Meritorious Team Prize: $7,500
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The Hidden Costs of Ethanol

Team 198

A Summary

A group of high school seniors recently conducted an extensive survey of the feasibility and consequences of alternative energy sources, focusing on the replacement of gasoline with ethanol. Ethanol, manufactured from crops such as corn or sugar cane, is a rapidly growing sector of America's energy production. Due to the fact that it is a renewable resource, since it is grown and takes very little time to produce, it is a good candidate for the future of America's energy. Many states have already been incorporating ethanol into a gasoline mixture known as E10, which contains 90% of traditional gasoline and 10% of ethanol. The object of this slow conversion to this alternative energy is to save the country from encountering a catastrophe when all fossil fuels, such as the oil and coal commonly used today, are eventually gone. With a renewable resource such as ethanol, we need not worry about running out of ways to produce energy.

There are, however, a few concerns in scientists' minds about the use of ethanol. These are its impact on the environment, its cost effectiveness, and its effect on the global economy of grain prices. The high school students created models to predict each one of these three parameters in the coming years. This is what they found.

The results showed that ethanol had an increasingly negative impact on the environment after the conversion from pure gasoline to E10. This impact leveled off at about 10% damage after 10 to 20 years. These estimates, however, were not completely accurate. Corn, like all other plants, undergoes the process of photosynthesis, using up carbon dioxide from the environment. It is highly probable that the carbon dioxide it leaches from the atmosphere more than makes up for the emissions that come about from ethanol production, making ethanol an environment-friendly source of energy.

One problem that was found, however, was that ethanol is not very cost effective. In fact, it is only about two-thirds as cost effective as gasoline, and it will only become less reasonable. The outlook is bright, though, with new technologies of ethanol production in development, allowing producers to extract even more ethanol from the base crops. Also, with the imminent rise of gas prices, ethanol might become much more practical in the near future.

Finally, the students created an economic model showing the impact of ethanol production from American corn on global corn, wheat, and rice prices. They found that the global prices went up steeply in the first year and then steadily each year after that. This is a disadvantage to developing nations, who are dependent on these staple crops as sources of food. This is the one pitfall of ethanol as opposed to gasoline.

These students, through extensive modeling and hours of crunching numbers and working figures, found that ethanol is indeed a good prospect for the future. Although it may not be the best source of energy for Americans right now, its development in the coming years is sure to make ethanol a major player in American lives.

The Energy Problem

In a world that is constantly progressing towards a future of industrialization, the use of energy is rapidly increasing. One of the major problems faced is the depletion of fossil fuels at rates faster than their rates of replenishment. The world reserves of coal, oil, and natural gas are diminishing at unprecedented rates. For this reason, many countries are striving to find alternative sources of energy – sources that are less harmful to the environment and renewable in the short term. Some of these alternative energy methods include solar, wind, geothermal, nuclear, and biofuel energy. These methods have the potential to provide clean, cost-effective energy to homes around the world. However, the current infrastructure is organized to produce the majority of its energy by burning fossil fuels. Examples include burning coal for electricity, natural gas for heating, and oil for automotive gasoline. As the supplies of these resources decrease, the world's infrastructure is quickly being structured towards alternative energies. One of these main alternative sources of energy currently being used and developed around the world is ethanol, which can take the place of petroleum in liquid carbon-based combustion applications.

Ethanol has the chemical formula C_2H_5OH and is a basic hydrocarbon, commonly referred to as alcohol. Its polarity and ability to hydrogen-bond with other ethanol molecules gives it a liquid composition. It is valuable to nations as an alternative fuel due to its combustibility and relatively high content of energy. Ethanol is different from fossil fuels since it is produced from ordinary crops, and thus renewable, classifying it as a biofuel.

Ethanol is already widely used today as a form of energy. Many gas stations offer E10 gasoline, which is a mixture of 90% pure gasoline with 10% ethanol. In fact, certain states even mandate the use of E10 as opposed to traditional ethanol. Some people are even making the transition to E85 (85% ethanol) or E100 (pure ethanol) to fuel their cars. This is an important transition in the United States and the world, and it is helping to conserve petroleum resources. Also, as the price of oil is rising, it is becoming more and more feasible to switch to ethanol as a cost-effective source of energy. Many foreign nations have already made the transition to using ethanol as a major source of energy. For example, Brazil relies on ethanol for over 30% of its automobile fuel. Europe is also close behind, with many European nations catching up on the transition. The United States is currently the world's largest producer of ethanol, showing the importance of this source of energy in the modern world.

Ethanol is also, however, causing concerns as it becomes an increasingly important method of energy production. It is being researched mainly in the regions of its effect on the environment, its cost efficiency, and its consequences on nations that require corn as a food source or do not have the land to produce enough corn for subsistence. The production and consumption of ethanol releases carbon dioxide into the environment, just like other fossil fuels. However, a major argument supporting the use of ethanol is that the corn harvests its energy from the sun by photosynthesis and creates organic molecules using carbon dioxide from the air. Essentially, the use of ethanol is capturing the sun's energy without much damage to the environment. Most of the carbon dioxide that is released into the environment by the combustion of ethanol had been previously taken from the air during the planting of the corn. Thus the net effect on the environment is nearly zero. Another concern with ethanol as an energy source is its cost effectiveness. Because ethanol technologies have not been developed to the extent that other technologies have, it is still more expensive to use than conventional sources of energy.

However, it has the potential to become cheaper in the future. Right now, sources of ethanol include crops such as corn and sugar cane, used as feedstock for ethanol production. This does not allow all of the energy to be harvested, as much is retained in the cellulose fibers in the plants. Prospective technologies are looking toward using this cellulose for energy as well, greatly increasing the energy yield and allowing new crops such as switchgrass and poplar, which are less harmful to the environment and more cost efficient, to be used. Furthermore, as the cost of oil continues to rise, ethanol is becoming more cost effective. The final concern is that the production of ethanol will harm developing nations that rely on corn as a staple crop. It is possible that the increase in corn production will cause other grain prices to rise as well, harming other nations. This is, however, yet to be seen.

This work attempts to research these three areas of concern for ethanol usage. First, it will be assumed that all gasoline is being converted to E10 ethanol-gasoline mixture in the near future. The amount of ethanol and gasoline needed will be modeled over the next 5 years, and 10-year and 20-year projections will also be made. This is making the assumption that gasoline consumption will continue its trend from the last 25 years. This data will be applied to carbon dioxide emissions relating to fuel productions to analyze the relative impact of the ethanol production on the environment. Assumptions made here are that the carbon dioxide emissions of production, transportation, and consumption processes will not change in the future. The cost of ethanol will be modeled over the next 5 years to analyze the cost efficiency of ethanol. It is difficult to make predictions for 10 and 20 years in the future because of unforeseen advances in technology. An assumption made is that all energies are equally energy efficient in their production. Also, it is assumed that all ethanol is produced from corn and that the current trends in the prices of wheat, corn, and rice will continue. Finally, an analysis is conducted rating all energy sources on a scale of 0 to 40 to determine the best energy balance plan for the future of the United States, assuming the data from current prices and technology to hold true in the future.

The Models Used

Modeling in this project was performed through the MATLAB Curve Fitting Toolbox. Values regarding the specific variables that were to be fit were determined from the sources that are discussed in specific sections. Using the manipulation of HTML and then Excel spreadsheets, this data was secured into a form that could be used as input for MATLAB analysis. The GUI and command-line tools of the Curve Fitting Toolbox were then used to allow for the understanding of the general form of the data in a plot. Then, a specific fit was chosen to accompany the data. The best fit was determined by three main characteristics: R^2 (coefficient of determination), bias in the residual plot, and its ability to extrapolate reasonable values. A variety of fits, including polynomial, Gaussian, and power were tested before a fit was chosen. The following are specific discussions of certain fits. Examples of both fits and the MATLAB code that can be used to generate these plots are shown in Appendix A.

Quantity of Ethanol Needed to Replace 10% of Annual Gasoline Usage and Effect of Fuel Substitution on Carbon Dioxide Emissions:

For ethanol production, a high R^2 = 0.9854 value was found with a power regression. The gasoline production was modeled using a linear fit, with an $R^2 = 0.9939$.

The Cost Efficiency of Ethanol:

For the price of gasoline, a Gaussian fit with two peaks was found. This fits the history of consumption, as we are currently reaching a peak similar to the peak during the 1970s. R^2 = 0.801 for this fit. The price of ethanol was modeled using a linear fit, which produced an R^2 = 0.700.

Effect of Ethanol Policy on Grain Prices and Developing Nations:

All fits for this section were made using linear fits, in order to predict later overall trends with a smaller amount of initial data. All R^2 values were in the 0.5-0.6 range.

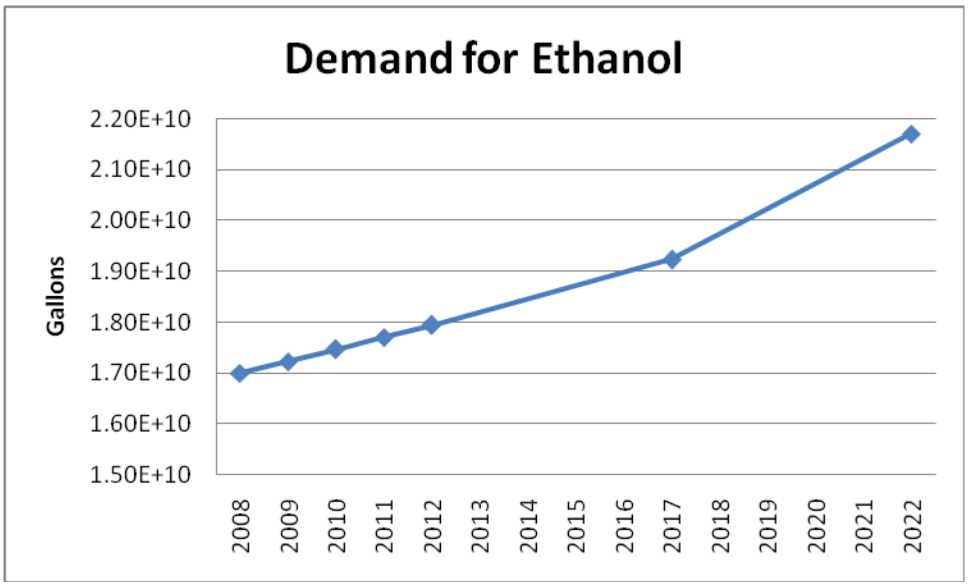
Quantity of Ethanol Needed to Replace 10% of Annual Gasoline Usage

Methodology

The projected values for gasoline consumption over the next 5 years and for 10 and 20 years model the expected number of gallons of gas needed for the given years. 10% of the energy from this gasoline will be replaced by energy from ethanol. Also, it must be accounted for that approximately 1.18 gallons of ethanol have the same amount of energy as 1 gallon of gasoline [3]. Assuming that this projection is accurate, the amount of ethanol needed is calculated using the following formula:

$$Demand\ for\ ethanol = Gasoline\ Consumption\ (gal) \times 0.10 \times 1.18 \frac{gal\ ethanol}{gal\ gasoline}$$

Demand for Ethanol							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
Gallons	*1.6997×10^{10}*	*1.7228×10^{10}*	*1.7464×10^{10}*	*1.7700×10^{10}*	*1.7936×10^{10}*	*1.9234×10^{10}*	*2.1712×10^{10}*



Conclusions

The demand for ethanol is a direct function of the consumption of gasoline. Since ethanol is replacing 10% of gasoline usage, it is directly proportional to the projected values for gasoline consumption. The projections show a relatively steady rate of increase in demand for ethanol for 20 years.

Effect of Fuel Substitution on Carbon Dioxide Emissions

Methodology

The change in carbon dioxide emissions is calculated using the projections from gasoline consumption and ethanol production over the last 25 years. The gasoline consumption values are important because they are directly proportional to the carbon dioxide emissions. Current emissions data is used to calculate emissions in the three fields of production, transportation, and consumption.

Gasoline Consumption							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
Gallons	$1.4404\text{x}10^{11}$	$1.4600\text{x}10^{11}$	$1.4800\text{x}10^{11}$	$1.5000\text{x}10^{11}$	$1.5200\text{x}10^{11}$	$1.6300\text{x}10^{11}$	$1.8400\text{x}10^{11}$

First, gasoline production values are analyzed to find the amount of carbon dioxide emission from initial production. The carbon dioxide intensity value for gasoline is .0848 $\frac{kg\,CO_2}{MJ}$[10]. Furthermore, each gallon of gasoline produces 121.3 MJ of energy [5]. The resulting formula is

$$CO_2\ Emissions\ from\ production\ (kg) = Gasoline\ Consumption\ (gal) \times 121.3\frac{MJ}{gal} \times 0.0848\frac{kg\ CO_2}{MJ}$$

CO_2 Emissions from Production							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg CO_2	$1.4817\text{x}10^{12}$	$1.5018\text{x}10^{12}$	$1.5224\text{x}10^{12}$	$1.5429\text{x}10^{12}$	$1.5635\text{x}10^{12}$	$1.6767\text{x}10^{12}$	$1.8927\text{x}10^{12}$

The next phase analyzed is transportation. Transportation of gasoline occurs in three main ways – through pipelines, ships, and trucks. The greenhouse gas contribution of pipeline transportation, which accounts for 38% of major gasoline transportation, is insignificant [11]. The other 62% is covered by ships. It is assumed that all gasoline, either from pipelines or ships, is transported by trucks en route to fueling stations.

The average distance of transport overseas was calculated to be 2000 km [8]. The carbon dioxide emissions based on transport is calculated from the weight of the goods, which is 2.79 $\frac{kg}{gal}$, the efficiency of the transportation method, which is 0.20 $\frac{MJ}{tonne \times kg}$ for maritime transportation, and the fuel emissions of the transportation method, which is 0.087 $\frac{kg\,CO_2}{MJ}$ for ships [10]. The final equation becomes

$$CO_2\ Emissions\ from\ ship\ transport\ (kg) = Gasoline\ Consumption\ (gal) \times 0.62 \times 2.79\frac{kg}{gal} \times \frac{1}{1000}\frac{tonne}{kg} \times 2000\ km \times \frac{0.20MJ}{tonne \times kg} \times 0.087\frac{kg\ CO_2}{MJ}$$

CO_2 Emissions from Ship Transport							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg CO_2	*8.6710×10^{9}*	*8.7888×10^{9}*	*8.9092×10^{9}*	*9.0296×10^{9}*	*9.1500×10^{9}*	*9.8121×10^{9}*	*1.1076×10^{10}*

The average distance of transport on trucks was calculated to be 300 km [8]. The weight of the goods is again 2.79 $\frac{kg}{gal}$, the efficiency of trucks is 1.46 $\frac{MJ}{tonne \times kg}$, and the fuel emissions is 0.086 $\frac{kg\ CO_2}{MJ}$ [10]. This equation, similar to the first, is

$$CO_2\ Emissions\ from\ truck\ transportation\ (kg) = Gasoline\ Consumption\ (gal) \times 2.79\frac{kg}{gal} \times \frac{1}{1000}\frac{tonne}{kg} \times 300\ km \times 1.46\frac{MJ}{tonne \times kg} \times 0.086\frac{kg\ CO_2}{MJ}$$

CO_2 Emissions from Truck Transport							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*1.5138×10^{10}*	*1.5344×10^{10}*	*1.5554×10^{10}*	*1.5764×10^{10}*	*1.5974×10^{10}*	*1.7130×10^{10}*	*1.9337×10^{10}*

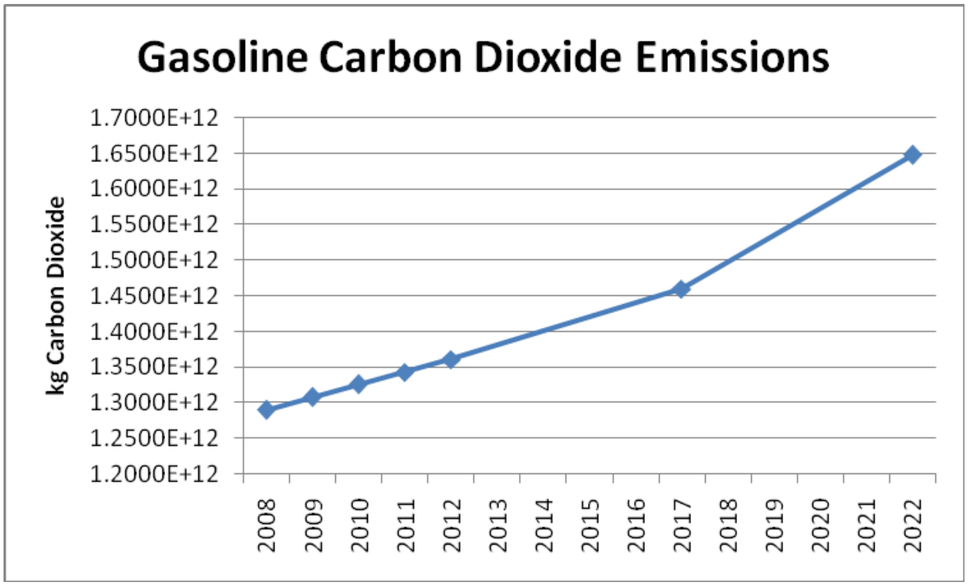
The final variable factored into the total carbon dioxide emissions is the consumption by users of gasoline. Each gallon of gasoline produces 8.788 kg of CO_2 based on carbon content [6]. The formula to calculate emissions based on consumption is

$$CO_2\ Emissions\ from\ consumption\ (kg) = Gasoline\ Consumption\ (gal) \times 8.788\frac{kg\ CO_2}{gal}$$

CO_2 Emissions from Consumption							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*1.2658×10^{12}*	*1.2830×10^{12}*	*1.3006×10^{12}*	*1.3182×10^{12}*	*1.3358×10^{12}*	*1.4324×10^{12}*	*1.6170×10^{12}*

The total carbon dioxide emissions are then the sum total of these three sectors of production, transportation, and consumption, which have the following values:

Total Gasoline CO_2 Emissions							
Year	***2008***	***2009***	***2010***	***2011***	***2012***	***2017***	***2022***
kg	***1.2897×10^{12}***	***1.3072×10^{12}***	***1.3251×10^{12}***	***1.3430×10^{12}***	***1.3609×10^{12}***	***1.4594×10^{12}***	***1.6474×10^{12}***



Next, the carbon dioxide emissions are calculated with the inclusion of ethanol as 10% of the energy source. The Domestic Ethanol Production is assumed to be the maximum capacity of American ethanol production.

Domestic Ethanol Production							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
Gallons	$5.2843x10^{9}$	$6.5760x10^{9}$	$8.1359x10^{9}$	$1.0001x10^{10}$	$1.2209x10^{10}$	$2.9983x10^{10}$	$1.2205x10^{11}$

For the first 5 projected years of the new ethanol policy, the United States cannot cover the required amount of ethanol. It must import the ethanol deficit from partnering countries.

Ethanol Deficit							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
Gallons	$1.1713x10^{10}$	$1.0652x10^{10}$	$9.3281x10^{9}$	$7.6994x10^{9}$	$5.7267x10^{9}$	*0*	*0*

Currently, almost 100% of imported ethanol is imported from Brazil and neighboring Caribbean nations [12]. It is assumed that this will not change over the next 20 years. It must also be stated that these nations produce ethanol with sugar canes, as opposed to corn, the American method [10]. The differences in methods of production impact the amount of carbon dioxide emissions.

The total carbon dioxide emissions is calculated in the same way as that of gasoline consumption, with the sum of production, transportation, and consumption, taking into consideration the necessity of import and resulting transportation costs.

For the production of ethanol, the carbon dioxide intensity value varies between nations and methods. Domestically, it is 0.108 $\frac{kg\ CO_2}{MJ}$ by corn production and in Brazil it is 0.024 $\frac{kg\ CO_2}{MJ}$ by cane production [10]. Furthermore, each gallon of ethanol has an energy content of 80.2 MJ [5]. The resulting formula is

$$CO_2\ Emissions\ from\ production\ (kg) = Domestic\ production \times 80.2\frac{MJ}{gal} \times 0.108\frac{kg\ CO_2}{MJ} + Foreign\ production \times 80.2\frac{MJ}{gal} \times 0.024\frac{kg\ CO_2}{MJ}$$

CO_2 Emissions from Production							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$6.8315x10^{10}$*	*$7.7462x10^{10}$*	*$8.8425x10^{10}$*	*$1.0144x10^{11}$*	*$1.1677x10^{11}$*	*$1.6660x10^{11}$*	*$1.8806x10^{11}$*

The transportation costs are the next factor included in emissions. The ethanol that is imported from overseas is transported on ships to the United States. Domestically, ethanol is shipped either by rail or by truck. Statistics show that 46% is transported by truck and 54% by rail. These percentages are of the total ethanol consumption, including foreign imports. The values not yet provided are the efficiency of railway transport, which is 0.19 $\frac{MJ}{tonne \times km}$, and the fuel emissions of trains, which is 0.069 $\frac{kg\ CO_2}{MJ}$, based on emissions from the electric power used by the trains [10, 4]. Finally, the average transport distances are 8000 km traveled by ship from Brazil to America, 150 km traveled by truck, and 1900 km traveled by rail [13]. The formulas then used to calculate the emissions for this shipping are analogous to the ones used in the transportation emissions of gasoline, adjusted for the quantity of ethanol being transported.

CO_2 Emissions from Ship Transport							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$4.5489x10^{9}$*	*$4.1369x10^{9}$*	*$3.6227x10^{9}$*	*$2.9902x10^{9}$*	*$2.2241x10^{9}$*	*0*	*0*

CO_2 Emissions from Truck Transport							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$4.1085x10^{8}$*	*$4.1643x10^{8}$*	*$4.2213x10^{8}$*	*$4.2784x10^{8}$*	*$4.3354x10^{8}$*	*$4.6492x10^{8}$*	*$5.2481x10^{8}$*

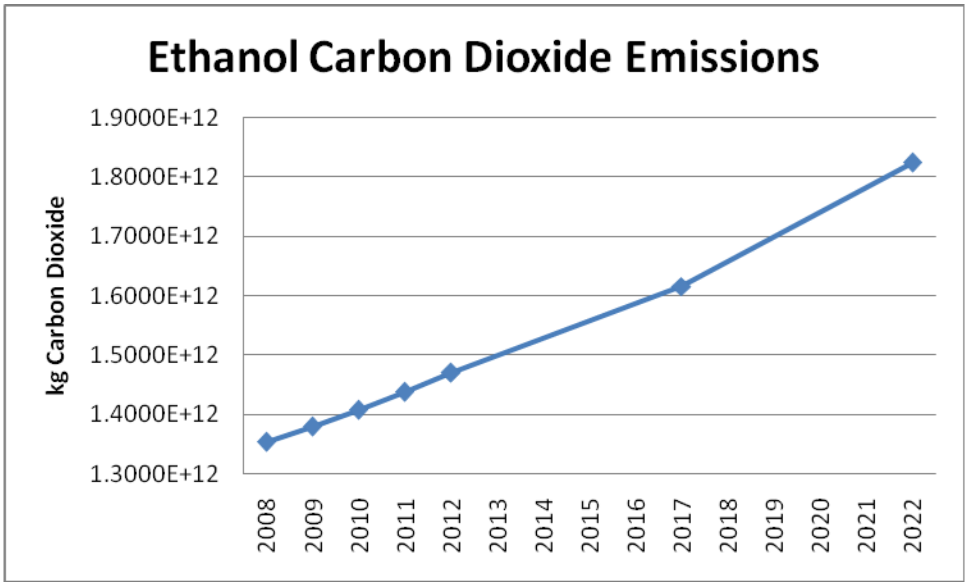
CO_2 Emissions Rail Transport							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$6.3786x10^{8}$*	*$6.4653x10^{8}$*	*$6.5539x10^{8}$*	*$6.6424x10^{8}$*	*$6.7310x10^{8}$*	*$7.2181x10^{8}$*	*$8.1481x10^{8}$*

The final step in ethanol production and usage is its consumption. Using the value of 6.987 $\frac{kg\ CO_2}{gal}$ for ethanol, the carbon dioxide emissions are calculated.

CO_2 Emissions from Consumption							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$1.1876x10^{11}$*	*$1.2037x10^{11}$*	*$1.2202x10^{11}$*	*$1.2367x10^{11}$*	*$1.2532x10^{11}$*	*$1.3439x10^{11}$*	*$1.5170x10^{11}$*

Finally, these values are added to 90% of the values from gasoline consumption (since the new source of energy is 90% gasoline and 10% ethanol).

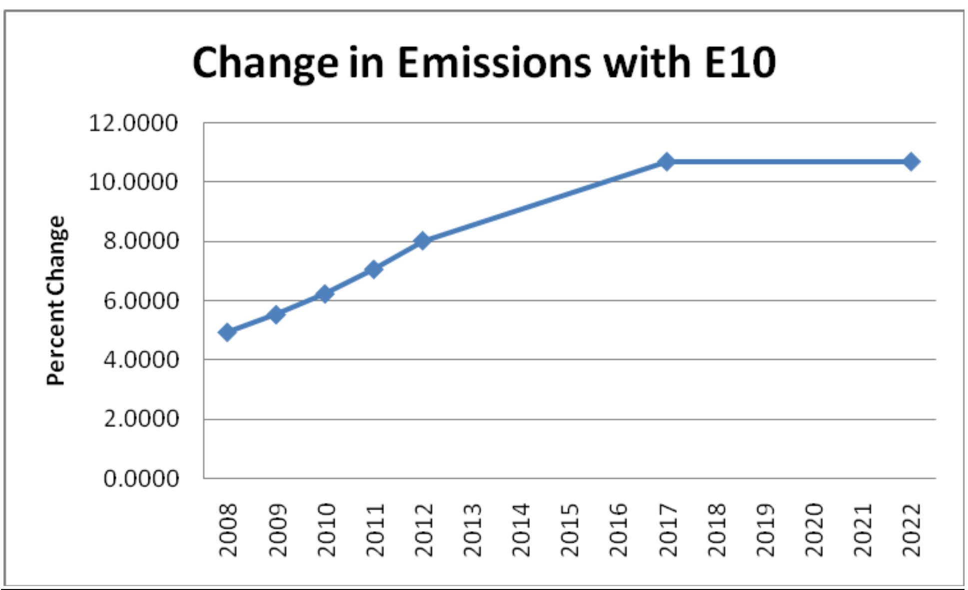
Total Ethanol CO_2 Emissions							
Year	***2008***	***2009***	***2010***	***2011***	***2012***	***2017***	***2022***
kg	***$1.3534x10^{12}$***	***$1.3795x10^{12}$***	***$1.4077x10^{12}$***	***$1.4379x10^{12}$***	***$1.4702x10^{12}$***	***$1.6156x10^{12}$***	***$1.8238x10^{12}$***



The differences between the emissions of E10 gas and regular gasoline are the final result.

Difference between E10 and Gasoline							
Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2017*	*2022*
kg	*$6.3705x10^{10}$*	*$7.2316x10^{10}$*	*$8.2637x10^{10}$*	*$9.4894x10^{10}$*	*$1.0933x10^{11}$*	*$1.5623x10^{11}$*	*$1.7636x10^{11}$*

Percent Change							
Year	2008	2009	2010	2011	2012	2017	2022
kg	4.9397	5.5322	6.2364	7.0658	8.0340	10.7054	10.7054



<u>Conclusions</u>

Although only 10% of gasoline is being substituted for ethanol, it still has a negative impact on the environment. This effect is constantly increasing but appears to be leveling out around 11% more emissions than the gasoline equivalent. However, this is not completely accurate. As discussed, the farming of corn removes carbon dioxide from the atmosphere, as all plants naturally do through photosynthesis. The extent to which this happens is extremely difficult to predict or to model. However, more likely than not, the effect of switching to ethanol will have a positive impact on the environment, as the corn will probably reduce atmospheric carbon dioxide by a greater level than the production of ethanol increases it.

The Cost Efficiency of Ethanol

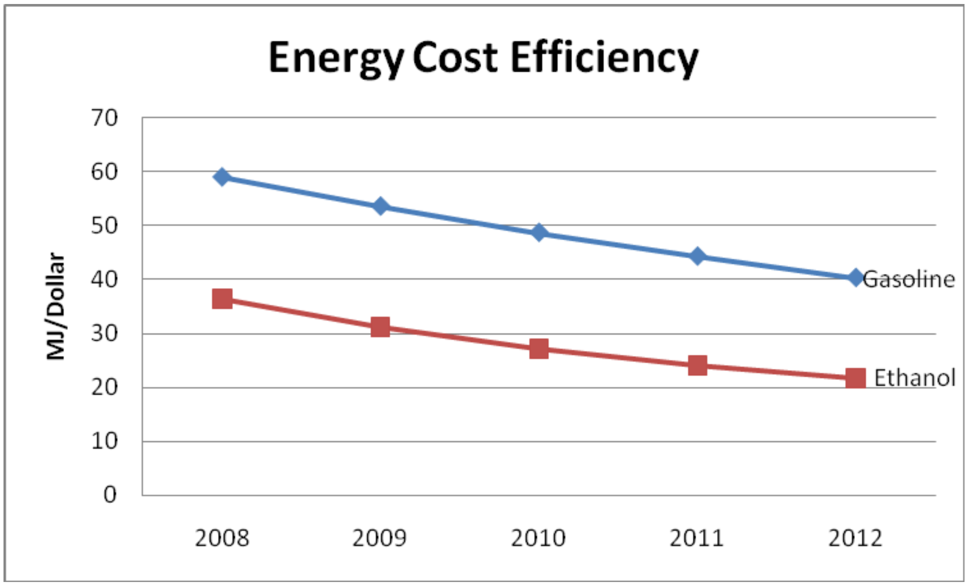
Methodology

The cost efficiency of corn-derived ethanol was determined by comparing its energy yield versus its input costs, refining costs, and transportation costs. For our data, the U.S. price of ethanol, adjusted for inflation, is used because it would most accurately reflect the costs of production. In addition, the government subsidy on ethanol is added back onto the price in order to reflect the actual cost of ethanol to the consumer. This is justified with the reasoning that the price elasticity of demand is relatively inelastic for ethanol and thus the consumer would bear the burden of the subsidy. The cost efficiency of gasoline is found by the same process, and federal and state taxes are subtracted to represent its true cost.

The energy efficiency of gasoline, as used before, is 121.3 $\frac{MJ}{gal}$, while the energy efficiency of ethanol is 80.2 $\frac{MJ}{gal}$ [5]. To find the cost efficiency from these values, this value is simply divided by the cost of gasoline at the time. Based on the model created for ethanol and gasoline prices, this was easily calculated [13, 14].

$$Energy\ efficiency\ (\frac{MJ}{dollar}) = Energy\ content\ (\frac{MJ}{gal}) + Price(\frac{dollars}{gal})$$

Year	Gas Price ($)	Ethanol Price ($)	Gasoline Efficiency (MJ/$)	Ethanol Efficiency (MJ/$)
2008	*2.51315*	*2.196008*	*59.03124*	*36.52082*
2009	*2.72092*	*2.574175*	*53.6065*	*31.15561*
2010	*2.94833*	*2.95235*	*48.70737*	*27.1648*
2011	*3.19648*	*3.3305*	*44.29048*	*24.08047*
2012	*3.46666*	*3.710925*	*40.31051*	*21.61186*



Conclusions

It was shown that ethanol has a much lower cost efficiency than gasoline, making gasoline the more cost-effective source of energy. The main reason for this difference is the overwhelmingly high energy content of gasoline in comparison to ethanol. This is concerning because the government heavily subsidizes the use of ethanol as an additive to gasoline, even though it is much less cost efficient. However, this is justified because the cost efficiency of ethanol can be expected to rise in comparison to gasoline as newer technologies are developed, such as cellulosic technology, and as gasoline prices rise.

Effect of Ethanol Policy on Grain Prices and Developing Nations

Methodology

In order to determine the effect on price of grains worldwide following the implementation of a policy in the United States that involved substituting 10% of gasoline consumption with ethanol, the economic methods of elasticity were used. First, a fit was determined for the level of increase in the price of corn over time, using data from the past seven years [15]. The prices from the next five years are shown in the table above that were determined through this fit.

Year	2008	2009	2010	2011	2012
Price of Corn ($/millions of metric tons)	157.518	162.872	168.241	173.611	178.98
Percent Increase in Price	0.31616	0.03399	0.032965	0.031918	0.030925
Percent Increase in Rice Demanded	0.237752	0.02556	0.024789	0.024003	0.023256
Percent Increase in Wheat Demanded	0.359474	0.038646	0.037481	0.036291	0.035162
Quantity Demanded of Rice (millions of metric tons)	1156.06	1185.61	1215	1244.164	1273.098
Quantity Demanded of Wheat (millions of Metric Tons)	820.1015	851.7955	883.7213	915.7928	947.9941
Price of Rice ($/millions of metric tons)	314.897	330.418	345.856	361.175	376.373
Price of Wheat ($/millions of metric tons)	247.315	255.602	263.949	272.335	280.754

The values of cross-elasticity of demand for corn and wheat, and corn and rice, were then determined. Using data from the past seven years for wheat, rice, and corn [16, 17], the percent increase in the amount of corn demanded worldwide was first determined. Following this, the percent increase in the price of rice and the percent increase in the percent of wheat were determined. The cross-elasticity of demand was determined by the percent increase in the quantity demanded of either the wheat or the rice over the percent increase in the price. From this analysis, wheat was determined to have a cross-elasticity of 1.137 and rice was determined to have a cross-elasticity of 0.7524.

The prices from the next five years for corn were then combined with the elasticity and other fits to determine the predictions for wheat and rice prices. First, the percent increase in the price of corn each year was determined. Then, this was multiplied by the elasticity to yield the percent increase in the quantity demanded for both wheat and rice. The quantity demanded for wheat and rice could then be determined. Finally, a fit was determined for the price of both wheat and rice as it relates to the quantity demanded of both. This was performed using the data that was discussed earlier, from the past seven years. The quantity demanded was then inputted to the best-fit line in order to determine the price for each year.

Conclusions

This model indicates that the price of both wheat and rice will be pushed higher by the increased corn consumption caused by ethanol production mandated by the policy discussed in this paper. The largest increase will take place before year 1, because the policy change takes place here. Following this, a steady increase takes place, due to both the increased gasoline consumption indicated by our model in the section of our paper that discusses this topic and the increased needs of wheat, rice, and corn in developing countries. The latter variable is taken into account by this model in its fitting of the current trend in wheat, rice, and corn based on worldwide price and consumption values.

The assumption in this model that all of the ethanol that is produced in the United States is valid because of the pre-existing surplus of corn existing in the country. In addition, the veracity of the values of elasticity that have been obtained is indicated by an analysis of their significance. Wheat, with elasticity greater than one, is more elastic because the diets of Westerners, who represent a current majority of wheat consumption, is more varied and can therefore rely on substitute goods. The opposite is true of rice, which is the staple of Eastern diets that are more specialized. However, as Eastern diets change over time, the values of elasticity are likely to change.

This final conclusion relates to the general humanitarian effect of these predictions. As the price of wheat and rice increases, it will become more difficult for poorer people to obtain the grain needed for their diets. The effects of this have already been seen over the public conflicts regarding tortillas in Mexico and pasta in Italy. Although this may benefit farmers, it will hurt consumers. Governments may need to turn to techniques such as genetic engineering to increase yield in order to keep the price of grains lower.

Alternatives to U.S. Energy Independence

Methodology

The United States must manage all of its current energy resources to yield the optimal energy usage over time. In order to determine a better way for the United States to attain long-term national energy independence, the study assessed alternative fuel sources with respect to their energy yield, environmental impact, reliability, and renewability over a timeframe of 100 years. The most important characteristics of nonrenewable energy sources, such as coal, petroleum, and nuclear power, were quantified, in addition to those of renewable energy sources, such as solar, wind, geothermal, biofuel, and hydroelectric power. Then the data was used to determine the optimal proportion of energy that should be derived from each source in the long term. For energy yield, data on cents per kilowatt was utilized to gauge the relative amount of energy yielded by each source. Reliability was based on the dependability of an energy source to produce electricity at all times. Environmental impact was based on the negative effects that a energy source had on the environment over time. These figures included noise, light, and air pollution, in addition to nuclear waste. Nuclear power was given a more favorable outlook by this study than many others studies because it was reasoned that the ability to build long-term waste storage facilities would offset the dangers posed by nuclear waste. Data that measured the sustainability of a fuel source over a long period of time was used [19].

Conclusions

The model showed that in the long run, energy use should be redistributed from nonrenewable fossil fuels to renewable energy sources. Geothermal energy demonstrated the greatest growth in optimal usage, to producing 18.69% of all energy in the United States. This correlated with the findings of other studies on geothermal energy [20]. The optimal use of nonrenewable energy sources saw a decrease from 77% of current totals to 30% of the optimal total. Although nonrenewable sources have largely negative effects on the environment, their greater reliability over renewable fuel sources makes them advantageous in economic terms. Solar power and wind power also saw significant increases in their optimal usage over current usage, but we felt that their widespread usage would not be possible without advances in reliability and efficiency.

In addition to the fuel sources selected for evaluation, there are other alternatives that were not included in our calculations. This was largely due to the unpredictable nature of human technological advancement and our inability to quantify the development of these technologies. For instance, ocean thermal energy conversion is one technology proposed by scientists in recent years, yet we chose to omit it because of its status as a developing technology. However, the data still shows an evident trend moving from nonrenewable resources towards renewable ones.

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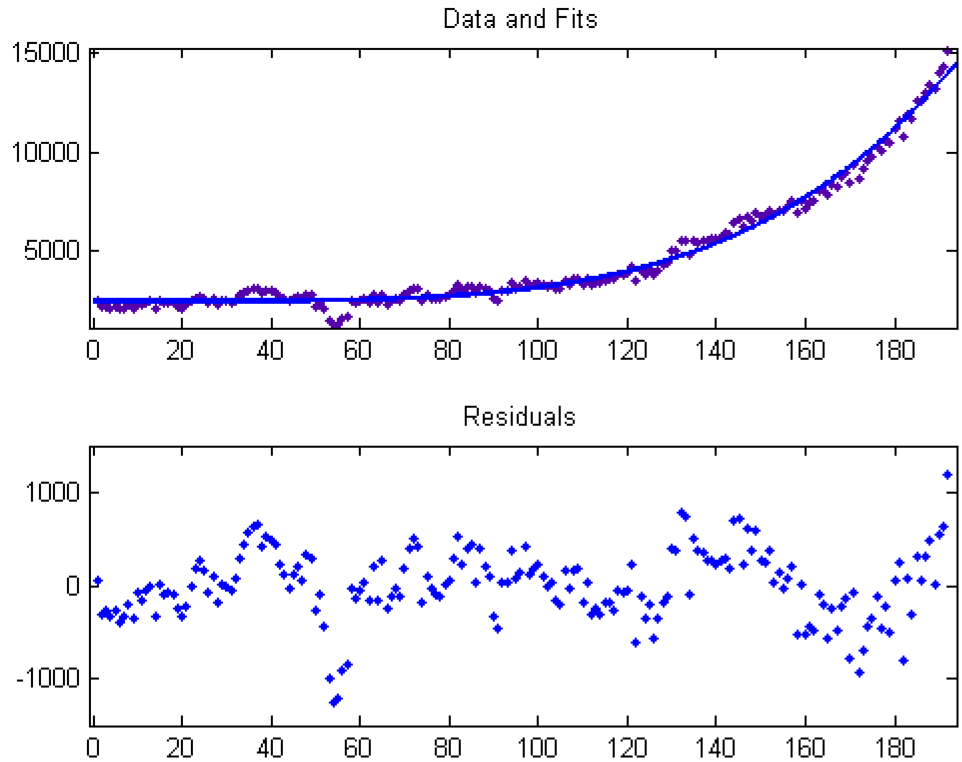
Appendix A:



Fit of Ethanol Production

```
function ethanolproduction(month,values)
%ETHANOLPRODUCTION    Create plot of datasets and fits
%   ETHANOLPRODUCTION(MONTH,VALUES)
%   Creates a plot, similar to the plot in the main curve fitting
%   window, using the data that you provide as input.  You can
%   apply this function to the same data you used with cftool
%   or with different data.  You may want to edit the function to
%   customize the code and this help message.
%
%   Number of datasets:  1
%   Number of fits:  1


% Data from dataset "Ethanol vs. Month":
%    X = month:
%    Y = values:
%    Unweighted
%
% This function was automatically generated on 09-Mar-2008 20:43:06
```

```
% Set up figure to receive datasets and fits
f_ = clf;
figure(f_);
set(f_,'Units','Pixels','Position',[444.667 130 688 486]);
xlim_ = [Inf -Inf];       % limits of x axis
ax_ = axes;
set(ax_,'Units','normalized','OuterPosition',[0 .5 1 .5]);
ax2_ = axes;
set(ax2_,'Units','normalized','OuterPosition',[0 0 1 .5]);
set(ax2_,'Box','on');
set(ax_,'Box','on');
axes(ax_); hold on;


% --- Plot data originally in dataset "Ethanol vs. Month"
month = month(:);
values = values(:);
h_ = line(month,values,'Parent',ax_,'Color',[0.333333 0 0.666667],...
     'LineStyle','none', 'LineWidth',1,...
     'Marker','.', 'MarkerSize',12);
xlim_(1) = min(xlim_(1),min(month));
xlim_(2) = max(xlim_(2),max(month));

% Nudge axis limits beyond data limits
if all(isfinite(xlim_))
   xlim_ = xlim_ + [-1 1] * 0.01 * diff(xlim_);
   set(ax_,'XLim',xlim_)
   set(ax2_,'XLim',xlim_)
else
    set(ax_, 'XLim',[-0.91000000000000014, 193.91]);
    set(ax2_,'XLim',[-0.91000000000000014, 193.91]);
end


% --- Create fit "Exponential2"
ok_ = isfinite(month) & isfinite(values);
if ~all( ok_ )
    warning( 'GenerateMFile:IgnoringNansAndInfs', ...
        'Ignoring NaNs and Infs in data' );
end
st_ = [3052.6670474220791 0.087873585411350444 129.46971844493052 ];
ft_ = fittype('power2');

% Fit this model using new data
cf_ = fit(month(ok_),values(ok_),ft_,'Startpoint',st_);
```

```
% Or use coefficients from the original fit:
if 0
  cv_ = { 1.6609899218817092e-006, 4.3114029749820126, 2374.2149997011325};
  cf_ = cfit(ft_,cv_{:});
end

% Plot this fit
h_ = plot(cf_,'fit',0.95);
legend off;  % turn off legend from plot method call
set(h_(1),'Color',[0 0 1],...
    'LineStyle','-', 'LineWidth',2,...
    'Marker','none', 'MarkerSize',6);
res_ = values - cf_(month);
[x_,i_] = sort(month);
axes(ax2_); hold on;
h_ = line(x_,res_(i_),'Parent',ax2_,'Color',[0 0 1],...
    'LineStyle','none', 'LineWidth',1,...
    'Marker','.', 'MarkerSize',6);
axes(ax_); hold on;

% Done plotting data and fits.  Now finish up loose ends.
hold off;
```