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Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts are Negative

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Several studies suggest that the $1.4 billion in government subsidies are encouraging the ethanol program without substantial benefits to the U.S. economy. Large ethanol industries and a few U.S. government agencies, such as the USDA, support the production of ethanol. Corn-farmers receive minimal profits. In the U.S. ethanol system, considerably more energy, including high-grade fossil fuel, is required to produce ethanol than is available in the energy-ethanol output. Specifically about 29% more energy is used to produce a gallon of ethanol than the energy in a gallon of ethanol. Fossil energy powers corn production and the fermentation/distillation processes. Increasing subsidized ethanol production will take more feed from livestock production, and is estimated to currently cost consumers an additional $1 billion per year. Ethanol production increases environmental degradation. Corn production causes more total soil erosion than any other crop. Also, corn production uses more insecticides, herbicides, and nitrogen fertilizers than any other crop. All these factors degrade the agricultural and natural environment and contribute to water pollution and air pollution. Increasing the cost of food and diverting human food resources to the costly inefficient production of ethanol fuel raise major ethical questions. These occur at a time when more than half of the world's population is malnourished. The ethical priority for corn and other food crops should be for food and feed. Subsidized ethanol produced from U.S. corn is not a renewable energy source.

KEY WORDS: Ethanol; costs; environment; food; pollution.

INTRODUCTION

A few government agencies, such as the USDA (Shapouri, Duffuld, and Wang, 2002), support ethanol production. Some industries, including Archer, Daniels, Midland (EV World, 2002), are making huge profits from ethanol production, which is subsidized by federal and state governments. Some politicians have the mistaken belief that ethanol production provides large benefits for farmers, whereas in fact the farmer profits are minimal. In contrast, numerous scientific studies have concluded that ethanol production does not provide a net energy balance, is not a renewable energy source, is not an economical fuel, and its production and use contributes to air pollution and global warming (Sparks Commodities, 1990; Citizens for Tax Justic, 1997; Giampietro, Ulgiati, and Pimentel, 1997; Youngquist, 1997; Pimentel, 1998; NPRA, 2002; Croysdale, 2001; Pimentel, 2001; Fuel's Gold, 2002; CalGasoline, 2002; Lieberman, 2002; Hodge, 2002). Growing the large amounts of corn necessary for ethanol production occupies cropland suitable for food production and causes diverse environmental degradation problems (Pimentel, 1991; Pimentel and Pimentel, 1996).

Conclusions drawn concerning the benefits of ethanol production are incomplete or misleading when only some of the total energy inputs in the ethanol system are included in the assessment. The objective of this analysis is to update and assess all the recognized inputs that operate in the entire ethanol production system. These inputs include the direct costs in terms of energy and dollars for producing the corn feedstock as well as for the fermentation/distillation process. Additional costs to the

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consumer include federal and state subsidies, plus costs associated with environmental pollution and/or degradation that occur during the entire production system. Ethanol production in the United States does not benefit the nation's energy security, its agriculture, the economy, the environment, as well as government and consumer expenditures. Also, ethical questions are related to diverting land and precious food into fuel and actually adding a net amount of pollution to the environment.

ENERGY BALANCE

The conversion of corn and other food/feed crops into ethanol by fermentation is a well-known and established technology. The ethanol yield from a large plant is about 2.5 gallons of ethanol from a bushel of corn (56 pounds or 25.5 kg) (2.7 kg per liter of ethanol) (Pimentel, 2001). Thus, a hectare (2.47 acres = 1 hectare) of corn yielding 8,590 kg could be converted into about 842 gallons of ethanol.

The production of corn in the United States requires a significant energy and dollar investment (Table 1). For example, to produce 8,590 kg/ha of corn using average production technology requires the expenditure of about 33.9 million BTU for the large number of inputs listed in Table 1 (about 293 gallons of gasoline equivalents/ha or 40,221 BTU/gallon of ethanol). This costs about $580/ha for the 8,590 kg or approximately 6.8¢/kg of corn produced. Thus, for a gallon of ethanol, an energy equivalent of only 66% per gallon of gasoline, the corn feedstock alone costs 69¢ (Table 2).

Full irrigation (when there is little or no rainfall) requires about 100 cm of water per growing season. Only approximately 15% of U.S. corn production currently is irrigated (USDA, 1997). Of course not all of this requires full irrigation, so a mean value was used. The mean irrigation for all land growing corn grain is 8.1 cm per ha during the growing season. As a mean value, water is pumped from a depth of 100 m (USDA, 1997b). On this basis, the mean energy input associated with irrigation is 3.8 million BTU per hectare (Table 1).

The average costs in terms of energy and dollars for a large (65 to 75 million gallons/year), modern ethanol plant are listed in Table 2. Note the largest energy inputs are for corn feedstock and for the fuel energy used in the fermentation/distillation process. The total energy input to produce a gallon of ethanol is 99,119 BTU (Table 2). However, a gallon of ethanol has an energy value of only 77,000 BTU. Thus, there is a net energy loss of 22,119 BTU per gallon of ethanol produced. Put another way, about 29% more energy is required to produce a gallon of ethanol than the energy that actually is in the gallon of ethanol produced (Table 2). Not included in this analysis was the distribution energy to transport the ethanol. DOE (2002) estimates this to be 8¢/gallon or approximately more than 5,000 BTU/gallon of ethanol.

Table 1. Energy Inputs and Costs of Corn Production Per Hectare in the United States

Inputs	Quantity	BTU × 1000	Costs
Labor	6.2 hrs[q]	1,000[f]	$62.00[h]
Machinery	55 kg[a]	5,656[w]	103.21[m]
Diesel	90 L[b]	3,600[e]	23.40[t]
Gasoline	56 L[b]	2,212[e]	14.60[t]
Nitrogen	148 kg[c]	10,952[v]	81.40[i]
Phosphorus	53 kg[c]	876[g]	12.72[i]
Potassium	57 kg[c]	744[g]	17.67[i]
Lime	699 kg[c]	880[e]	14.00[n]
Seeds	21 kg[a]	2,080[e]	74.00[c]
Irrigation	8.1 cm[s]	3,764[r]	81.00[u]
Herbicides	2.1 kg[c]	840[e]	21.00[j]
Insecticides	0.15 kg[c]	60[e]	6.00[l]
Electricity	13.2 kWh[b]	136[e]	2.38[k]
Transportation	222 kg[d]	1,072[e]	66.60[o]
TOTAL		33,872	$579.98
8,590 kg yield[p]		123,696	
	BTU input: output = 1:3.65		

[a]Pimentel and Pimentel (1996).
[b]USDA (1991).
[c]USDA (1997a).
[d]Goods transported include machinery, fuels, and seeds that were shipped an estimated 1,000 km.
[e]Pimentel (1980).
[f]It is assumed that a person works 2,000 hrs per year and utilizes an average of 8,100 liters of oil equivalents per year.
[g]FAO (1999).
[h]It is assumed that farm labor is paid $10 per hour.
[i]Soil Fertility Guide (2002).
[j]It is assumed that herbicide prices are $10 per kg.
[k]Price of electricity is 7¢ per kWh (USBC, 2001).
[l]It is assumed that insecticide prices are $40 per kg.
[m]Hoffman, Warnock, and Hinman (1994).
[n]Assumed to be 2 ¢ per kg (Clary and Haby, 2002).
[o]Transport was estimated to cost 30¢ per kg.
[p]USDA (2001).
[q]NASS (1999).
[r]Batty and Keller (1980).
[s]USDA (1997b).
[t]Diesel and gasoline assumed to cost 26.5 ¢ per liter.
[u]Irrigation for 100 cm of water per hectare costs $1,000 (Larsen, Thompson, and Harn, 2002).
[v]An average of energy inputs for production, packaging, and shipping per kilogram of nitrogen fertilizer from FAO (1999), Duffy (2001), and Fertilizer (2002).
[w]Hulsbergen and others (2001).

Table 2. Inputs Per Gallon of 95% Ethanol Produced from Corn[a]

Inputs	kg	BTU	Dollars
Corn	10.2[b]	40,221[b]	$0.69[b]
Transport of corn	10.2[b]	4,727[c]	0.22[d]
Water	601[e]	1,353[h]	0.08[d]
Stainless steel	0.023[e]	1,348[e]	0.04[d]
Steel	0.045[e]	2,106[e]	0.04[d]
Cement	0.12[e]	909[e]	0.04[d]
Coal	1.40[f]	39,076[f]	0.08[g]
Electricity	0.91 kWh[f]	9,379[f]	0.06[g]
Pollution control costs	—	—	0.23[d]
TOTAL		99,119	$1.48

[a]Outputs: 1 gallon of ethanol = 77,000 BTU
[b]Table 1.
[c]Estimated (90 mile roundtrip).
[d]Pimentel and others (1988).
[e]Slesser and Lewis (1979).
[f]Larry Johnson (personal communication, Delta-T, 2001).
[g]USBC (2001).
[h]Pimentel and others (1997).

In the fermentation/distillation process, the corn is finely ground and approximately 13 gallons of water are added per 10.2 kg of ground corn. After fermentation, to obtain a gallon of 95% pure ethanol from the 8% ethanol and 92% water mixture, the ethanol must come from the approximately 13 gallon ethanol/water mixture. A total of about 12 gallons of waste water must be removed per gallon of ethanol produced. Although ethanol boils at about 78°C in contrast to water at 100°C, the ethanol is not extracted from the water in one distillation process. Instead, about 3 distillations are required to obtain the 95% pure ethanol (Wereko-Brobby and Hagan, 1996; S. Lamberson, pers. comm., Cornell University, 2000). To be mixed with gasoline, the 95% ethanol must be processed further and more water removed requiring additional fossil energy inputs to achieve 99.8% pure ethanol. The entire distillation accounts for the large quantities of fossil energy that are required in the fermentation/distillation process (Table 2). Note, in this analysis all the added energy inputs for fermentation/distillation process are totalled, including the apportioned energy costs of the stainless steel tanks and other industrial materials (Table 2).

About 50% of the cost of producing ethanol ($1.48/gallon) in a large-production plant is for the corn feedstock itself (69¢/gallon) (Table 2). The next largest input is for transportation of the corn feedstock (Table 2).

Based on current ethanol production technology and recent oil prices, ethanol costs substantially more to produce in dollars than it is worth on the market. Clearly, without the more than $1.4 billion of government subsidy each year, U.S. ethanol production would be reduced or cease, confirming the basic fact that ethanol production is uneconomical (National Center for Policy Analysis, 2002). Federal subsidies average about 60¢/gallon and state subsidies average 20¢/gallon (Pimentel, 1998). Because the relatively low energy content of ethanol, 1.5 gallon of ethanol have the energy equivalent of 1 gallon of gasoline. Thus, the cost of producing an equivalent amount of ethanol to equal a gallon of gasoline is $2.24, whereas the current cost of producing gasoline is about 63¢/gallon (USBC, 2001).

Federal and state subsidies for ethanol production total more than $1.4 billion/year and are paid mainly to large corporations (EV World, 2002). To date, a conservative calculation suggests that corn farmers are receiving optimistically only an added 2¢ per bushel for their corn or about $2.80 per acre because of the corn ethanol production system (Pimentel, unpubl. data). Some politicians have the mistaken belief that ethanol production provides large benefits for farmers, while in fact the farmer profits are minimal. However, several industries, such as Archer, Daniels, Midland, are making huge profits from ethanol production (EV World, 2002). The costs to the consumer are greater than the $1.4 billion/year used to subsidize ethanol production because producing the required corn feedstock increases corn prices. One estimate is that ethanol production is adding more than $1 billion to the cost of beef production (National Center for Policy Analysis, 2002). Because about 70% of the corn grain is fed to U.S. livestock (USDA, 2001), doubling or tripling ethanol production can be expected to increase corn prices further for beef production and ultimately increase costs for the consumer. Therefore, in addition to paying tax dollars for ethanol subsidies, consumers are expected to pay significantly higher food prices in the market place.

Currently about 1.7 billion gallons of ethanol (1.1 billion gallons of gasoline equivalents) are being produced in the United States each year (Shapouri, Duffuld, and Wang, 2002). This amount of ethanol provides only about 0.9% of the gasoline utilized by U.S. automobiles each year. To produce the 1.7 billion gallons of gasoline equivalents (only 0.8% of total gasoline) using ethanol we must use about 2.2 million ha of land; if we produced 10% of U.S. gasoline, the land requirement would be 22 million ha. Moreover, significant quantities of energy are needed to sow, fertilize, and harvest the corn feedstock.

In part, the energy and dollar costs of producing ethanol can be offset partially by the by-products produced, such as the dry distillers grains (DDG) made from dry-milling. From about 10 kg of corn feedstock, about 3.3 kg of DDG can be harvested that has 27% protein (Stanton, 1999). This DDG has value for feeding cattle that are ruminants, but has only limited value for feeding hogs and chickens. The DDG generally is used as a substitute for soybean feed that has 49% protein (Stanton, 1999). Soybean production for livestock production is more energy efficient than corn production because little or no nitrogen fertilizer is needed for the production of this legume (Pimentel and others, 2002). Only 2.1 kg of 49% soybean protein is required to provide the equivalent of 3.3 kg of DDG. Thus, the credit fossil energy per gallon of ethanol produced is about 6,728 BTU (Pimentel and others, 2002). Factoring this credit in the production of ethanol reduces the negative energy balance for ethanol production from 29% to 20% (Table 2). Note, the resulting energy output/input comparison remains negative even with the credits for the DDG by-product.

Although the by-products provide a few benefits, when considering the advisability of producing ethanol for automobiles, the amount of cropland required to grow sufficient corn to fuel each automobile should be understood. To make ethanol production seem positive, I use the Shapouri, Duffield, and Wang (2002) suggestion that all natural gas and electricity inputs be ignored and only gasoline and diesel fuel inputs be assessed. Then, using Shapouri, Duffield, and Wang's input/output data, this results in an output of 775 gallons of ethanol per hectare. The lower energy content of ethanol means that this has the same energy as 512 gallons of gasoline. An average U.S. automobile travels about 20,000 miles/yr and uses about 1,000 gallons of gasoline per year (USBC, 2001). To replace only a third of this with ethanol, 0.6 ha of corn must be grown—0.6 ha of cropland currently is required to feed each American. Therefore to feed one automobile with ethanol, using Shapouri, Duffield, and Wang's optimistic data, in order to substitute for a third of the gasoline used per automobile, Americans would require as much cropland as they need to feed themselves!

Until recently, Brazil had been the largest producer of ethanol in the world. Brazil used sugarcane to produce ethanol and sugarcane is a more efficient feedstock for ethanol than corn grain (Pimentel and Pimentel, 1996). However, the energy balance was negative and the Brazilian government subsidized the ethanol industry. There the government was selling ethanol to the public for 83¢ per gallon that was costing them $1.25 per gallon to produce for sale (Pimentel and others, 1988). Because of serious economic problems in Brazil, the government has abandoned subsidizing ethanol (Spirits Low, 1999; Coelho and others, 2002), and without the subsidy, ethanol production is no longer economically feasible for the producers.

ENVIRONMMENTAL IMPACTS

Some of the economic and energy contributions of the by-products mentioned earlier are negated by the environmental pollution costs associated with ethanol production. These are estimated to be more than 23¢ per gallon (Table 2). U.S. corn production causes more total soil erosion that any other U.S. crop (Pimentel and others, 1995; Pimentel, 2002). In addition, corn production uses more herbicides and insecticides than any other crop produced in the U.S. thereby causing more water pollution than any other crop (Pimentel and others, 1993). Further, corn production uses more nitrogen fertilizer than any crop produced and therefore is a major contributor to ground water and river water pollution (NAS, 2002). In some Western irrigated corn acreage, ground water is being mined 25% faster than the natural recharge of its aquifer (Pimentel and others, 1997).

All these factors suggest that the environmental system in which U.S. corn is being produced is being rapidly degraded. Further, it substantiates the conclusion that the U.S. corn production system is not environmentally sustainable for the future, unless major changes are made in the cultivation of this major food/feed crop. Corn is raw material for ethanol production, but cannot be considered to provide a renewable energy source.

Major air and water pollution problems also are associated with the production of ethanol in the chemical plant. EPA (2002) has issued warnings to ethanol plants to reduce their air pollution emissions or be shut down. Another pollution problem is the large amounts of waste water that each plant produces. As mentioned, for each gallon of ethanol produced using corn, about 12 gallons of waste water are produced. This waste water has a biological oxygen demand (BOD) of 18,000 to 37,000 mg/liter depending of the type of plant (Kuby, Merkoja, and Nackford, 1984). The cost of processing this sewage in terms of energy or dollars was not included in the cost of producing ethanol. If added, it would increase the ethanol production costs by 6¢ per gallon (Pimentel and others, 1988).

Ethanol contributes to air pollution problems when burned in automobiles (Youngquist, 1997; Hodge, 2002). In addition, the fossil fuels expended for corn production and later in the ethanol plants amount to expenditures of 99,119 BTU of fossil energy per gallon of ethanol produced (Table 2). The consumption of the fossil fuels release significant quantities of pollutants to the atmosphere. Furthermore, carbon dioxide emissions released from burning these fossil fuels contribute to global warming and are a serious concern (Schneider, Rosencranz, and Niles, 2002). When all the air pollutants associated with the entire ethanol system are measured, ethanol production contributes to the U.S. air pollution problem (Youngquist, 1997). Overall, if air pollution problems were controlled and included in the production costs, then ethanol production costs in terms of energy and economics would be significantly increased.

ETHANOL PRODUCTION—POSITIVE OR NEGATIVE?

The interesting recent USDA report concerning ethanol production as referred to (Shapouri, Duffield, and Wang, 2002), presents a more optimistic perspective than the one detailed in the analysis contained in this paper. Unfortunately, some major energy inputs in corn production were either out-of-date or omitted. Information on corn input production data were from 1991, and production data covered only nine states instead of all 50 states. The increased energy required to produce hybrid corn, which now is planted exclusively in the United States, was not included.

Energy input assumed for nitrogen fertilizer was about half of the usual production costs. In addition, energy inputs required for construction and maintenance of the farm machinery were not included. The USDA analysis limits irrigation use to only nine states and does not include any energy for the irrigation equipment. These nine states have limited irrigation compared with the inputs from all 50 states.

The USDA assigns a high credit of 19% for the coproduct DDG that is used to feed cattle. However, if the DDG is used as a soybean substitute, then logically credit should be based on soybean feed. When this is done, the credit in DDG is calculated to be only 9%, not 19%.

Last but not the least, the USDA does not acknowledge the costs of the many environmental impacts that result in ethanol production. These include, serious soil erosion, heavy insecticide and herbicide use, and the use of enormous quantities of nitrogen fertilizer. All of these cause serious pollution in the United States (NSA, 2002); plus, ethanol production contributes to the global warming problem.

Based on the optimistic use of data, the USDA report states that the total inputs amount to 75% of the ethanol output (Shapouri, Duffield, and Wang, 2002). Also, the authors point out that gasoline, diesel and fuel oil constitute only a part of the total inputs that also include large amounts of natural gas and electricity. However, on the same basis of Shapouri, Duffield, and Wang's analysis, Ferguson (2003) demonstrates that it is impossible to justify ethanol production even on the terms of gain in liquid ethanol; he shows that in order to satisfy transport demands of *just one year* of U.S. population growth, would require 5 million hectares (50,000 km^3) devoted to corn-ethanol crops. Moreover, to supply this one year of population growth, for a period of 70 years (a lifetime) environmental pollutants would amount to 52,000 tons of insecticides, 735,000 tons of herbicides, plus a total of 93 million tons of fertilizers (nitrogen, phosphorus, and potassium). It also would cause the loss of 5 cms of soil (averaged for conventional and no-till corn).

FOOD VERSUS FUEL ISSUES

Using corn, a human food resource, for ethanol production, raises major ethical and moral issues. Today, malnourished (calories, protein, vitamins, iron, and iodine) people in the world number about 3 billion (WHO, 2000). This is the largest number of malnourished people and proportion ever reported in history. The expanding world population that now number 6.2 billion complicates the food security problem (PRB, 2001). More than a quarter million people are added each day to the world population, and each of these human beings requires adequate food.

Malnourished people are highly susceptible to various serious diseases, this is reflected in the rapid rise in number of seriously infected people in the world as reported by the World Health Organization (Pimentel and others, 1999; Kim, 2002).

The current food shortages throughout the world call attention to the importance of continuing U.S. exports of corn and other grains for human food. Cereal grains make up 80% to 90% of the food of people worldwide. During the past 10 years, U.S. corn and other grain exports have nearly tripled, increasing U.S. export trade by about $3 billion per year (USBC, 2001). Not only does corn exports strengthen the U.S. trade balance, but more importantly they are helping to feed people who need food for survival.

Concerning the U.S. balance of payments, the U.S. is importing more than 60% of its oil at a cost of more than $75 billion per year (USBC, 2001). Oil imports are the largest deficit payments incurred by the United States (USBC, 2001). Ethanol production requires large fossil energy inputs, therefore it is contributing to oil and natural gas imports and U.S. deficits (USBC, 2001).

At present, world agricultural land based on calories supplies more than 99.7% of all world food, whereas aquatic ecosystems supply less than 0.3% (FAO, 1998). Already worldwide, during the last decade per capita available cropland decreased 20%, irrigation 12%, and fertilizers 20% (Brown, 1997). Expanding ethanol production could entail diverting valuable cropland from producing corn needed to feed people to producing corn for ethanol factories. This creates serious practical as well as ethical problems. Thus, the practical aspects, as well as the moral and ethical issues, should be seriously considered before steps are taken to convert corn into ethanol for automobiles.

CONCLUSIONS

The forgoing analysis, for which all major energy inputs required in ethanol production were assessed, confirms that ethanol production produces a 29% negative energy balance. Ethanol is not a net additional energy source, is an uneconomical fuel, and its overall production system causes serious environmental degradation. This analysis agrees with the findings of the U.S. Department of Energy (ERAB, 1980, 1981), Sparks Commodities (1990), Giampietro, Ulgiati, and Pimentel (1997), Pimentel (2001), and Hodge (2002).

At present, the total cost to produce a gallon of ethanol from corn is $2.24. Using the by-products produced in ethanol production may reduce the cost to about $1.79. But then, adding on an estimated 36¢ to cover some of the pollution brings the cost up to $2.15 per gallon of gasoline equivalent.

Certainly, in terms of economics ethanol would not be produced without the high federal and state subsidies which average about 80¢ per gallon. Doubling or tripling the amount of ethanol produced would increase the cost to tax payers two to four times the current $1.4 billion in current subsidies each year. With current budget deficits, is this increasing ethanol production a sound policy?

The real costs to the consumer, however, are considerably greater than the $1.4 billion in subsidies (federal and state) and would involve large environmental costs. Not only do subsidies increase taxes, but result in high corn prices that translate into higher meat, milk, and egg prices for the consumer, without any actual energy or environmental benefits.

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