Summa Cum Laude Team Prize: $20,000
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ETHANOL:
NOT ALL IT SEEMS TO BE

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I. Summary

If you look in any other newspaper in the U.S., it's oil dependence this and greenhouse gases that. That's why this column is going to take you on an in depth journey of one of the most-discussed solutions: ethanol fuel.

Just what would it be like if the U.S. replaced 10% of its current gasoline with ethanol? This column has all the answers. First, the approximate amount of gasoline that will be used in 2008 was extrapolated from historical data. Then, the quantity of gasoline required to produce a given volume of ethanol was used along with the ethanol to gasoline efficiency factor to calculate the amount of ethanol needed for the 10% replacement. The amount of ethanol needed was found to be 21,630,000,000 gallons, not a small number by any means!

Everyone is worried about global warming these days, so it is important to factor in the impact ethanol has on greenhouse gas (GHG) emissions. The final mass of GHGs produced after the switch to an extra 10% ethanol was compared to the initial mass before the new policy implementation. Although the use of ethanol as a gasoline alternative is often touted as an environmentally friendly option, it was found that there was an increase in GHG production due to large releases of gases from the change in land needed for producing all that extra corn. Although this seems a short term consequence, the constantly increasing fuel demand means that this added gas just won't go away.

Could ethanol be feasible economically? To find out, the net expense of creating ethanol from the costs for harvesting, constructing extra refineries, and refining was calculated. Then, the point at which this cost would break even with the cost of gasoline was found, a high price of $233.82 per barrel. Seeing as oil has been at an all-time high currently at $106.54, it seems ethanol will not be economically feasible in the near future.

One acknowledged problem of ethanol production is that it takes essential food from developing nations. This column tried to find a correlation between the price of corn and the worldwide demand, as modeled by studying the world population versus the global supply of corn. However, no significant relationship was discovered, so another approach was taken. The group modeled the decrease in supply of corn after a historical parallel of the oil crisis in the U.S. in the 1970s. Using the model from this embargo, the price increase was high enough to be crippling to developing countries' food supplies and is another strike against ethanol.

How will we achieve energy independence you ask? A number of alternative energy options such as solar power and nuclear energy were considered. Calculations concerning the cost and amount of solar panels or nuclear power plants needed to achieve the same 10% substitution as the ethanol plan. This column found that nuclear power is the most cost effective and practically feasible by far. More research should be spent on this issue to see if a solution to the problem of foreign oil dependence is foreseeable. Until then, this column suggests you stay off the ethanol bandwagon – it just doesn't make sense.

II. Introduction

Because of the actions of the Organization of the Petroleum Exporting Countries (OPEC), the petroleum economy has become more restricted and inflationary pressures have been placed on the market. The U.S. needs to establish energy independence to break free from the shackles of foreign oil cartels such as OPEC. One solution on the forefront of discussion is ethanol fuel. In particular, corn-derived ethanol has been proposed as a promising gasoline alternative.

III. Global Assumptions

1. It is assumed that all of the ethanol discussed is corn-derived.

IV. Phased Replacement of Gasoline with Ethanol

<u>Assumptions</u>

1) It is assumed that increases in alternative energy usage will be minimal and thus will not significantly impact gasoline consumption for 2008.
2) It is assumed that a linear model will produce accurate predictions over a short time (i.e., 5 years) but will yield a significant error after this period.

<u>Concept and Rationale</u>

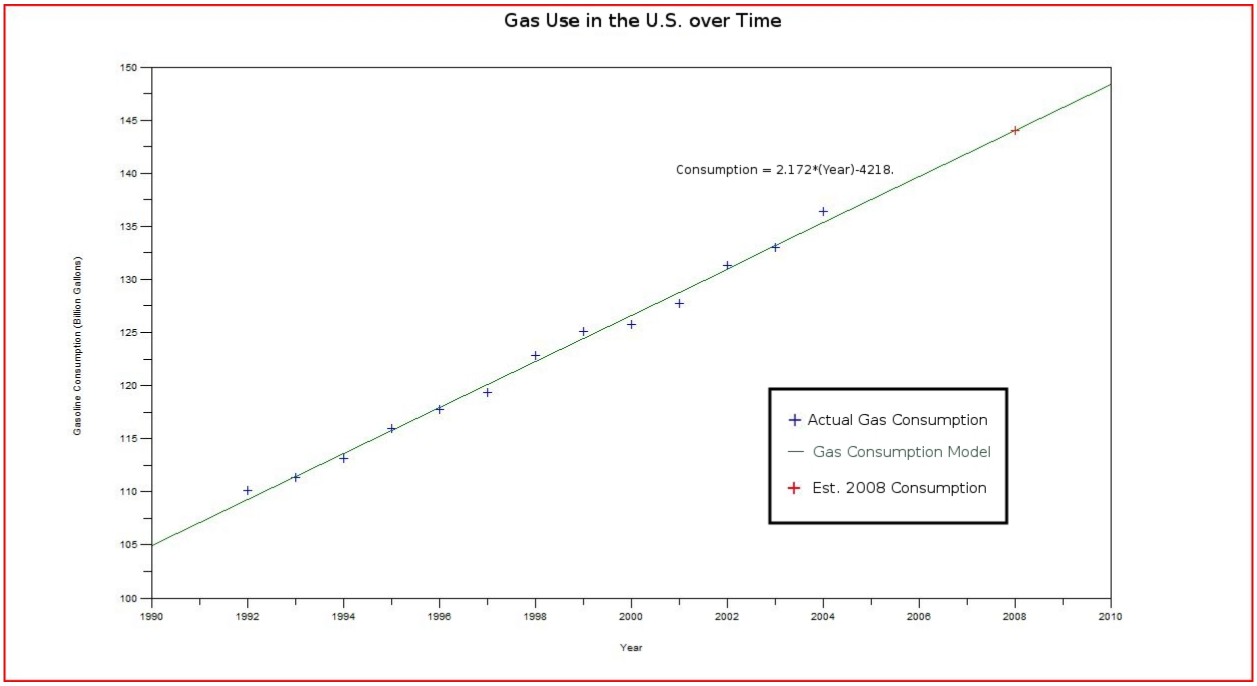
The transition to alternative fuels such as ethanol will be a gradual one, requiring adjustments in production patterns, technology, and political attitudes. For the purposes of this model, it is feasible to replace 10% of the energy demand currently fulfilled by petroleum-based gasoline with ethanol by the end of 2008. In order to predict the quantity of ethanol needed to accomplish this, one must first extrapolate the volume of gasoline that will be consumed in the U.S. in 2008, taking into account the discrepancy in energy yield between the two substances to find 10%. Additional gasoline will be required to create this ethanol, and additional ethanol to replace this gasoline, thus yielding a second term in the equation.

<u>Calculations</u>

The beginning step in creating the model was to perform a regression analysis, using data from 1992-2005 to extrapolate the amount of gasoline that will be used by the U.S. in 2008. Statistics from the U.S. Department of Transportation showed the following trend:

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Gasoline consumption (million gallons)	110,135	111,333	113,144	115,943	117,783	119,336	122,849	125,111	125,720	127,768	131,299	132,961	136,374

("Table 4-10")



The curve generated from the data chart yielded an r-value of 0.996, indicating a strong positive correlation. The r^2 value of 0.993 confirms that scattering occurs due almost exclusively to randomness and is not attributable to a systemic error source. By the regression equation, in 2008, approximately 144,000,000,000 gallons of gasoline will be consumed.

Next, the model addressed the quantity of gasoline required to produce a given volume of ethanol. This conversion amounts to 3.09 gallons of gas per acre of corn (Shapouri, Duffield, and Wang 6). Each acre of corn contains 151.2 bushels (Fitzgerald), and each bushel yields 2.7 gallons of ethanol (Rapier). Thus, one can derive a conversion factor for the volume of gasoline used in the production of a single gallon of ethanol:

$$3.09\ gal_{gas}/acre * 1/151.2\ acre/bushel * 1/2.7\ bushel/gal_{ethanol} = 0.00757\ gal_{gas}/gal_{ethanol}$$

At this time, it was also necessary to factor in the 67% (≈2/3) efficiency of ethanol to gasoline (Rapier). Therefore, for each gallon of gasoline, 1.5 gallons of ethanol are needed to replace the energy demand.

Bearing these factors in mind, one can model through a summation of a geometric series:

$$\sum_{n-1}^{\infty}(ga\lg as2008(.1*1.5)^{n}(conversionfactor)^{n-1})$$

This equation converges to 0.15017, meaning that 15.017% of the gallons of gas projected to be consumed in 2008 will need to be replaced with ethanol to yield a 10% transition.

By multiplying the gasoline extrapolation by 0.15017, one can conclude that approximately 21,630,000,000 gallons of ethanol will be needed to replace 10% of the annual U.S. gasoline usage.

Testing the Model

A good way to test this model is to do an experiment on a small scale, burning a known amount of gasoline in a calorimeter. Then, take another sample of gasoline with 10% less by volume and add to it the amount of ethanol calculated by the model. If it burns with the same amount of energy, it will show the power of the efficiency factor. Then, gather data from farmers that produce ethanol on their gasoline usage. This will tell the power of the conversion factor.

V. Greenhouse Gas Emissions from Ethanol

Assumptions

1. It is assumed that nearly all of the gasoline required for the production of ethanol is used in the farming and harvesting stage, while other energy sources (i.e., coal) are utilized during the refining stage.
2. It is assumed that carbon dioxide accounts only for a portion of greenhouse gases (GHGs), and to accurately assess the environmental effects of ethanol versus those of gasoline, one must analyze emissions as a whole.

Concept and Rationale

In addition to political, economic, and mechanical feasibility, one must consider the environmental consequences of choosing ethanol over gasoline. In particular, the amount of air pollution released in the form of CO_2 and other GHGs is a crucial point of interest. In order to model the difference in ethanol and gasoline emissions, it is necessary to calculate the final mass of GHGs (in the case where 10% of the gasoline energy supply has been replaced by ethanol) minus the initial mass (before the 10% was implemented). If the result is negative, the 10% ethanol scenario gives off fewer GHGs; if it is positive, it gives off more.

Calculations

The first step in modeling the situation is to calculate the initial GHG contribution from the projected consumption of gasoline in 2008. Gasoline produces 4 g/MJ in petroleum harvesting, 15 g/MJ in refinement, and 72 g/MJ in burning. Thus, each megajoule of energy from gasoline yields 92 grams of GHGs, or 11.96 kg/gal of gas when multiplied by the energy conversion for gasoline, 130 MJ/gal (Golnik). Multiplying this figure by the gallons of gasoline from section IV yields an initial emission of approximately 1,722,000,000,000 kg.

Then, one must calculate the final GHG contribution, given by the contribution from the total gallons of gasoline to be used in 2008 minus the gallons replaced by ethanol; this totals to approximately 1,464,000,000,000 kg. Also, it is necessary to add the contribution from the gallons of ethanol in 2008, which produces GHGs by a different conversion factor. These gases are evolved through growing corn (24 g/MJ), refining (40 g/MJ), and burning (71 g/MJ), in addition to the large initial production from the change in land use to corn farmland (104 g/MJ). However, the corn crops also remove 62 g/MJ from the environment. This sums to a contribution of 177 g/MJ, or 15.4167 kg/gal total when multiplied by the energy conversion factor of 87.1 MJ/gal (67% of that of gasoline) (Searchinger, et. al.). By multiplying this number by the estimated gallons of ethanol, one can arrive at the total GHGs produced, or approximately 333,400,000,000 kg. Overall, this amounts to a final GHG contribution of 1,797,000,000,000 kg the first year.

These two calculations may be combined to find the change in GHG contributions through the following:

$\Delta GHG = GHG_f - GHG_i = (gal_{gas}2008 - gal_{ethanol}2008) * GHG/gal_{gas} + gal_{ethanol}2008 * GHG/gal_{ethanol} - (gal_{gas}2008 * GHG/gal_{gas})$

Thus, ΔGHG amounts to 74,760,000,000.

The positive value indicates that by replacing 10% of the gasoline energy demand with ethanol, the amount of GHGs released actually increases. However, this is primarily for the short term, as the large release of gases from the change in land use accounts for a significant portion of this number. After more than a century, this emission would be "paid back," and the ethanol switch would begin to produce less mass of GHGs (Searchinger, et al.). However, if it were necessary to continue planting crops on new farmland, the contribution would continue to increase.

Testing the Model

The best way to test this model is to look at data of known fuel use versus the yearly change in atmospheric composition before ethanol became popular and then look at the current yearly change in composition, factoring in the extra ethanol. That will tell whether the model makes accurate predictions about land-use change affecting GHG emissions.

VI. Cost Analysis of Ethanol Implementation

Assumptions

1. It is assumed that farming conditions are roughly the same in 2008 as over the past two years.

Concept and Rationale

Perhaps the single most scrutinized factor in the feasibility of ethanol implementation is the cost of such a transition. In order to compare the prices of gasoline to those of ethanol, a reasonable approximation first had to be developed for each, accounting for the costs at each stage of harvesting, refining, etc; since data on gasoline production costs was scarcer, more inventive methods were employed to determine a trend. Then, these models were set equal to each other to determine the break-even point below which it would be less expensive to produce ethanol than gasoline.

Calculations

The modeling began with a determination of the cost to create ethanol in dollars per megajoule of energy. The cost to farm an acre of corn is $604.21/acre (Duffy and Smith), while the cost to convert it to a gallon of ethanol is $1.10 ("Biomass Energy"). Multiplied by the aforementioned conversion factors and added together, these two costs produce the overall price of ethanol with respect to energy. Also, additional ethanol refineries must be built. These cost about $75 million, and they produce 50 million gallons of ethanol per year (Palmeri and Pressman). Taking the unmet need of 21.6 billion gallons of ethanol, one must divide that number by the production of each refinery. Approximately 433 plants will need to be constructed. At $75 million per refinery, this comes to be $32.44 billion as the initial cost. This must be divided by the total energy demand the first year to get the cost of the refineries in terms of the MJ they produce:

Harvest Cost:

$604.21/acre * 1/151.2 acres/bushel* 1/2.7 bushel/gal * 1/87.1 gal/MJ = $0.016992/MJ

Production Cost:

$1.10/gal * 1/87.1 gal/MJ = $0.012629/MJ

Cost of New Refineries:

$32,440,000,000/21,630,000,000 gal * 1/87.1 gal/MJ = $.017219/MJ

Total Cost:

$0.012629/MJ + $0.016992/MJ + $0.017219/MJ = $.04684/MJ

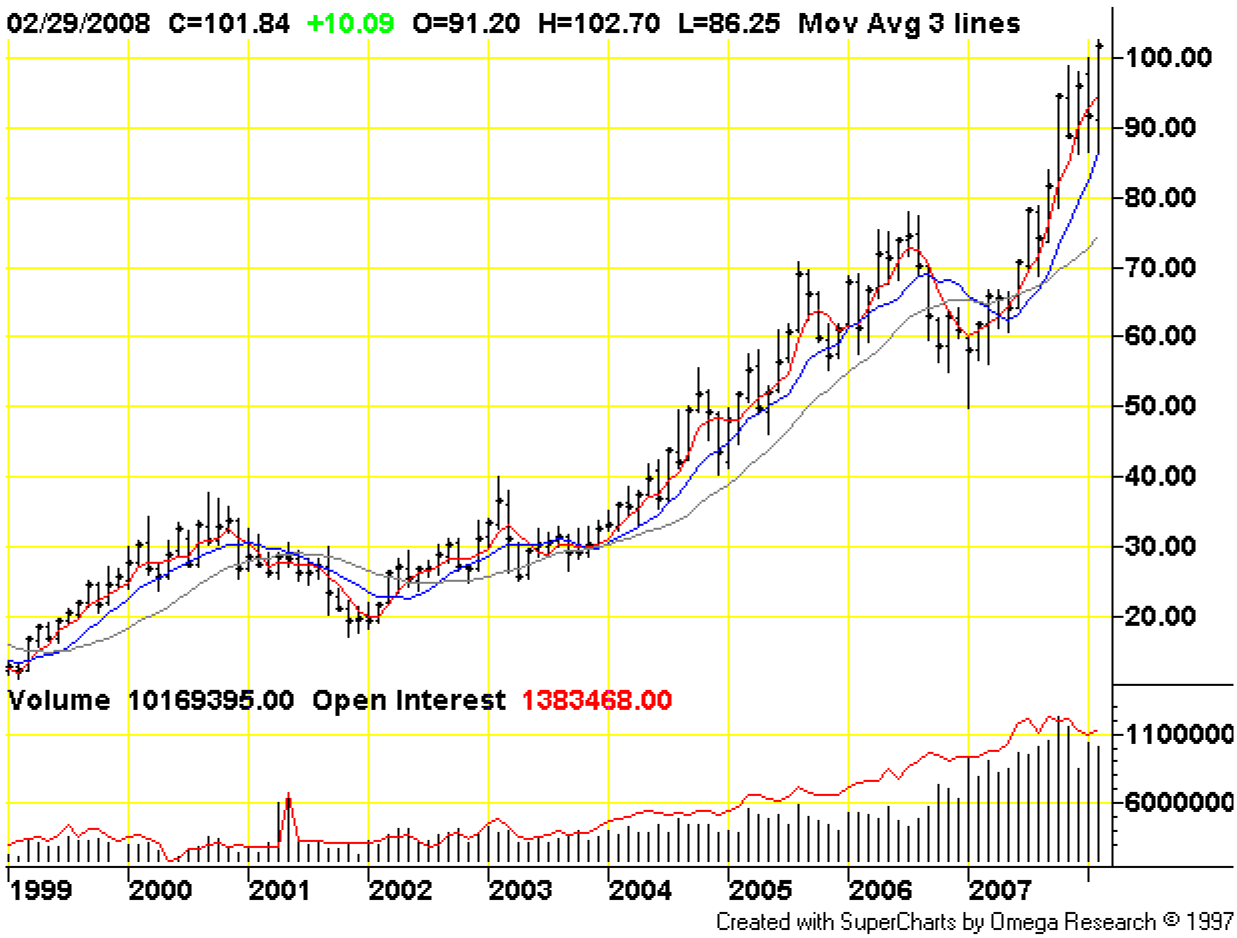
The cost to produce gasoline comes from two previously established data points; when oil is $24/barrel (i.e., in 2002), it costs $0.21/L of gasoline produced, and when it is $30/barrel (i.e., projected for 2020), it costs $0.25/L of gasoline produced ("Table 2.12"). One can conclude that in addition to a constant "base" cost, the cost to make gasoline is dependent upon the price of oil by the barrel. Thus, it is possible to find the function of these data points to find an equation based on barrel price.

To find the oil barrel price at which ethanol becomes less expensive to produce than the traditional fuel of gasoline, one must set the cost of ethanol per megajoule equal to the regression equation:

$$\$0.04684/MJ = 1.941*10^{-4}/MJ * (\text{barrel price}) + \$0.0014559/MJ$$

where barrel price can be solved for to equal $233.82 at the break-even point. As the all-time high for oil is $106.54 (see graph below), set March 7th, 2008, it is unlikely that ethanol will be an economically feasible alternative to gasoline in the near future.

Oil Price for 1999-2007 in $ per Barrel



("Light Crude Oil")

Testing the Model

The best way to test this model is to query farmers and ethanol producers to get actual operating costs and to query oil refineries for actual production costs. The true price of the production of gasoline and ethanol could then be determined very accurately, and the financial history of both ethanol-producing companies and gasoline companies could be used as confirmation of the model.

VII. Effect on Developing Nations of Ethanol-Driven Grain Prices

Assumptions

1. It is assumed that fluctuations in grain prices may be most accurately modeled by predicting the price of corn, as outside factors from different grains (i.e., shortages of wheat, a poor barley harvest) could provide a misleading impression in the statistics.
2. It is assumed that tariffs and other international trade regulations would negligibly affect the trends in corn price.

Concept and Rationale

To model the effect of a transition to ethanol on corn prices in developing countries, one must invoke the inverse relationship between supply and demand. Early attempts at a model endeavored to compare world supply to world market price to derive a relationship that would describe demand; this would show a correlation between availability and price. In order to do this, past data was graphed, with world population divided by world supply of corn available for food (minus that used annually on ethanol) on the x-axis and price on the y-axis, the latter being an indicator of demand. However, attempts to find a discernable relationship were abortive.

There are several reasons for the failure of this model. For instance, since ethanol has only recently been accepted as a viable alternative energy source, there are less than 10 years of available data on the amount of the corn supply it consumes. Also, this consumption is small when compared with the overall corn supply and thus does not show a visible trend.

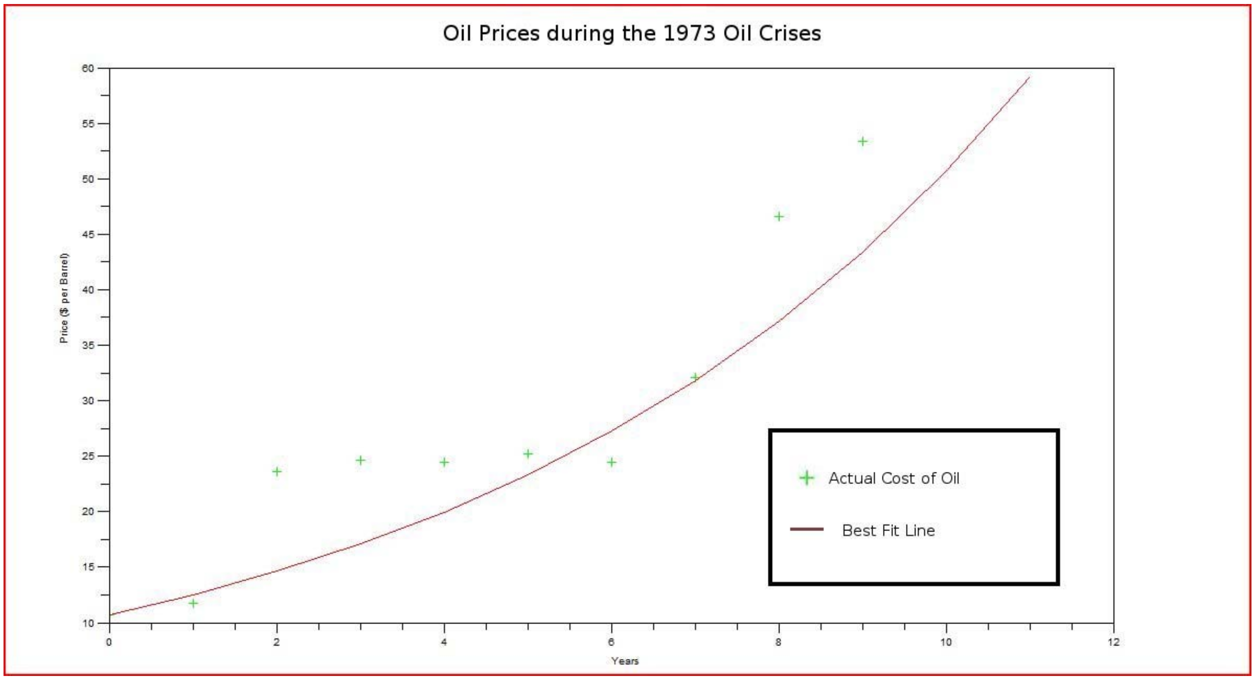
Instead, an alternative model was devised which used an historical parallel of another commodity shortage: the oil crisis of 1973. During this embargo, the oil supply to the U.S. from OPEC nations was reduced to zero (Billig). Although there are many differences between this situation and a reduction in the corn supply due to the implementation of ethanol, the model is still an acceptable indicator of the general direction in which prices would move.

Calculations

The first step in creating the corn shortage model was to establish data points from the oil crisis. Ten points were taken beginning in 1972 at t = 0 through 1981 ("25th Anniversary"):

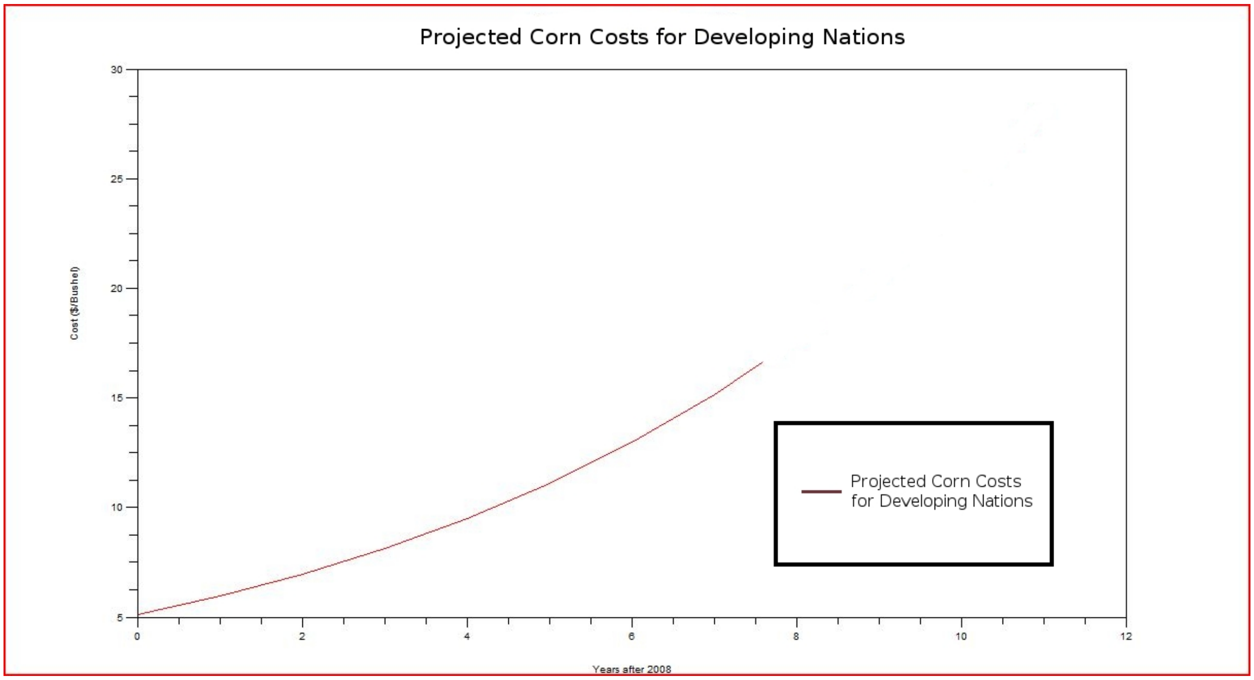
Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Price/barrel (2007 USD)	\$10.72	\$11.76	\$23.56	\$24.66	\$24.42	\$25.23	\$24.48	\$32.10	\$46.55	\$53.39

Then, these values were graphed and an exponential regression analysis performed to find a trend via a growth factor.



The function given was $C(t) = \$10.72 * 1.1681^t$. The r-value amounted to 0.928, indicating a strong correlation, with an encouraging r^2 value of 0.861. To apply this model to a reduced corn supply due to its diversion for ethanol, it was necessary to substitute a different initial value, the current cost of a bushel of corn. Thus, $10.72 was replaced with $5.11 ("Long Liquidation"), and the following projections were developed for a six year period:

Year	2008	2009	2010	2011	2012	2013
Price/bushel	$5.11	$5.97	$6.97	$8.14	$9.51	$11.11



It can be assumed that this model will begin to deteriorate over time, as within five years another country would likely begin to pick up production of corn for food purposes, replacing that reduced by the U.S. However, it is a reasonable model for before that because developing nations would likely not respond for five years due to a lack of infrastructure, i.e. communication, distribution, etc.

Testing the Model

There are two good ways to test this model. First, and most preferable, would be to get accurate data on corn demand versus corn cost. With that data, the new cost for the high demand that a dearth of corn would create can be calculated. This can then be compared to the prediction made by the model. The second, less preferable way, would be to find other historical shortages and compare the values of the commodities over time to see if those models match that of the oil crisis of 1973. If they were similar, it would show the power of using this model as a predictor for corn.

VIII. Feasibility of Ethanol and Other Energy Alternatives

Assumptions

1. It is assumed that the demand for gasoline will not increase drastically in the next few years.
2. It is assumed that any alternative energy program that is adopted can be implemented without delay.

Concept and Rationale

The previous calculations showed that while the production of ethanol would reduce U.S. dependence on oil, it was not an economically viable solution. It is possible that another alternative energy source could be found that would be more cost effective. Safety and GHG emissions were taken into account when choosing and finding this alternative. Several sources of energy were considered such as coal, nuclear, natural gas, solar, and wind power. Solar and wind sources have no GHG emissions. However, they are not very productive per unit of land when compared to the other fuels. We calculated before that a total of 21.6 billion gallons of ethanol would be needed per year to replace 10% of gasoline use. From this we can approximate the land needed to grow all of this corn that will be converted to ethanol and use that as a comparison for the wind and solar power sources.
(http://www.americanenergyindependence.com/solarenergy.html)

For solar energy, 270 times less land area will be need than for ethanol. However, solar is 4.7 times more expensive. Another drawback to solar power is that it is dependent on the weather. In overcast weather, no energy can be produced. For the reasons of initial cost and dependency on weather, solar power was found to be ineffective. Wind power was considered to have similar setup costs, less yield, and even more dependency on weather. It is also ineffective for providing such a large amount of energy that people depend on. It must be noted that solar and wind systems do exist that charge up batteries, but they are 20%-30% more costly.
(http://www.solar-electric.com/solar_system_costs.htm)

Data was found on the other fuel sources that still had not been considered.

U.S. Electricity Production Costs and Components

1995 - 2006, In 2006 cents per kilowatt-hour

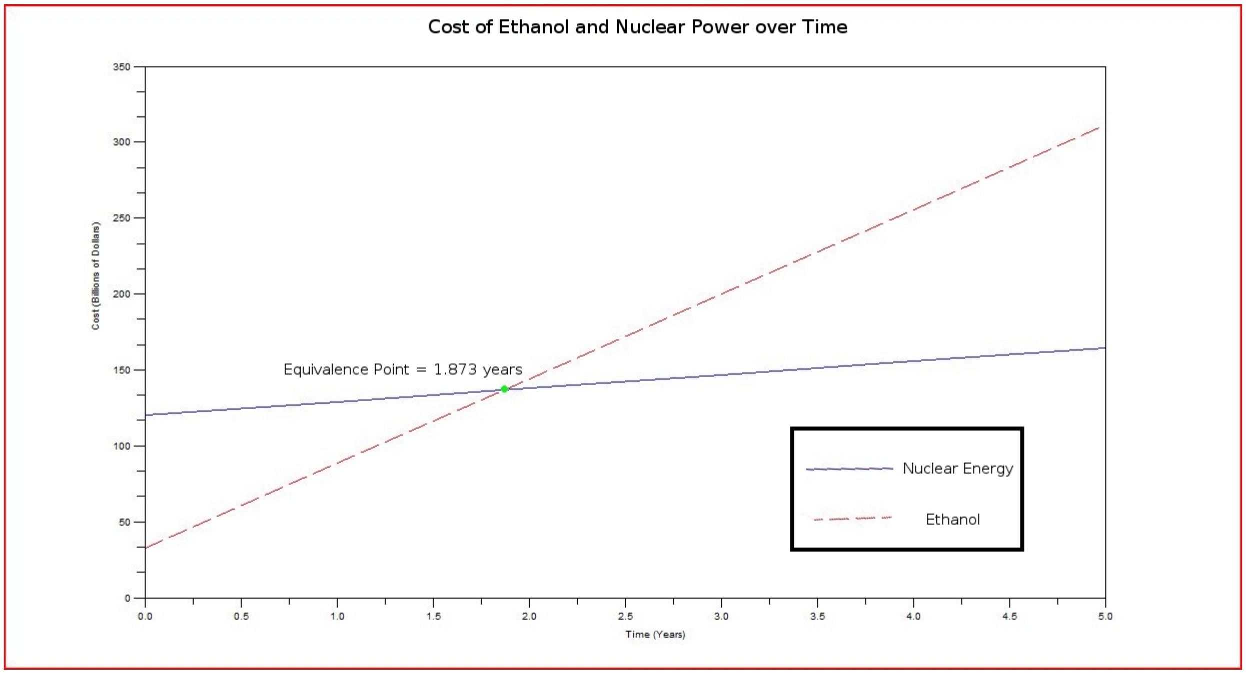
	Total Production Costs				Operations & Maintenance Costs			
Year	**Coal**	**Gas**	**Nuclear**	**Petroleum**	**Coal**	**Gas**	**Nuclear**	**Petroleum**
1995	2.41	3.51	2.53	5.51	0.57	0.67	1.78	1.57
1996	2.27	4.28	2.37	5.60	0.50	0.66	1.69	1.30
1997	2.19	4.34	2.47	5.03	0.49	0.63	1.81	1.11
1998	2.14	3.80	2.30	3.53	0.52	0.55	1.65	0.69
1999	2.06	4.11	2.07	4.24	0.49	0.48	1.47	0.97
2000	2.00	6.80	2.03	6.14	0.48	0.53	1.47	0.79
2001	2.09	6.87	1.89	5.62	0.51	0.60	1.37	0.77
2002	2.05	4.38	1.90	5.40	0.52	0.60	1.40	0.89
2003	2.03	5.98	1.86	6.41	0.51	0.61	1.36	1.01
2004	2.13	6.22	1.84	6.18	0.53	0.51	1.34	0.92
2005	2.31	7.79	1.76	8.47	0.54	0.49	1.30	0.90
2006	2.37	6.75	1.72	9.63	0.54	0.52	1.26	1.20

Production Costs = Operations and Maintenance Costs + Fuel Costs

Source: Global Energy Decisions

Updated: 6/07

Nuclear power was found to be the least costly to produce as of 2006. Also, unlike fossil fuels, nuclear power is extremely clean and does not produce air pollution. An analysis of cost was used to deduce the feasibility of nuclear power. 60 nuclear power plants would need to be built at around $2 billion a plant. This cost would be $120 in construction + $9 a year in production costs. This is about 1.5 times more expensive than ethanol for the first year, assuming that all power plants are operational. However, the yearly cost of maintenance for nuclear power is only $9 billion while for ethanol it is $56 billion. This means that after the second year of operation, the nuclear power would be cheaper than the ethanol power.



Nuclear power was found to be the best choice. It is cheaper than solar and ethanol and environmentally friendly. Safety factors are not a concern. While a catastrophe is always possible, it is not probable since proper maintenance costs were factored in to make sure that the plants would be well kept and safe. The only other advantage of ethanol vs. nuclear was that ethanol is readily portable and can be used in combustion engines. However, the nuclear energy will not replace all of the energy generated by gasoline but only 10%. Also, cars powered by hydrogen fuel cells are being rapidly developed. Nuclear power may be used to create the hydrogen fuel cells. (http://www.fueleconomy.gov/feg/fuelcell.shtml)

<u>Calculations</u>

Solar

21,626,307,221 gal * 1 / 2.7 bu/gal * 1 / 151.2 bu/acre = **52,974,493.5 acres of land**

Solar panels with today's technology can produce 7.26 megawatt-hours of electricity per day per acre.

7.26 (MWH/day)/acre * X acres * 365 days/ year = 520,042,142 MWH/year
X = **196250 acres of land**

This shows that solar energy will use 270 times less land than ethanol.

Average installed cost of solar electric is around $7 per watt. (http://www.solar-electric.com/solar_system_costs.htm)

520,042,142 x 10^6 WH/yr * 1/24 day/ hr * 1/365 day/yr * 7 $/W = **$416 billion**
This is the total cost for the installation of the solar panels. This does not include maintenance costs.

21626307221 gallon ethanol needed = 50x10^6 gallon/year x $75x$10^6$ X plants
X = 433 plants
433 plants x $75 million = $32.550 billion construction cost for ethanol plan

$0.02962 / MJ * 87.1 MJ/Gal * 21,626,307,221 gal/yr = $55.8 billion per year.

The cost of Ethanol is $32.550 billion + $55.8 billion per year = **$88.35 for the first year for ethanol**

Nuclear

10% of gas x 130MJ/gal = 1872151714.285GJ → total energy produced per year needed from nuclear

1000MW plant at $2billion/plant and 5 year construction
http://www.rff.org/Documents/RFF_Resources_156_nuclear.pdf

1000 x 60 x 60 x 24 x 365 /10^9 /3.6 = 8760000 MWhr/yr per plant
1872151714.285GJ/3.6GJ/MWhr = 520042142 MWhr produced per year needed
520042142 = 8760000x plants
X = **60 plants needed** x $2 billion = **$120 billion construction cost**

520042142000 kWhr/year x $.0172/kWhr = **$8944724842 per year in production costs of energy**)
$5.57938x$10^{10}$ each year for ethanol – more than $8.9 billion each year for nuclear

As of 2006, the annual production cost of nuclear energy was lower than coal, gas, and petroleum.

Testing the Model

Nuclear power in the U.S. currently accounts for about 20% of the total electricity produced. In other countries it is the primary source of energy. In France, nuclear power accounts for 75% of the total electricity produced (http://www.uic.com.au/nip28.htm).

Future results may be inferred from past data. The U.S. had 103 reactors in operation in 2001. France has 59 reactors operating. There have not been any significant incidents with these reactors. The setup in France demonstrates the cost effectiveness of the nuclear power method. France decided to develop its nuclear power in 1974. Now, it boasts energy independence. Moreover, it overproduces energy every year, which it sells for a profit to surrounding nations.

IX. Conclusion

From the studies performed, it was determined that 21,630,000,000 gallons of ethanol will be needed to replace 10% of the annual U.S. gasoline usage. This ethanol production will increase GHG emissions by 74,760,000,000 kilograms. In addition to this negative effect of using more ethanol, the plan would not be cost effective until oil prices reached over $233 per barrel. The change of corn production from use as food to ethanol fuel will also raise grain prices, as seen by the model of the 1970s oil embargo on the U.S. More importantly, this will hurt developing countries significantly due to their dependence on foreign crop imports such as corn. Through additional research and modeling, it was found that nuclear power may actually be a better alternative for attaining national energy independence.

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