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Corn Ethanol: Is it worth it?

The National Corn Growers Association of America is giddy about the recent mandate by president Bush to up alternative fuels to 35 billion gallons by 2017 (15 percent of projected annual gasoline use) coming from corn ethanol, cellulosic ethanol and other domestically produced alternative fuels [1]. Corn ethanol, as an alternative fuel, has come under some scrutiny, with a few researchers finding that this fuel may be energy negative [2], but an average consensus of up to 20% efficiency [3]. Thus, it is interesting to see whether corn ethanol is a sound investment for the US economy. It is important to note that there are two reasons for alternative fuel use in the US. The first is environmental, where an alternative fuel, such as ethanol, has the potential to reduce greenhouse gases [3]. The second, which is more likely the reason for corn ethanol's cameo in the state of the union address, is a powerful corn lobby and an attempt to disengage the US economy from its reliance on foreign energy sources.

Ethanol Fuel Efficiency:

Ethanol has an energy content of ~ 21 MJ/liter, compared to ~ 35 MJ/liter of gasoline. A comparison of Ethanol containing fuels to gasoline can be found here [4] and is reproduced in Table 1.

Table 1: A gasoline gallon equivalent (GGE) describes how many gallons of the fuel would be equivalent to one gallon of typical gasoline.

Fuel Type	Unit of Measure	BTUs per Unit (LHV)	GGEs per Unit	Units to comprise 1 GGE
Gasoline (typical)	gal	116,090	1.00	1.00
Diesel (U.S. typical)	gal	128,450	1.11	0.90
Ethanol (E100)	gal	76,330	0.66	1.52
Ethanol (E85)	gal	82,294	0.71	1.41
Gasoline, RFG (10% Ethanol)	gal	112,114	0.97	1.04
Gasoline, CaRFG (5.7% Ethanol)	gal	113,824	0.98	1.02

Thus, pure ethanol fuels are approximately 35% less efficient due to the lower combustion energy. However, Ethanol engines can have higher compression ratios (11:1 for ethanol fuels and 9:1 for gasoline [5]). Since the efficiency of a Carnot engine goes as $\eta = 1 - r^{1-\gamma}$. Higher ratios would result in larger values of efficiency, but not quite enough to offset the drop due to energy content. The EPA 2007 Fuel Economy guide notes that low alcohol content blends (10% and under) do not lead to significant fuel consumption loss, but flexible fuel vehicles operating on a 85% ethanol 15% gas mixture (E85) suffer a 20-30% drop in efficiency [6]. The Clean Cities Alternative Fuel Price Report issued by the department of energy lists nationwide average E85 costs at $2.63 / gallon and $3.03 / gallon for regular unleaded gasoline. A 25% drop in gas mileage boosts the cost of E85 to $3.28 / gallon, and this does not take into account costs associated with farm subsidies and tax credits.

Corn ethanol efficiency

Photosynthetic efficiency is generally in the range of ~2-8% [5] and therefore lower than the 15% of standard photo-voltaics. However, bio-ethanol may be a good alternative if costs are sufficiently low.

A bushel of corn on average yields 2.5 gallons of ethanol, with an average per acre yield of 125 bushels [7]. With an ethanol energy of combustion of approximately 21 MJ/liter, and an average insolation for the midwestern corn producing states (such as Iowa) of 166 M/m^2 [Insolation], this can be used to estimate the solar conversion efficiency of corn derived ethanol. Given the corn yields, the US produces approximately 0.3 liters/m^2 of ethanol, which, when combusted gives ~ 7 MJ / m^2 / year or ~ 0.22 W/m^2. This is a photosynthetic energy conversion efficiency of 0.1 %, and compares rather dismally to the 15% efficiency of currently available solar cells. The photosynthetic efficiency of sugarcane crops should be higher than that of corn, since the yield per hectare is roughly 6 times better (see Table 2).

The United States plants about 70 million acres of corn. Thus the potential yield of ethanol from the entire corn crop would be 22 billion gallons. The US annual gasoline consumption is ~ 140 billion gallons. The combustion energy of gasoline is approximately 32-35 MJ/liter compared to 21 MJ/liter, and so this corn output would correspond to around 10% of the energy of gasoline currently used in the US. In order to replace the projected 35 billion gallons, corn production would have to increase to 185 million acres, or a square of land that is ~ 865 km on each edge. In order to replace all of our gasoline with corn ethanol, a 2200 km on edge square would be needed, which is about 50% of the US land area, and is quite absurd. Obviously, a crop with higher area yield, or solar cells can be used to generate energy with far less area.

Ethanol Fuel Cleanliness:

Bio ethanol, by itself, is a clean fuel. CO_2 taken from the environment during the growth phase of the plant can be converted into energy and the same amount of CO_2. The photosynthesis reaction is [5]:

$$6CO_2 + 6H_2O + \text{light} \rightarrow (CH_2O)_6 + 6O_2$$

The ethanol fermentation reaction is

$$(CH_2O)_6 \text{ -> } 2\ CO_2 + 2\ C_2H_6OH$$

The combustion reaction for ethanol is:

$$C_2H_6OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

In total 6 molecules of CO_2 and light are converted into 6 molecules of CO_2 and energy. Obviously, oil that is used to create gasoline also comes from CO2 that was once in the atmosphere, but CO_2 from ethanol is CO_2 that was in the atmosphere within 1-5 years and does not cause a change in the average levels.

In reality, energy inputs during the growth phase of the plants, the harvest, transportation, fermentation, distillation and distribution add to the CO_2 output of the process. By utilizing energy sources which are lower in emissions than gasoline, the overall production can have a lower greenhouse gas output than the gasoline. The table below, taken from [8], shows Greenhouse Gas Savings (GGS) for corn and cane ethanol. GGS is a measure of how much less greenhouse gas emissions result in burning of one liter of ethanol compared to one liter of gasoline. It is quite clear, that the competitive advantage of corn (at 20% maximum), vanishes when the fuel efficiency drop of 25% is considered. A good comparison of corn and cane ethanol is found in [8], and is summarized in Table 2 below.

Table 2: Comparison of Sugar Cane and Corn ethanol sources

Plant	Ethanol Yield (liters/ha) ha=10000 m^2	Greenhouse Gas Savings over gasoline	US yield (tons/ha)*	US total output 10^6 tons
Sugar Cane	5300-6500	87-96%	67.76	25
Corn	3100-3900	10-20%	9.2	282

* data from Food And Agriculture Organization of The United Nations http://faostat.fao.org

While the sweet potato was not found in [8] or most other sources, it would seem to be competitive with corn on the U.S. market with an ethanol yield of ~ 4031 liters/hectare and a crop yield of 43 tons/ha. but calculated from [9].

The previous estimates are based on standard fermentation of corn kernels. However, cellulosic ethanol production is expected to result in higher efficiency with fewer effects on the environment. To date, cellulosic processing has been cost inefficient, but a recent program [10] has been set up to spend $385 million in federal funding on six cellulosic ethanol plants. Cellulosic ethanol has become the primary focus of the US energy policy, as the DOE has recognized that current corn ethanol production may not be the most efficient. However, currently there are no operating production scale cellulosic ethanol plants, and the ethanol supplied to the US market is produced with standard fermentation of kernels.

<u>Corn Ethanol cleanliness:</u>

A comprehensive summary of Corn Ethanol studies and cleanliness can be found in [3], which summarizes key research papers published on the cleanliness of corn ethanol. The study used previous research data and their own estimates to find the average values for corn ethanol cleanliness based on energy inputs. The summarizing figure is reproduced below:

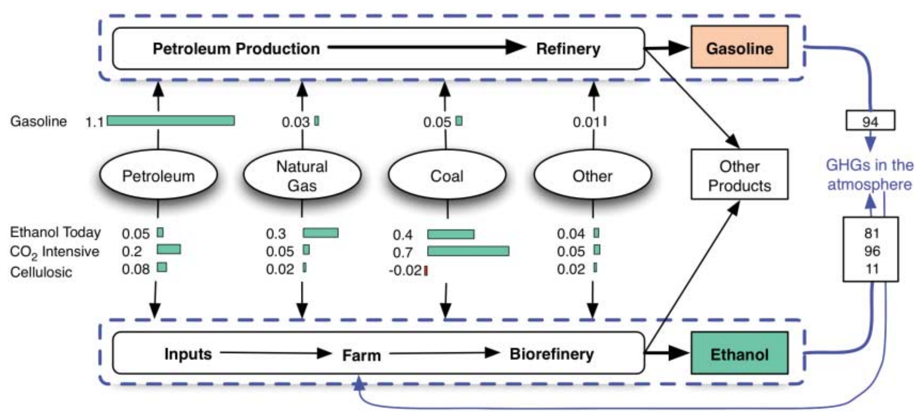

Fig. 2. Alternative metrics for evaluating ethanol based on the intensity of primary energy inputs (MJ) per MJ of fuel and of net greenhouse gas emissions (kg CO_2-equivalent) per MJ of fuel. For gasoline, both petroleum feedstock and petroleum energy inputs are included. "Other" includes nuclear and hydrological electricity generation. Relative to gasoline, ethanol produced today is much less petroleum-intensive but much more natural gas– and coal-intensive. Production of ethanol from lignite-fired biorefineries located far from where the corn is grown results in ethanol with a high coal intensity and a moderate petroleum intensity. Cellulosic ethanol is expected to have an extremely low intensity for all fossil fuels and a very slightly negative coal intensity due to electricity sales that would displace coal.

As can be seen, corn ethanol production with current technology yields ~ 14% less green house emissions compared to gasoline (20% is thus a fairly optimistic number). The major inputs to to the production process come from natural gas and coal, which can both be domestically produced. Ethanol production does not strongly rely on petroleum availability, and can thus be potentially be sufficient for energy independence, with the only caveat being that 50% of the land mass of the US would have to be covered in corn crops, as will be sown below. Cellulosic ethanol, on the other hand, is predicted to have a roughly 8.5 fold reduction of green house gas emissions over gasoline. If E85 fuels are made with cellulosic corn ethanol, the net benefit to greenhouse gases will be reasonable. With a one to one gallon efficiency between gasoline and E85, emissions would go down to 25% those of gasoline. If the fuel consumption is increased by 25% per mile, the benefit is reduced, but still reasonable at 31%.

Economics of Corn Ethanol

The economics of corn are rather questionable. Corn farmers receive hefty subsidies from the US government. Corn has been so cheap to buy that it has permeated almost all areas of the food industry. Cattle feed is corn based, corn syrups can be found in most food ingredients. Corn exported from the US floods foreign markets. Corn subsidies in the US from 1995 to 2005 are reproduced below.

Table 3: Corn Subsidies by year in the US

Year	Corn Subsidies
1995	$2,723,846,939
1996	$1,861,475,819
1997	$2,694,553,005
1998	$4,826,101,164
1999	$7,238,282,386
2000	$7,722,105,815
2001	$5,483,720,758
2002	$1,981,339,791
2003	$2,812,727,118
2004	$4,503,551,234
2005	$9,413,574,771
Total	**$51,261,278,801**

According to the Univeristy of Minnesota, the US produces 80% of the world's corn, of which 5% go to ethanol. However, since the price for corn has been closely linked to the expectations of ethanol fuels. This has lead to a doubling of the price per bushel of corn on the commodity market, and has resulted in tortilla shortages in Mexico and higher prices on beef in the US. The US government and local state governments have encouraged ethanol fuel installations. The Volumetric Ethanol Excise Tax Credit results in a $0.51 credit for each gallon of ethanol blended into fuel, and the 2006 Energy bill includes a 30% federal tax credit (up to $30,000) for installing fueling facilities that are capable of providing E85 fuel.

Conclusion

Corn ethanol based on current production technology is completely inefficient, and hardly justifiable. For FFV's running on E85, current fuel efficiency is lower by up to 30% when running on Ethanol unless the automotive industry implements severe changes. Green house gas savings of corn ethanol with current technology are only up to 20%, and so the fuel efficiency drop completely negates the benefits. Cane, or cellulosic processes that rely on less GGS emissions in the process may be the way to go in areas where insolation is insufficient to supply energy year round, and stored ethanol can be used for fuel or as an energy source. Current federal subsidies will most likely encourage the sustained expansion of corn production.

References:

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