a domestically produced energy supply. We'd be able to decrease our reliance on other nations, and, in times of war or broken relations, we'd be in a better position to maintain energy supplies. We might be able to decrease the volatility of the energy market, which would benefit U.S. citizens who rely on petroleum-based gasoline. Certain citizens may also place intrinsic value on reductions in CO2 emissions, which might help reduce global warming and environmental degradation, that is not reflected in the prevailing price of CO2 emission credits. Additionally, as leaders in renewable energy, the United States could gain valuable international respect that is difficult to quantify. Finally, due to our depletion of fossil-fuel resources, we can only expect the price of oil and gasoline to continue rising. There might be some value in developing the technology and infrastructure available for renewable production in case we face an acute energy shortage in the future. Without government subsidies, corporations may not pursue ethanol technology, the value of which is impossible to quantify or account for at the current time. In short, many benefits of the changes proposed in Problem #1 are impossible to include in our equations. However, by leaving these benefits as a variable, we can solve for the hypothetical value of these non-quantifiable resources that would make the proposed changes energy efficient.

Final Equation:

TotalCosts = TotalBenefit + NonQuantitativeBenefits
\$71,080,433,894 = \$43,948,811,852.1 + NonQuantitativeBenefits

NonQuantitativeBenefits = \$27,131,622,041.80 (per year)

So, we can conclude that, for the changes proposed in Problem #1 to be considered cost efficient, their non-quantitative value would need to be greater than or equal to \$27,131,622,041.80 per year. Remember, this would be "cost" of reducing our reliance on gasoline by only 10% for one year. This figure does not include the fact that most of the U.S.'s consumption of fossil fuels is used to generate electricity, heat, and industrial power. In fact, according to the Energy Information Association, only 28% of U.S. energy consumption is accounted for by the transportation sector.

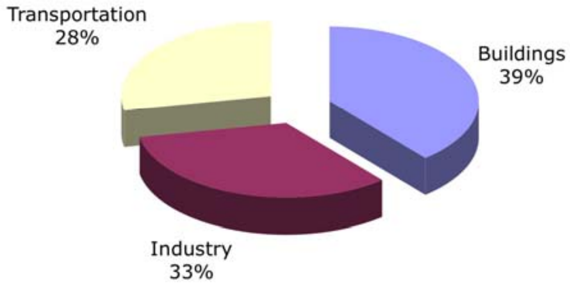


Figure 2: Buildings and Industry Consume More Energy than Transportation

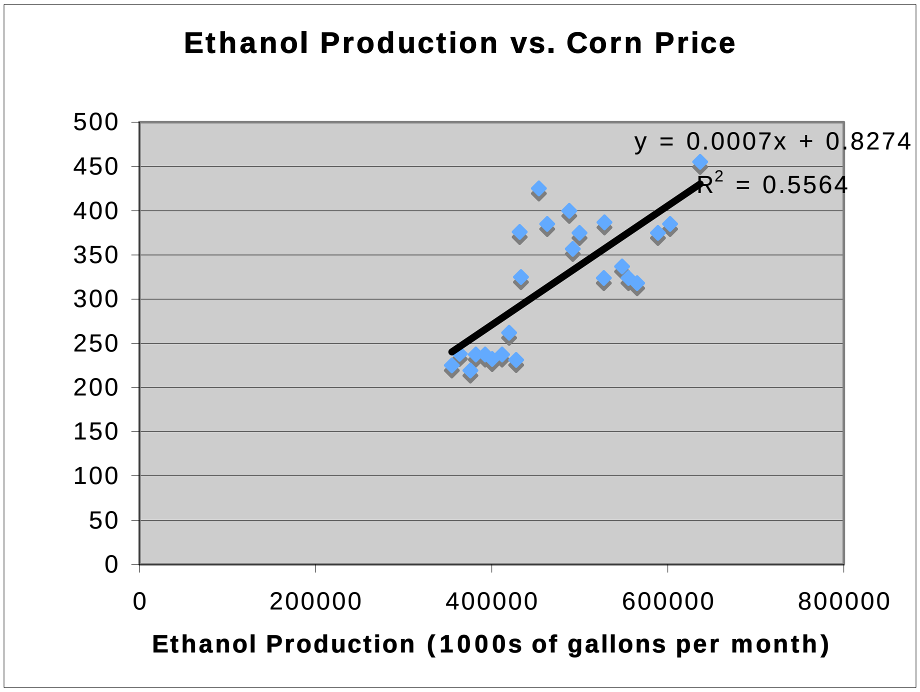
Source: US Energy Information

With 86% of this total energy coming from fossil fuels (EIA), we would effectively be reducing our dependence on non-renewable fuels by about 3%. Due to the extremely small size of this step towards energy independence, it is the opinion of our group that the non-quantifiable consequences of the changes proposed in Problem #1 would not account for the predicted 27 billion dollar cost. A 3% reduction in our reliance on fossil fuels is not likely to significantly affect our relations with other countries. Additionally, a reduction of this caliber would probably be cheaper to obtain through increased energy efficiency and reliance on renewable resources for electricity production - although the cost models for these changes would need to be evaluated in debt. **Nevertheless, our group does not believe that the changes proposed in Problem #1 represent a cost-efficient way of producing fuel.**

Problem #4: Estimate the Effect of This Policy on Grain Prices and Developing Nations over the Next Five Years.

The proposed policy to replace 10%ten percent of the annual U.S. gasoline usage with the ethanol blends E10 and E85 will have an extremely negative effect on developing nations. The main area of concern with the policy is its effect on the food prices in developing nations.

From data obtained from the Renewable Fuels Association and the Chicago Board of Trade, it is possible to model the relationship between ethanol production and corn prices in each month between January 2006 to January 2007:



From this model, we can calculate the expected price of corn, P(C), for this year (based on the predicted U.S. production of 9.3 billion gallons of ethanol in 2008) and the hypothetical situation where we follow the policy laid out in Problem #1.

Predicted Value in 2008: P(C) = ([EthanolProduced/(12*1000)] * 0.0007 + 0.8274)/100

= **$5.43/bushel**

Predicted Value if we follow policy laid out in Problem #1: Ethanol Produced = 23,305,060,293.1 gallons/yr.

P(C) = ([EthanolProduced/(12*1000)] * 0.0007 + 0.8274)/100

= **$13.42/bushel**

This is an extremely high value for corn prices, more than double the projected price for this year and six times the price of a bushel in 2004.

Examples of this darker side of the increased emphasis on ethanol production can be found in many countries, including our very own southern neighbor: Mexico. According to mexicolaw.com, the average Mexican family currently spends 45% of its income on food necessities. Assuming that we implement our plan within 5 years, that the average real income for a Mexican family increases by 5% every year (using the ratio of 2005 to 2004 Mexican GDP given by finfacts.com), and that the price of food will correlate closely with the price of corn (a valid assumption considering the large role that corn plays in the Mexican diet and the fact that increasing corn prices result in corresponding increases in substitute food goods), we find that

Percent of Mexican Income Spent on Food after the plan in problem one is proposed:
= (Predicted Food Expenditure) / (Predicted Income)
= [(CurrentPercent * (PredictedPrice / CurrentPrice)]/ PredictedIncome *100
= $([45*(13.42/5.43)]/(100*[1.05^5]))*100$

= **87.1%**.

This huge predicted effect of ethanol production on Mexican families is just one example of how the U.S. energy policy can have ugly side effects in the developing world. It is an important cost to consider before promoting a large scale shift to ethanol fuels.

Problem #5: Are There Better Ways for the U.S. to Attain National Energy Independence?

Although the proposed switch to ethanol would decrease CO_2, it is not the most effective way. A decrease of 32 million metric tons of emissions is not significant to the total amount of CO_2 produced in the U.S. every year. In addition, corn-based ethanol is very expensive to create because it would require the government to give subsidies to farmers. Such a major shift to of corn crops to the production of ethanol will also have a severe effect on grain prices in other nations, as shown by Problem #4. Both cellulose-based ethanol and hydrogen fuel cells provide better ways for the U.S. to attain nation energy independence.

Cellulose-based ethanol can be made from a larger variety of plants, including sugarcane and saw grass. The major advantage to cellulose-based ethanol is that it is much more efficient than corn-based ethanol. While corn-based ethanol decreases emissions only 10 – 20% over gasoline, cellulose-based ethanol decrease emissions by 90% (wikipedia.org). Data has show that cellulose-based ethanol produces significantly fewer kg of CO_2 per gallon.

Corn-based:
$(1392\ \text{kg/m}^3)*(\text{m}^3/\ 264.172053\ \text{gal}) =$ **5.27 kg/gal**
Cellulose-based:
$(461/\text{m}^3)*(\text{m}^3/264.172053\ \text{gal}) =$ **1.75 kg/gal**
(Dias De Oliveira et. al.)

As this data shows cellulose-based ethanol creates about a third as much CO_2 per gallon. Using cellulose-based ethanol will not detract from grain supplies that are needed to provide food in developing nations. This will prevent these prices from skyrocketing, as demonstrated in Problem #4. In fact, most plants used in the production of cellulose-based ethanol are not used to make food products. Although this type of ethanol has it advantages, it is very expensive. It costs $2.20 to create a gallon of cellulose-based ethanol, which is twice as expensive as it is to create corn-based ethanol (wikipedia.org). Despite this, if there is a larger shift to the development of cellulose-based ethanol, it is likely that this cost will drop. The success of cellulose-based ethanol is evident in Brazil, where 30% of their automotive fuel is made of ethanol.

Another method that would make the U.S. energy independent would be the development and implementation of hydrogen fuel cells. Hydrogen fuel cells produce no pollution because it's only by-product is water. In addition, the use has an abundant source of hydrogen. One of the most significant advantages to hydrogen fuel cells is that hydrogen has the highest energy to unit weight ratio (U.S. Department of Energy). On the other hand, hydrogen fuel cells still have not been perfected. They still are not that efficient, most being only 50% efficient, but newer models promise for them to improve in the future. In addition, it still cost a lot of money to create hydrogen fuel, but this has been steadily dropping. In 2003, it cost $5 to create one gge (gallon of gasoline equivalent), but this dropped to $3 in 2007, and the U.S. is hoping to get it down to $2 by 2015 (wikipedia.org). Finally, hydrogen fuel cells would require the creation of new pumping stations. Although, at first it would be very expensive to institute hydrogen fuel cells; in the end it is the best solution to the US' growing demand to become energy independent.

Although corn-based ethanol would help the U.S. become energy independent it would not be the most effective way. Although they would be harder and more expensive to implement, both cellulose-based ethanol and hydrogen fuel cells would be much more beneficial compared to their costs.

Work Cited

http://alternativefuels.about.com/od/resources/a/gge.htm

http://en.wikipedia.org/wiki/Barrel_(unit)

http://en.wikipedia.org/wiki/Cellulose_ethanol#Economics

http://en.wikipedia.org/wiki/Ethanol_fuel#Fuel_economy

http://en.wikipedia.org/wiki/United_States_Department_of_Agriculture

http://farm.ewg.org/farm/progdetail.php?fips=00000&progcode=corn (The Farm Subsidy Database)

http://futures.tradingcharts.com/chart/AC/W (Chicago Board of Trade)

http://tonto.eia.doe.gov/dnav/pet/hist/mgfupus1m.html (Energy Information Association)

http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbblpd_a.html (Energy Information Association)

http://wiki.answers.com/Q/What_is_the_density_of_ethanol

http://www1.eere.energy.gov/hydrogenandfuelcells/presidents_initiative.html (U.S. Department of Energy)

http://www.api.org/aboutoilgas/otherfuels/upload/Ethanol_Fact_Sheet_Final.pdf

http://www.eia.doe.gov/cneaf/alternate/page/atftables/afvtrans_c1.xls (Energy Information Association)

http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf (Energy Information Association)

http://www.eia.doe.gov/kids/energyfacts/science/energy_calculator.html (Energy Information Association)

http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html (Energy Information Association)

http://www.eia.doe.gov/oiaf/analysispaper/biomass.html (Energy Information Association)

http://www.eia.doe.gov/oiaf/analysispaper/errata_biofuels.html (Energy Information Association) http://www.eia.doe.gov/pub/international/iea2005/table35.xls (Energy Information Association)

http://www.epa.gov/OMS/climate/420f05001.htm (Environmental Protection Agency)

http://www.ethanolrfa.org/industry/statistics/#D (Renewable Fuel Association)

http://www.ethanolrfa.org/resource/facts/agriculture/ (Renewable Fuel Association)

http://www.europeanclimateexchange.com/default_flash.asp (European Climate Exchange)

http://www.finfacts.com/biz10/globalworldincomepercapita.htm (FinFacts)

http://www.foreignaffairs.org/20070501faessay86305/c-ford-runge-benjamin-senauer/how-biofuels-could-starve-the-poor.html (Foreign Affairs)

http://www.ftc.gov/reports/ethanol/Ethanol_Report_2006.pdf (Federal Trade Commission)

http://www.mexicolaw.com/Agriculture.htm

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2W-4RGFYHJ-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e038ec1c6439828eb0e8e40a7295be0d

http://www.smithsonianmag.com/science-nature/presence-biofuel-200711.html?c=y&page=3 (Smithsonian)

http://www.wilsoncenter.org/news/docs/ethanol%20as%20a%20fuel.pdf