**Cum Laude Team Prize: $10,000**
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# Unintended Consequences

## A Quantitative Analysis of the Effects of Ethanol on the World's Food Supply

**Team 178**

# Summary

## The Ethanol Corn-undrum

In recent years, corn-based ethanol has gained much attention as a source of alternative energy. Ethanol demand has skyrocketed, and it is now a common ingredient in most automobile gasoline today. However, corn is a staple food for many countries including the U.S. A trip to the grocery store will reveal thousands of products with high-fructose corn syrup. This has led to concerns about future food supplies in developing nations. Our group has analyzed a number of factors relating to ethanol production and consumption.

If our entire current corn crop were converted into ethanol, it would account for only 12% of the U.S. oil demand. Clearly, all of the corn cannot be converted to ethanol. Some of it must be used for animal feed, food (both high-fructose corn syrup and corn cobs), and seed. Therefore, more corn must be planted to replace 10% of our gasoline consumption with ethanol.

It has been stated that ethanol represents a dramatic reduction in carbon dioxide emissions versus gasoline. However, our analyses indicate that this is not the case. In fact, burning corn-based ethanol represents only a 3% decrease in total carbon dioxide emissions versus burning gasoline.

In addition, the planting of additional corn will reduce the farmland available for other food staples such as wheat and soybeans. This will lead to a dramatic increase in the prices of other grains. The price of soybeans has already skyrocketed in the past few months. These elevated prices will lead to greater food shortages in third-world countries, causing a caloric consumption decrease and starvation.

There are many more cost-efficient and emissions-friendly ways to obtain energy independence from foreign oil imports. Some of these ways include increasing the efficiency of the internal combustion engine and using alternative energy sources such as electricity, photovoltaic cells, and fuel cells. The government can stimulate use of these new technologies by increasing the corporate average fuel economy, implementing a market-based cap and trade system for carbon credits, or educating the general populace. Ultimately, we do not believe that ethanol is a viable replacement for gasoline as a motor fuel in the long term due to its lack of both cost and emissions efficiency.

# Assumptions

- There are no major droughts, epidemics, natural disasters, or alien invasions that would significantly affect corn production in the next five years.
- The total amount of farmland in the U.S. remains constant over the next five years.
- There are no major technological advances in the next five years that would lead to significantly increased corn production or ethanol yield.
- The population of the world will remain approximately constant for the next five years.

# Analysis

## *How much ethanol is needed to replace 10% of annual U.S. gasoline usage?*

Significant research has been conducted on this matter in the past. According to David Pimentel, professor at the College of Agriculture and Life Sciences at Cornell University, the entire nation's corn crop would only amount to 7% of U.S. oil consumption (Pimentel, 2008). The Minnesota Pollution Control Agency's Peter Ciborowski (Manuel, 2007) states that the total corn crop would only meet 12% of gasoline fuel demand, a figure further supported by a 2006 University of Minnesota study (Morrison).

In March 2008, the U.S. Energy Information Administration estimated that 388.6 million gallons of gasoline will be used per day, or 141.8 billion gallons for the whole year. Ten percent of this comes down to 14.18 billion gallons. The energy equivalence of ethanol to one gallon of gasoline is 2.66 gallons of ethanol to 1.74 gallons of gasoline, or 1.53 gallons of ethanol per unit gallon of gasoline (Patzek, 2004). Based on this and the widely accepted figures of ~114,000 BTU/gallon gasoline and 76,000 BTU/gallon methanol (NAFA, 2008), ~1.5 gallons of ethanol convert to 1eegg, meaning approximately **21. billion gallons** of ethanol are required to replace 10% of annual U.S. gasoline usage.

## *Effect of ethanol usage on carbon dioxide emissions*

### Introduction

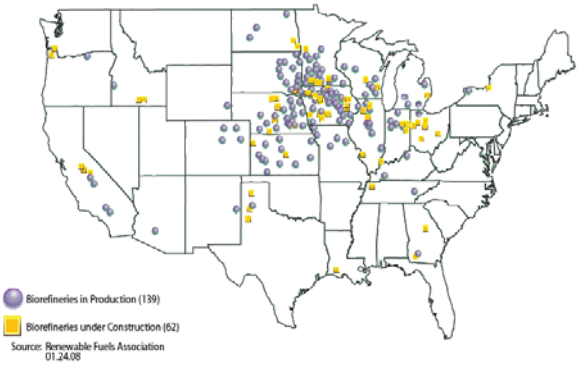
Liquid fuel consumption (i.e., petroleum) is projected to grow from 83 million barrels per day in 2004 to 118 million barrels per day in 2030 (Department of Energy International Energy Outlook Report, 2007). However, in order to reach the target $CO_2$ atmospheric level of 550 ppm by 2050, we must use as much power from carbon-neutral sources as from all present energy sources combined (Lewis, 2006).

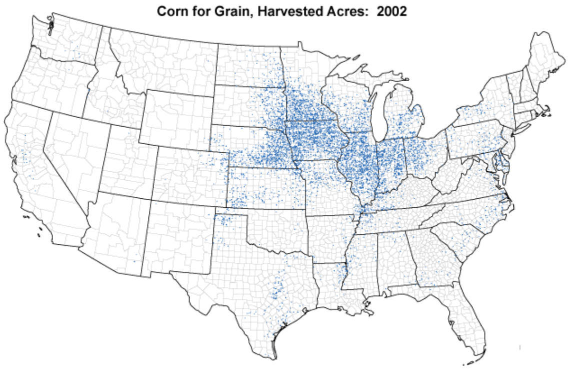
One way to accomplish this is by utilizing ethanol fuel, specifically substituting 10% of annual U.S. gasoline usage with ethanol, equivalent to roughly 21 billion gallons of ethanol (#1). This section of the report deals with the effect of the usage of ethanol on $CO_2$ emissions. Some of the transportation modeling used in this section will be referred to again in the next section, which deals with the cost of the incorporation of ethanol.

The overall ethanol cycle has four main steps. The first step is the transportation of corn from the farm to refining plants. The next step is the actual production of ethanol from corn. Third, the ethanol is shipped from the plants to their destinations. Finally, the ethanol is burned as fuel in cars and other vehicles. Each of these steps is analyzed in detail below.

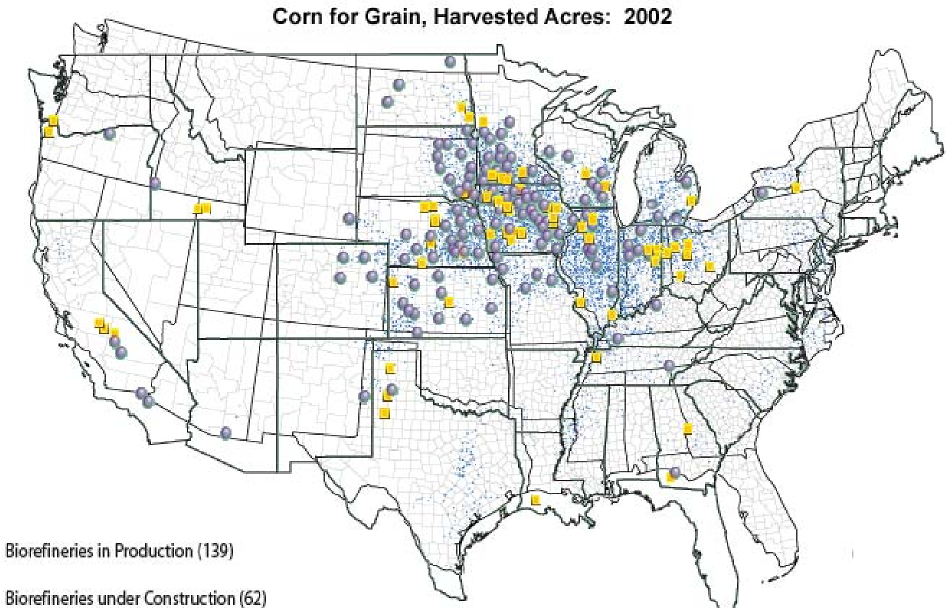
## Step 1 – Transportation of Corn from Farm to Refining Plants

Most plants are located near farms to minimize transportation. Consider the graphs below:





In the graph to the left, each dot represents an ethanol refining plant, and in the graph to the right, darker areas have a higher corn farming land to total land area ratio. Overlaying the two results in the below:



Note that the dots from the refining plant graph and the dark regions from the farming land graph are well aligned. Aside from some farmland in Texas and scattered farmland in Region 3, we see that both plants and corn farming land are very highly concentrated in Region 1 and somewhat in Region 2.

The transportation of corn from the farm to refineries is a negligible process, since the transportation distance is generally less than 10 miles in Region 1, and is well less than 100 miles even in region 2, as can be discerned by the overlaid map above.

## Step 2 – Production of Ethanol

The production of ethanol and the eventual burning of ethanol do not contribute to the atmospheric $CO_2$ level because they are evenly balanced out by the $CO_2$ taken in by the corn during growth.

The majority of carbon that is released from the burning of ethanol enters the process when the corn plant takes in $CO_2$ during photosynthesis. The net equation for photosynthesis is

$$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2 \qquad \text{(i)}$$

The glucose ($C_6H_{12}O_6$) in the plant is then converted into ethanol via the following reaction:

$$C_6H_{12}O_6 + 3O_2 \rightarrow 2C_2H_6O + 2CO_2 \qquad \text{(ii)}$$

Finally, during combustion, ethanol undergoes the following reaction:

$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O + energy \qquad \text{(iii)}$$

Thus, we start out by consuming 6 $CO_2$ molecules through photosynthesis and produce 2 in reaction (ii) through the production of ethanol. This also results in 2 ethanol molecules, and both of these, when burned, result in an additional 2 $CO_2$ molecules being released. So, the net $CO_2$ introduced by the overall ethanol cycle is 2(2)+2-6 =0.

Thus, the creation and destruction of ethanol, collectively, result in a negligible change in atmospheric $CO_2$ levels.

## Step 3 – Transportation of Ethanol from Refining Plants to Destination:

We divide the mainland U.S. into three contiguous regions based on corn production:

| Region | States Contained | Population (millions, % of US) | Percentage of national corn production |
|---|---|---|---|
| **1** | OH, IN, KY, MO, KS, SD, WS | 59.92, **19.7%** | 84.4% |
| **2** | All states east of MT, WY, UT, and AZ, that are **not** in Region 1 | 185.43, **71.0%** | 14.8% |
| **3** | MT, WY, UT, AZ, and states west of these | 58.66, **19.3%** | 0.8% |

Because the supply gradient moves from Region 1 towards Region 3, to optimize transportation, Region 1 provides for all regions, Region 2 provides for itself and Region 3, and Region 3 provides crops only to itself.

We must thus determine the most efficient supply-demand matrix that relates the production fraction vector to the demand fraction vector. We assume here that energy demand is proportional to population. We thus want a matrix of the form:

$$\begin{pmatrix} a_{1,1} & 0 & 0 \\ a_{2,1} & a_{2,2} & 0 \\ a_{3,1} & a_{3,2} & 1 \end{pmatrix} \begin{pmatrix} 0.844 \\ 0.148 \\ 0.008 \end{pmatrix} = \begin{pmatrix} 0.197 \\ 0.710 \\ 0.193 \end{pmatrix}$$

where $a_{i,j}$ represents the fraction of corn delivered to Region *i* and produced in Region *j*. The sum of each column must be 1.

Solving this matrix equation, we get

$$\begin{pmatrix} 0.23341 & 0 & 0 \\ 0.76659 - t & 5.7207t - 0.25 & 0 \\ t & 1.25 - 5.7207t & 1 \end{pmatrix} \begin{pmatrix} 0.844 \\ 0.148 \\ 0.008 \end{pmatrix} = \begin{pmatrix} 0.197 \\ 0.710 \\ 0.198 \end{pmatrix}$$

for a free variable *t*. To force each entry to be between 0 and 1, we must have $t \in [0.0437, 0.2185]$.

We now want to minimize transportation. Since the regions are roughly even in width, we want to minimize:

$$\sum_{1 \le i,j \le 3} \left(|i - j| \cdot a_{i,j}\right) = a_{2,1} + 2a_{3,1} + a_{3,2} = 2.01659 - 5.7207t$$

Clearly, this is minimized as we maximize *t*, so *t* = 0.2185, and the transportation matrix is

$$\begin{pmatrix} 0.23341 & 0 & 0 \\ 0.54089 & 1 & 0 \\ 0.2185 & 0 & 1 \end{pmatrix}$$

This is particularly convenient because only Region 1 ships to other regions.

Shipping occurs by two means: trucks and trains. Trucks ship ethanol between train stations and specific locations, whereas trains, which are more fuel efficient, ship long distance.

The colored lines on the map to the left show the routes of the Class I railroads in North America. The map has been blackened in areas that are not within 100 miles of a railroad. As we can see, these are mainly in remote areas, such as in Wyoming and sparsely inhabited areas of Utah and Oregon. Hence, the vast majority of areas are within 100 miles of a railroad, which can give us an upper bound on truck usage (which is less efficient both in terms of cost and emission).

We now consider the burning of diesel for transportation.

The distance from a Region 1 location to a Region 2 location is, via a RMS average, about 1100 miles. The distance from a Region 1 location to a Region 3 location is about 1850 miles. Within any region, the transportation can be taken to be roughly 200 miles.

2.16 kg of $CO_2$ result from the production of one gallon of diesel, and 10.10 kg result from the burning of one gallon, for a total of 12.26 kg/gal.

A train can carry one ton of freight about 422 miles on one gallon of diesel, which results in 12.26 kg of carbon dioxide.

$$1\ ton_{Ethanol} = \frac{\left(\frac{2000 lbs}{2.2\, {}^{kg}/_{lb}}\right)\cdot 1000\frac{g}{kg}}{0.789\, {}^{g_{Ethanol}}/_{mL_{Ethanol}}}\cdot\frac{1 gal}{3785.412\, mL} = 304.3807\ gal_{Ethanol}$$

Thus, transporting 304.3807 gallons of ethanol 422 miles results in 12.26 kg of carbon dioxide.

We can now take a weighted average for train distance:

$$\begin{pmatrix} 0.23341 & 0 & 0 \\ 0.54089 & 1 & 0 \\ 0.2185 & 0 & 1 \end{pmatrix}\begin{pmatrix} 0.844 \\ 0.148 \\ 0.008 \end{pmatrix} = \begin{pmatrix} 0.197 \\ 0.710 \\ 0.193 \end{pmatrix}$$

$$\bar{d} = 0.844(0.54089 \cdot 1100 + 0.2185 \cdot 1850) = 843.3mi$$

Thus, the net emissions from trains is given by

$$\left(\frac{843.3mi}{422mi}\right)\left(\frac{1}{304.3807gal}\right)(12.26kg) = \frac{0.08kg}{gal}$$

Similarly, the emissions from trucks over 200 miles is given by

$$200mi\left(\frac{1}{6mpg}\right)\left(\frac{1}{6000gal}\right)12.26kg = \frac{0.07kg}{gal}$$

## Step 4 – Burning of Ethanol

*Refer to Step 2 – Production of Ethanol*

## Overall

Adding the numbers above, a total of 0.15 kg $CO_2$ is released per gallon of ethanol. This is the energy equivalent of 1/1.53 gallons of gas, which has an energy equivalent of 11gal/1.53 of gas. The equivalent volume of gas releases 11/1.53=7.18 kg $CO_2$ , which is significantly higher.

## Cost to transport ethanol:

Recall from the emissions section that the average gallon of ethanol is transported 843.3 miles, which results in $\left(\left(\frac{843.3mi}{422mi}\right)\left(\frac{1}{304.3807gal}\right) + 200mi\left(\frac{1}{6mpg}\right)\right) = 0.148601$ gallons of diesel. Multiplying this by the average price of diesel, roughly $3.65 per gallon, results in a cost of 5.4¢ for transportation.

The wages for the train locomotive engineer are negligible, since the train carries thousands of gallons of ethanol. However, the wages for the truck driver are not negligible. Namely, to travel 200 miles at average speed will result in 3 hours of wages, or about $69.90. This is used to transport about 6000 gallons of gas, resulting in a $69.90/6000=1.2¢ cost per gallon.

Thus, the total cost of transportation for ethanol is roughly 6.6¢ per gallon. Accounting for minor intermediate processing raises this to about 7¢.

### *Effects of this policy on grain prices and developing nations over the next five years*

Interpreting "this policy" to be that ethanol will replace 10% of all motor vehicle gasoline by March 1, 2013, a basic qualitative estimate may be made by considering modern economic principles, and this may be further grounded in quantitative data via analysis of grain prices in the past several decades. The three grains that were analyzed were corn, soybean, and wheat based on 2008 data from the University of Illinois (Table 1 for corn and Table 2 for wheat).

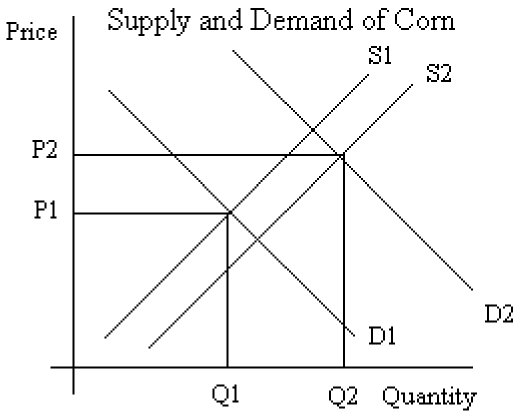
Assuming that usage of corn for domestic feed, food, seed, and industrial processes as well as for exports will remain approximately constant (USDA, 2008), it is evident that a higher number of bushels per corn must be supplied. Ways to achieve this include increasing imports, yield, or acreage.

It is impractical to increase imports, as import cost will be higher than domestic cost, since the U.S. itself exports much corn; in 2007, for example, the U.S. exported 56 million bushels (NCGA, 2008).

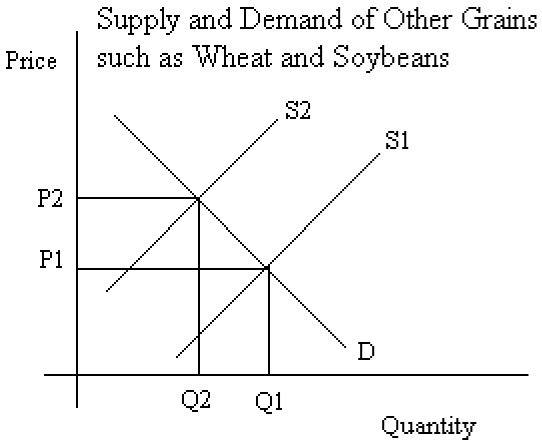
Yield is increasing constantly due to economic scaling, technological advances, and superior farming techniques. Based on historical data and estimates by the USDA (2008), the yield is expected to increase to an average of 170 by 2018. Interpolating linearly, the yield would increase to 160 by 2013. This would provide a 5.89% increase over the current yield of 151.1 bushels per acre (U. Illinois, 2008, Table 1).

Moreover, there is a constant amount of land devoted to farming in the next five years, which means the total amount of land cannot be increased for the corn crop. However, corn can be grown instead of other grains. Because of its regulated use in the mandated ethanol and significant government subsidies, growing corn will be more economically viable. For example, farmed acreage of wheat can decrease in favor of corn.

Thus based on this, we can suppose that the increase in supply of corn will be less than the increase in demand of corn (shown by S1 to S2 and D1 to D2). The supply of corn will increase much slower since there are significant roadblocks. On the other hand, the demand will increase much faster because of the policy. Thus, from the following graph, it can be deduced that the price of corn will increase significantly as a result of this policy.



Additionally, the supply of corn can only be increased by decreasing the supply of other grains such as wheat and soybeans (shown by change from S1 to S2). However, the demand of other grains remains the same since they are mostly used for food consumption, which we assume remains constant because population increase in the next five years is small. Hence, as seen from the following graph, the price of other grains such as wheat and soybeans will increase.



This will place significant pressure on developing nations where food is already scarce. According to Stewart Staniford (2008), a 60% increase in grain prices will lead to a 40% decrease in caloric consumption in third world countries. This will exacerbate the already critical food situation in places such as Africa. It has been seen throughout history that food scarcity is one of the leading causes of unrest and civil war. Countries in Africa and Asia will fall even further into the depths of war and poverty.

## *Are there better ways for the U.S. to attain national energy independence?*

There exist a host of methods for the U.S. to attain national energy independence. Considering that the U.S. has one of the largest coal deposits in the world, America has no significant energy independence issues related to electricity production. The energy dependence crisis instead lies in imported gasoline, mainly for motor fuels. The U.S. imports 10,118,000 barrels of oil per day, of which 5,517,000 barrels per day is from OPEC (EIA, 2008). Noting this massive volume, many methods must be implemented simultaneously to achieve energy independence.

Conventional economics state that the U.S. can either increase supply or decrease demand of oil. Ultimately, increasing supply is not plausible, as total world oil resources are limited and the further destruction of natural and especially virgin lands is a hefty sacrifice to make. Decreasing demand can be achieved through several ways:

- Tightening standards for fuel efficiency of motor vehicles, such as through raising Corporate Average Fuel Economy (CAFÉ) or implementing a market-based cap-and-trade system for miles per gallon (mpg) efficiency.
- Switching to alternative fuels, such as biofuels, fuel cells, or electricity.
- Educating the populace on current trends and consequences of overconsumption.

In considering these implementations, multiple facets must be taken into account, namely technology, economic viability, and education. One group that conducted an extensive analysis of all these factors was the Keystone Policy Summit on Energy Efficiency in 2007, of which one author (Shengzhi) was a board member.

## Technology

Technology comes in the form of higher efficiency vehicles and alternative fuels.

A large number of technologies exist to increase fuel efficiency. A small sample of these technologies includes using superior transmission technologies such as automated manual transmission (AMT) and continuously variable transmission (CVT), variable valve timing and lift (VVT&L), on demand cylinder deactivation, turbocharging, direct fuel injection, and integrated starter generators (ISGs) (Von Stein, 2007). Additional initial capital is necessary to implement these technologies, however.

With crude oil reaching 104 USD per barrel (Sunnucks, March 3 2008), alternative energies sources are becoming increasingly more lucrative. Possible alternative energy sources for transportation include alternative combustion fuels (ethanol and other biofuels), electricity, and fuel cells.

Alternative combustion fuels face similar environmental problems to gasoline, and the net energy balance is often in the red. For example, Patzek (2004) states that production of ethanol leads to negative energy balance: 1.76 gallons of gasoline are needed to produce 1.74 eegg of ethanol. Other sources, however, suggest energy gains, e.g. Shapouri, et al. (1995) claims a 24% net increase in energy balance. A survey of many different analyses is shown in Figure 1.

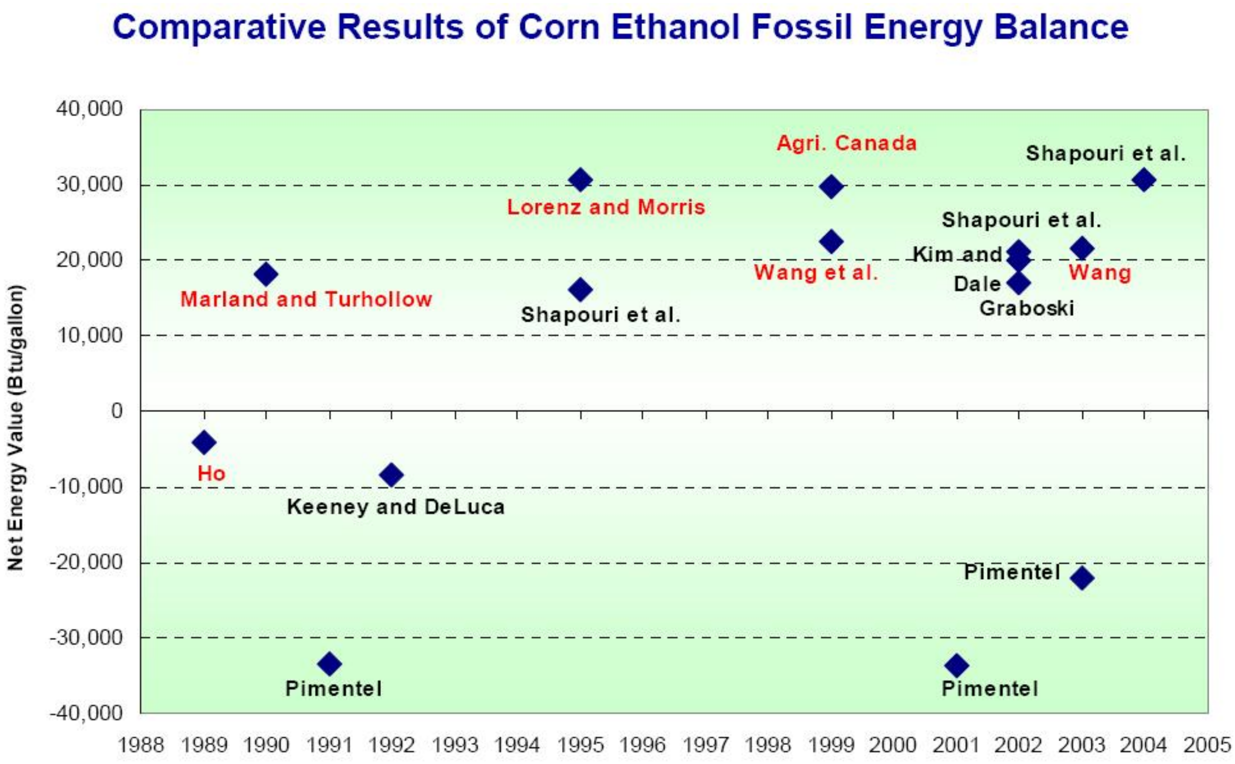


Figure 1 Comparative Results of Corn Ethanol Fossil Energy Balance (National Corn Growers' Association, 2005)

Clearly, the net energy balance issue is not conclusive. Furthermore, burning ethanol and other biofuels also produces negative environmental impacts. Despite the argument that ethanol carbon dioxide emissions are nil, as that amount of carbon dioxide is sequestered from the environment during the growing season, the growth and processing of the corn have certain negative impacts, which were extensively analyzed in Part II. Zah, et al. (2007) conducted a comprehensive survey of many different biofuels and their environmental impacts, assigning a relative quantitative value to the environmental impacts (Fig. 2).

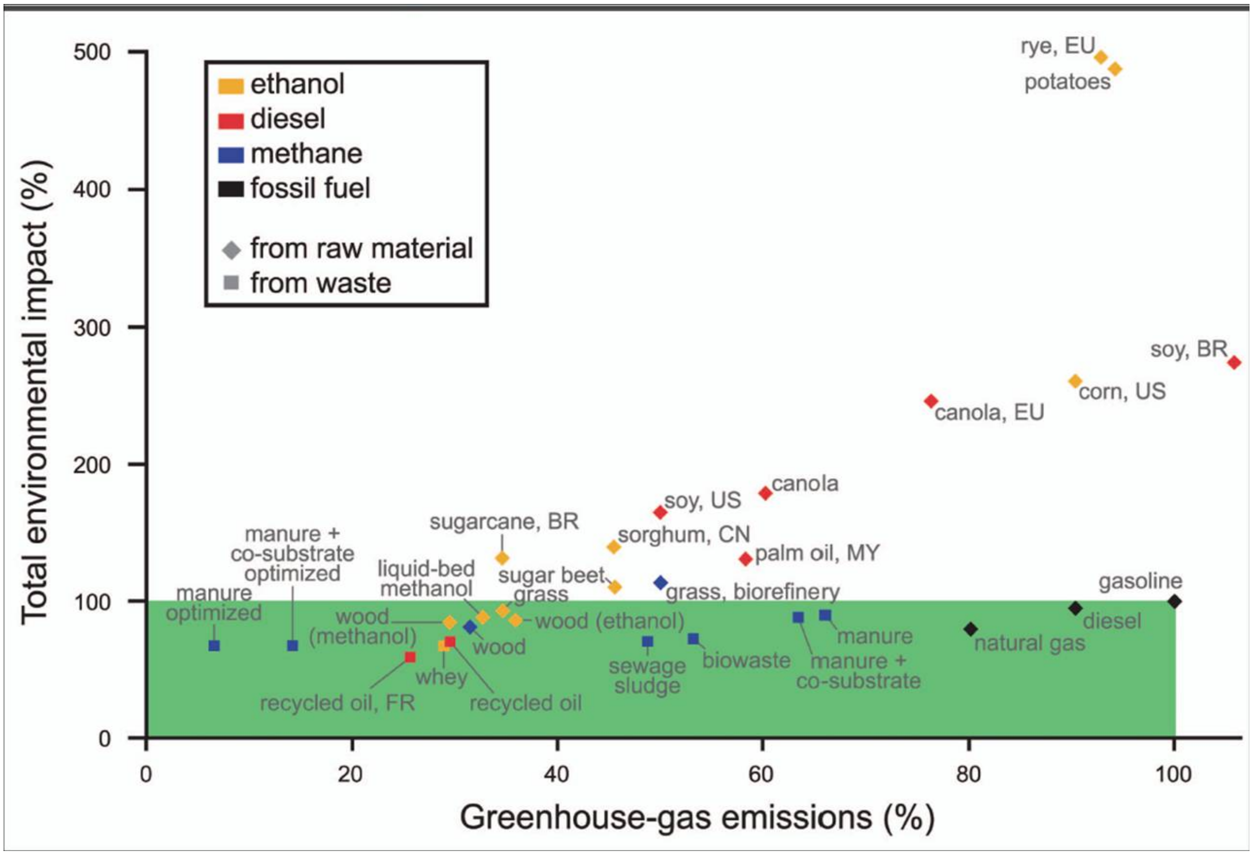


Figure 2 Total environmental impact vs. relative greenhouse-gas emissions (Zah et al., 2007)

The study asserts that using wastes or recycled products, such as sewage sludge or recycled oil, has much less environmental impact than using food crops, such as corn or soy.

In addition to food-based ethanol, cellulosic ethanol is another highly viable option that has seen much research in recent years. Cellulosic ethanol may be harvested from a large variety of crops such as sugarcane and even prairie grasses, such as switchgrass. This form of ethanol uses nearly the entire plant and is much more efficient in terms of using the plant's energy. As a more recent technology, however, cellulosic ethanol is still in a pilot stage and has not reached full commercial potential.

Another viable source of transportation fuel is electricity. Electric motors are far more efficient than internal combustion engines (ICEs) and are capable of converting 75% of the battery energy into mechanical energy compared to the 20% converted by ICEs (Von Stein, 2007). Furthermore, electricity is created at the power plant using non-petroleum energy sources, thus releasing the U.S. from dependence on foreign oil. Electricity, however, is at a disadvantage due to its generally low power as well as its low mileage per charge. Modern advances, however, have greatly reduced these disadvantages; Tesla Motors, the world's leading supplier of electric cars boasts its top-of-the-line Tesla Roadster which can go from 0 to 60 mph in 4 seconds and has a remarkable 135mpg (Tesla, 2008).

The sun shines approximately 100,000 TW onto the surface of the Earth yearly, or more energy in one hour than we consume in one year. This map shows the land area required to be covered with solar cells, at only 10% efficiency, in order to satisfy the current energy needs of the entire U.S.

A hot and upcoming transportation technology is the fuel cell. Fuel cell vehicles (FCVs) are expected to reach the market by 2010 (Von Stein, 2007). FCVs can convert 40-60% of the fuel energy to mechanical energy, a significant advance over ICEs. At the moment, fuel cells are still too expensive for mainstream use; however, prices are steadily decreasing. In the past 3 years, fuel cell prices have decreased ten-fold, and prices will only be decreasing over the next decade (General Motors Corporation, 2007).

A combination of multiple technologies take advantage of both the benefits of the cleaner and more efficient electric and fuel cell vehicles and the raw power and universal support for gasoline vehicles. This combination leads to the hybrid vehicle, of which the electric/ICE combination has been highly successful. The most prominent and well-selling hybrid car is the Toyota Prius, with over a million sales as of March 2008.

## Education

The public must be made more aware of the crisis and its consequences. This can be accomplished through a variety of methods such as public campaigning, public service announcements, radio discussions, internet web casts, and documentaries. Additionally, all schools should hold a short presentation to teach about the environmental crisis and how everyone can contribute to reducing it on Earth Day.

## Fuel Efficiency

Increasing fuel efficiency standards depends directly on the government. The current standard given by CAFÉ is 27.5mpg for cars and 20.7 for light trucks. Manufacturers whose average fuel economy falls below these numbers must pay fines to the government. Interestingly, CAFÉ has not increased for over 20 years, and total fleet (including cars and light trucks) mpg reached its peak in 1987 at 26.2mpg. In 2004, fleet mpg was 24.7, 1.5mpg *below* standards in 1987.

Considering the massive technological advance, even the U.S. legislature believed it practical and necessary to increase CAFÉ. In December 2007, the Senate finally passed raising CAFÉ to 35mpg by 2020.

Another way to increase fuel economy is to implement a cap-and-trade system. This market-based approach would be similar to the carbon cap-and-trade system, except that mpg credits are used instead of carbon credits.

Table I. **All Variables (1975/76 - 2007/08) for U.S. Corn**

| Year Beginning Sept. 1 | Acres Planted (1000 acres) | Acres Harvested (1000 acres) | Yield Per Acre (Bushels) | Production (Million Bushels) | Beginning Stocks (Million Bushels) | Total Supply (Million Bushels) |
|---|---|---|---|---|---|---|
| 1975/76 | 78719 | 67625 | 86.4 | 5841 | 558 | 6400 |
| 1976/77 | 84588 | 71506 | 88 | 6289 | 633 | 6925 |
| 1977/78 | 84328 | 71614 | 90.8 | 6505 | 1136 | 7643 |
| 1978/79 | 81675 | 71930 | 101 | 7268 | 1436 | 8705 |
| 1979/80 | 81394 | 72400 | 109.5 | 7928 | 1710 | 9638 |
| 1980/81 | 84043 | 72961 | 91 | 6639 | 2034 | 8675 |
| 1981/82 | 84097 | 74524 | 108.9 | 8119 | 1392 | 9511 |
| 1982/83 | 81857 | 72719 | 113.2 | 8235 | 2537 | 10772 |
| 1983/84 | 60207 | 51479 | 81.1 | 4174 | 3523 | 7699 |
| 1984/85 | 80517 | 71897 | 106.7 | 7672 | 1006 | 8680 |
| 1985/86 | 83398 | 75209 | 118 | 8875 | 1648 | 10534 |
| 1986/87 | 76580 | 68907 | 119.4 | 8226 | 4040 | 12267 |
| 1987/88 | 66200 | 59505 | 119.8 | 7131 | 4882 | 12016 |
| 1988/89 | 67717 | 58250 | 84.6 | 4929 | 4259 | 9191 |
| 1989/90 | 72322 | 64783 | 116.3 | 7532 | 1930 | 9464 |
| 1990/91 | 74166 | 66952 | 118.5 | 7934 | 1344 | 9282 |
| 1991/92 | 75957 | 68822 | 108.6 | 7475 | 1521 | 9016 |
| 1992/93 | 79311 | 72077 | 131.5 | 9477 | 1100 | 10584 |
| 1993/94 | 73239 | 62933 | 100.7 | 6338 | 2113 | 8472 |
| 1994/95 | 78921 | 72514 | 138.6 | 10051 | 850 | 10910 |
| 1995/96 | 71479 | 65210 | 113.5 | 7400 | 1558 | 8974 |
| 1996/97 | 79229 | 72644 | 127.1 | 9233 | 426 | 9672 |
| 1997/98 | 79537 | 72671 | 126.7 | 9207 | 883 | 10099 |
| 1998/99 | 80165 | 72589 | 134.4 | 9759 | 1308 | 11085 |
| 1999/00 | 77386 | 70487 | 133.8 | 9431 | 1787 | 11232 |
| 2000/01 | 79551 | 72440 | 136.9 | 9915 | 1718 | 11639 |
| 2001/02 | 75702 | 68768 | 138.2 | 9503 | 1899 | 11412 |
| 2002/03 | 78894 | 69330 | 129.3 | 8968 | 1596 | 10578 |
| 2003/04 | 78603 | 70944 | 142.2 | 10089 | 1087 | 11190 |
| 2004/05 | 80929 | 73631 | 160.4 | 11807 | 958 | 12776 |
| 2005/06 | 81779 | 75117 | 148 | 11114 | 2114 | 13237 |
| 2006/07 | 78327 | 70648 | 149.1 | 10535 | 1967 | 12514 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2007/08 | 93600 | 86542 | 151.1 | 13074 | 1304 | 14393 |

| Exports (Million Bushels) | Feed and Residual Use (Million Bushels) | Food, Seed, Ind. (Million Bushels) | Total Consumption (Million bushels) | Ending Stocks (Million Bushels) | Average Farm Prices ($/bu) |
|---|---|---|---|---|---|
| 1664 | 3582 | 521 | 5767 | 633 | 2.5 |
| 1645 | 3602 | 542 | 5789 | 1136 | 2.2 |
| 1896 | 3730 | 581 | 6207 | 1436 | 2 |
| 2113 | 4274 | 608 | 6995 | 1710 | 2.3 |
| 2402 | 4563 | 640 | 7604 | 2034 | 2.5 |
| 2391 | 4232 | 659 | 7282 | 1392 | 3.1 |
| 1997 | 4245 | 733 | 6975 | 2537 | 2.5 |
| 1821 | 4573 | 855 | 7249 | 3523 | 2.6 |
| 1886 | 3876 | 930 | 6693 | 1006 | 3.2 |
| 1850 | 4115 | 1067 | 7032 | 1648 | 2.6 |
| 1227 | 4114 | 1153 | 6494 | 4040 | 2.2 |
| 1492 | 4659 | 1234 | 7385 | 4882 | 1.5 |
| 1716 | 4789 | 1251 | 7757 | 4259 | 1.9 |
| 2028 | 3934 | 1297 | 7260 | 1930 | 2.5 |
| 2367 | 4382 | 1370 | 8120 | 1344 | 2.4 |
| 1727 | 4609 | 1425 | 7761 | 1521 | 2.3 |
| 1584 | 4798 | 1533 | 7915 | 1100 | 2.4 |
| 1663 | 5252 | 1556 | 8471 | 2113 | 2.1 |
| 1328 | 4680 | 1613 | 7621 | 850 | 2.5 |
| 2177 | 5460 | 1715 | 9352 | 1558 | 2.3 |
| 2228 | 4693 | 1628 | 8548 | 426 | 3.2 |
| 1797 | 5277 | 1714 | 8789 | 883 | 2.7 |
| 1504 | 5482 | 1804 | 8791 | 1308 | 2.4 |
| 1981 | 5472 | 1846 | 9298 | 1787 | 1.9 |
| 1937 | 5664 | 1913 | 9515 | 1718 | 1.8 |
| 1941 | 5842 | 1957 | 9740 | 1899 | 1.9 |
| 1905 | 5864 | 2046 | 9815 | 1596 | 2 |
| 1588 | 5563 | 2340 | 9491 | 1087 | 2.3 |
| 1900 | 5795 | 2537 | 10232 | 958 | 2.4 |
| 1818 | 6158 | 2686 | 10662 | 2114 | 2.1 |
| 2134 | 6155 | 2981 | 11270 | 1967 | 2 |
| 2125 | 5598 | 3488 | 11210 | 1304 | 3 |
| 2450 | 5950 | 4555 | 12955 | 1438 | 4 |

Table II **All Variables (1975/76 - 2007/08) for U.S. Wheat**

| Year Beginning June. 1 | Acres Planted (1000 acres) | Acres Harvested (1000 acres) | Yield Per Acre (Bushels) | Production (Million Bushels) | Beginning Stocks (Million Bushels) | Total Supply (Million Bushels) |
|---|---|---|---|---|---|---|
| **1975/76** | 74900 | 69499 | 30.6 | 2127 | 435 | 2564 |
| **1976/77** | 80395 | 70927 | 30.3 | 2149 | 666 | 2817 |
| **1977/78** | 75410 | 66686 | 30.7 | 2046 | 1113 | 3161 |
| **1978/79** | 65989 | 56495 | 31.4 | 1776 | 1178 | 2955 |
| **1979/80** | 71424 | 62454 | 34.2 | 2134 | 924 | 3060 |
| **1980/81** | 80788 | 71125 | 33.5 | 2381 | 902 | 3285 |
| **1981/82** | 88251 | 80642 | 34.5 | 2785 | 989 | 3777 |
| **1982/83** | 86232 | 77937 | 35.5 | 2765 | 1159 | 3932 |
| **1983/84** | 76419 | 61390 | 39.4 | 2420 | 1515 | 3939 |
| **1984/85** | 79213 | 66928 | 38.8 | 2595 | 1399 | 4003 |
| **1985/86** | 75535 | 64704 | 37.5 | 2424 | 1425 | 3866 |
| **1986/87** | 71998 | 60688 | 34.4 | 2091 | 1905 | 4017 |
| **1987/88** | 65829 | 55945 | 37.7 | 2108 | 1821 | 3945 |
| **1988/89** | 65529 | 53189 | 34.1 | 1812 | 1261 | 3096 |
| **1989/90** | 76615 | 62189 | 32.7 | 2037 | 702 | 2761 |
| **1990/91** | 77041 | 69103 | 39.5 | 2730 | 537 | 3303 |
| **1991/92** | 69881 | 57803 | 34.3 | 1980 | 868 | 2889 |
| **1992/93** | 72219 | 62761 | 39.3 | 2467 | 475 | 3012 |
| **1993/94** | 72168 | 62712 | 38.2 | 2396 | 531 | 3036 |
| **1994/95** | 70349 | 61770 | 37.6 | 2321 | 569 | 2981 |
| **1995/96** | 69132 | 60955 | 35.8 | 2183 | 507 | 2757 |
| **1996/97** | 75105 | 62819 | 36.3 | 2277 | 376 | 2746 |
| **1997/98** | 70412 | 62840 | 39.5 | 2481 | 444 | 3020 |
| **1998/99** | 65821 | 59002 | 43.2 | 2547 | 722 | 3373 |
| **1999/00** | 62664 | 53773 | 42.7 | 2296 | 946 | 3339 |
| **2000/01** | 62549 | 53063 | 42 | 2228 | 950 | 3272 |
| **2001/02** | 59432 | 48473 | 40.2 | 1947 | 876 | 2931 |
| **2002/03** | 60318 | 45824 | 35 | 1606 | 777 | 2460 |
| **2003/04** | 62141 | 53063 | 44.2 | 2345 | 491 | 2899 |
| **2004/05** | 59674 | 49999 | 43.2 | 2158 | 546 | 2775 |
| **2005/06** | 57229 | 50119 | 42 | 2105 | 540 | 2726 |
| **2006/07** | 57344 | 46810 | 38.7 | 1812 | 571 | 2505 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2007/08 | 60433 | 51011 | 40.5 | 2067 | 456 | 2613 |
| Exports (Million Bushels) | Feed and Residual Use (Million Bushels) | Food Use (Million Bushels) | Seed Use (Million Bushels) | Total Consumption (Million bushels) | Ending Stocks (Million Bushels) | Average Farm Prices ($/bu) |
| **1173** | 37 | 589 | 100 | 1899 | 666 | 3.56 |
| **950** | 74 | 588 | 92 | 1704 | 1113 | 2.73 |
| **1124** | 193 | 587 | 80 | 1983 | 1178 | 2.33 |
| **1194** | 158 | 592 | 87 | 2031 | 924 | 2.97 |
| **1375** | 86 | 596 | 101 | 2158 | 902 | 3.8 |
| **1514** | 59 | 611 | 113 | 2296 | 989 | 3.99 |
| **1771** | 135 | 602 | 110 | 2618 | 1159 | 3.69 |
| **1509** | 195 | 616 | 97 | 2417 | 1515 | 3.45 |
| **1426** | 371 | 643 | 100 | 2540 | 1399 | 3.51 |
| **1421** | 407 | 651 | 98 | 2578 | 1425 | 3.39 |
| **909** | 284 | 674 | 93 | 1961 | 1905 | 3.08 |
| **999** | 401 | 712 | 84 | 2196 | 1821 | 2.42 |
| **1588** | 290 | 721 | 85 | 2684 | 1261 | 2.57 |
| **1415** | 151 | 726 | 103 | 2394 | 702 | 3.72 |
| **1232** | 139 | 749 | 104 | 2224 | 537 | 3.72 |
| **1070** | 482 | 790 | 93 | 2435 | 868 | 2.61 |
| **1282** | 245 | 790 | 98 | 2414 | 475 | 3 |
| **1354** | 194 | 835 | 100 | 2481 | 531 | 3.24 |
| **1228** | 272 | 872 | 96 | 2468 | 569 | 3.26 |
| **1188** | 345 | 853 | 89 | 2475 | 507 | 3.45 |
| **1241** | 154 | 883 | 104 | 2381 | 376 | 4.55 |
| **1001** | 308 | 891 | 102 | 2302 | 444 | 4.3 |
| **1040** | 251 | 914 | 92 | 2298 | 722 | 3.38 |
| **1042** | 394 | 910 | 81 | 2427 | 946 | 2.65 |
| **1089** | 280 | 929 | 92 | 2390 | 950 | 2.48 |
| **1062** | 304 | 950 | 80 | 2396 | 876 | 2.62 |
| **962** | 182 | 926 | 83 | 2154 | 777 | 2.78 |
| **850** | 116 | 919 | 84 | 1969 | 491 | 3.56 |
| **1158** | 203 | 912 | 80 | 2353 | 546 | 3.4 |
| **1066** | 182 | 910 | 78 | 2235 | 540 | 3.4 |
| **1003** | 160 | 915 | 78 | 2155 | 571 | 3.42 |
| **909** | 125 | 933 | 81 | 2049 | 456 | 4.26 |
| **1200** | 110 | 945 | 86 | 2341 | 272 | 6.65 |

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