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An Assessment of the Role of Biofuels in the 21st Century

Erin C. Jolly
Eastern Kentucky University

Walter S. Borowski
Eastern Kentucky University, w.borowski@eku.edu

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Dr. Walter S. Borowski, Mentor

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INTRODUCTION

The Industrial Revolution began with the exploitation of coal reserves, both stateside and abroad, which fueled new innovations of industry, comfort, and lifestyle in the Western world. Coal was then followed by the discovery of petroleum, concentrated liquid carbon that could be consumed as a transportation fuel and eventually used to generate many modern products of today, including plastics. But more importantly, fossil fuels form the foundation of the economic system and conveniences of the United States and other countries abroad.

However, the fuel of the economic and social development of modern civilization as we know it cannot last. While oil reserves could eventually be replenished, this would require millions of years on the geologic timescale, much more time than the modern lifestyle of today can afford to wait. Many predict centuries of coal reserves remaining in home soils, but most agree that peak oil production has already occurred. A geologist by the name of M. K. Hubbert predicted in 1956 that United States oil production would peak in the year of 1970, afterward causing gradual decline in production and price per barrel increases (Swenson, 2007). There has been much debate as to whether or not peak oil production has occurred in the past when exactly it will occur in the future. There is no debate, however, in the fact that an oil production maximum will occur at some point.

One other issue in the American thirst for oil is the concentration of world oil reserves and the effect of that concentration on foreign affairs. Middle Eastern countries control around

65% of the world's oil, much of which is imported by the United States (ESRU). This monopolization of such a needed resource can result in international conflict, as is evident in the current situation surrounding US/Middle Eastern relations. The need for a stateside transportation fuel source and general energy independence is critical to avoid such conflict.

Many energy alternatives have been proposed and are currently in use to a certain extent, including solar, wind, and geothermal-generated energy. However, while these alternatives could present solutions in roles of a more local sector, the need for a replacement transportation fuel is continuously growing. The United States alone consumes more than 8.7 million barrels of finished motor gasoline per day for transportation purposes, which does not include the millions of other barrels used for the production of petroleum-based materials. Currently, the United States population stands at over 303 million and occupies only 5% of the population, yet it consume approximately 25% of all world oil produced (EIA). As is custom with the American lifestyle, the vast majority of these residents are solely dependent on petroleum gasoline to power their personal vehicles, bring foods and other goods to more convenient locations, and other necessary transportation uses.

Possible solutions to the fuel issue include conservation techniques and lifestyle change, which must indeed be utilized by the United States public due to our responsibility as the number-one consumer of oil. While these techniques could potentially relieve stress on world oil production, they do not present a solution to the issue at hand. The ultimate solution is that of a fuel substitution in order to avoid permanent and potentially dramatic depravation. One prospective alternative fuel includes the US production and refining of biofuels, which include any liquid or gas energy source that can be obtained through the digestion of plant materials.

The niche for biofuels in modern society has already been created. Currently, Brazil is the world leader in producing plant-based fuel refining and usage, with the United States as the second leading producer. It is a widely circulated belief that biofuels are automatically sustainable because they are derived from a renewable resource such as crop plants. However, the question at hand concerns the actual feasibility of biofuels in today's world as a sustainable alternative to petroleum in the transportation sector. The purpose of this assessment is to potentially determine the true costs of biofuels with current technological practices and the energy needed to create the fuel when compared with the energy content of the fuel itself. This will require an analysis of the currently proposed biofuel crops that could be utilized. Each crop must then be evaluated for individual energy input/output required for production and refining, including the amount of land for crop planting, along with water, fertilizers, pesticides, harvesting machinery, and refining requirements for the crops, each which require energy to maintain and have potentially significant environmental impacts if used improperly. Once the best prospective candidate for a biofuel crop is identified, an estimation of amount and degree of the biofuel derived from the crop must be achieved in order to determine the extent of the biofuel's usage as a feasible alternative when compared with food, land, and other natural resources that may be compromised in the biofuel production process.

The first step in this analysis is addressing the energy inputs for the crop growth alone for each of the three crops in question, which will include corn, switchgrass, and sugarcane. The second step will include those crop growth energy inputs, along with the energy inputs necessary for that actual production of the raw crop into a usable biofuel end product, which oftentimes include energy costs that are overlooked in many end energy input/output analyses. The third step will include the less tangible negative social and environmental effects of the entire biofuel production process. While not necessarily quantifiable at this time, these tertiary costs are real and may result in serious and potentially devastating effects. When each of these energy costs are compounded, biofuels have a negative net energy output and are currently unfeasible as a major player in the United States liquid fuel solution.

CORN

The first crop to be analyzed will be corn, a continuing leader in the American biofuel market in particular. Corn (*Zea mays*) is the most widely planted and harvested crop in the United States, with the US not only being the top corn producer in the world, but also the top exporter. According to the United States Department of Agriculture, an estimated 92.9 million acres of arable land were devoted to corn crops in 2007, or around 29% of the estimated 320 million acres in total used for primary crops (USDA). The US land devotion to corn crops in 2007 is the highest planted since 1944. This increase is most likely driven by the demand of corn-based ethanol. The total corn crop yielded around 13.1 billion bushels with a final average price of $4.00 per bushel at the end 2007, or a yield of an average of 151.1 bushels and $604 per acre. This is a rise in production from five years prior (2002) with 16% more land being used for corn, 14% higher crop yields, and a 31% increase in total corn production (USDA). Currently, biofuels from corn occupy a very small niche of the total US gasoline supply, but will likely rising due to the demand for alternative transportation fuels and fuel additives. This supply includes all types of gasoline/ethanol mixtures such as E85 and the use of ethanol as a replacement for the gasoline oxygenator, methyl tertiary butyl ether (MTBE).

Corn is currently the most popular US biofuel crop because of the high starch content within the plant's fruit, because it is established as a major crop, and because of continued government subsidies and tax incentives to farmers who grow the crop for biofuel production. While corn may be an established and familiar biofuel source in the US, the overall negatives of the fuel seem to greatly outweigh the supposed positives in terms of energy input and output, resources required for optimum growth, conflict with world food supplies and prices, and environmental degradation.

CROP PRODUCTION

The process of making corn into a usable fuel begins with crop growth itself. To obtain significant crop yield, resources must be utilized including water, fertilizer, pesticides, and harvesting equipment. These requirements add to the cost of biofuel production, potentially sap resources, and create potential environmental problems. David Pimentel of Cornell University has completed multiple analyses on potential biofuel crop candidates and their energy inputs and outputs for both crop and biofuel production. Pimentel (Table 1) has compiled the energy inputs and costs of corn production per hectare in the United States.

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

Inputs	Quantity	kcal × 1000	Costs $
Labor	11.4 hrs[a]	462[b]	148.20[c]
Machinery	55 kg[d]	1,018[e]	103.21[f]
Diesel	88 L[g]	1,003[h]	34.76
Gasoline	40 L[i]	405[j]	20.80
Nitrogen	153 kg[k]	2,448[l]	94.86[m]
Phosphorus	65 kg[n]	270[o]	40.30[p]
Potassium	77 kg[q]	251[r]	23.87[s]
Lime	1,120 kg[t]	315[u]	11.00
Seeds	21 kg[v]	520[w]	74.81[x]
Irrigation	8.1 cm[y]	320[z]	123.00[aa]
Herbicides	6.2 kg[bb]	620[ee]	124.00
Insecticides	2.8 kg[cc]	280[ee]	56.00
Electricity	13.2 kWh[dd]	34[ff]	0.92
Transport	204 kg[gg]	169[hh]	61.20
Total		8,115	$916.93
Corn yield 8,655 kg/ha[ii]		31,158	kcal input: output 1:3.84

The energy input/output ratio demonstrates whether crop production yields more energy than expended in raising the crop is calculated by dividing the energy content in the corn yield per hectare by the total energy inputs required for the growth of the corn crop (8115/31158). Pimentel then obtains an energy input/output ratio of 1:3.84. Any output greater than 1 results in a net energy return, where any output less than 1 results in a negative energy return, meaning that more energy is required for the production process of the fuel than the resulting total energy content of the fuel. In the case of corn in the growth phase, there is a resulting positive energy return of 284%, which is almost three times the energy required as inputs (Pimentel, 2005). However, this is the energy balance in the corn crop growth phase alone, and the necessary inputs for the production of corn ethanol itself have not yet been considered.

CROP AND BIOFUEL PRODUCTION

The calculation of energy balance for the entire process is controversial. In order to determine the energy required for corn ethanol production, we will first use the 2001 corn ethanol energy balance study of Hosein Shapouri of the United States Department of Agriculture. Shapouri's work in biofuel crop analysis provides the foundation for much of the governmental and public beliefs on the topic. Shapouri (2001), derives an energy input/output ratio is derived much in same manner as that of Pimentel (2005) (Tables 3 and 4).

Table 3–Energy use and net energy value per gallon without coproduct energy credits, 2001

	Milling process		Weighted
Production process	Dry	Wet	average
	Btu per gallon		
Corn production	18875	18551	18713
Corn transport	2138	2101	2120
Ethanol conversion	47116	52349	49733
ethanol distribution	1487	1487	1487
Total energy used	69616	74488	72052
Net energy value	6714	1842	4278
Energy ratio	1.10	1.02	1.06

Table 4–Energy use and net energy value per gallon with coproduct energy credits, 2001

	Milling process		Weigted
Production process	Dry	Wet	average
	Btu per gallon		
Corn production	12457	12244	12350
Corn transport	1411	1387	1399
Ethanol conversion	27799	33503	30586
ethanol distribution	1467	1467	1467
Total energy used	43134	48601	45802
Net energy value	33196	27729	30528
Energy ratio	1.77	1.57	1.67

The types of co-products that result depend on the type of milling process used, which can be either dry or wet milling. Wet milling is a much more versatile process that produces a wide spectrum of marketable products such as corn syrup, sweeteners, stock feed, etc. However, wet milling is also much more energy and cost intensive, but cost is often offset by its coproducts. Dry milling is less intensive, but does not result in as many usable products. In the case of the unsubsidized corn ethanol production, an energy input/output ratio of 1.06 results from the averaging of the dry and wet milling processes, which produces a net energy gain of 6%. In the case of the subsidized corn ethanol production, an average energy input/output ratio of 1.67 results, which produces a net energy gain of 67%. This net energy gain for both subsidized and unsubsidized accounts would lead one to believe that corn ethanol production is a sustainable and feasible alternative for liquid petroleum fuel (Shapouri, 2001). The analysis displayed by Table 4 takes into account the subsidizing of ethanol production through the crediting of products that are created as a result of the corn milling and ethanol production processes.

However, it should be recognized that Shapouri omits many energy inputs when performing his analysis of corn as a biofuel crop. In order to refute Shapouri's claim of corn ethanol's net energy return, Pimentel successfully produced a corn ethanol biofuel study, which included all calculable energy inputs for corn ethanol production (Table 2).

Table 2. Inputs Per 1000 l of 99.5% Ethanol Produced From Corn[a]

Inputs	Quantity	kcal × 1000	Dollars $
Corn grain	2,690 kg[b]	2,522[b]	284.25[b]
Corn transport	2,690 kg[b]	322[c]	21.40[d]
Water	40,000 L[e]	90[f]	21.16[g]
Stainless steel	3 kg[i]	12[i]	10.60[d]
Steel	4 kg[i]	12[i]	10.60[d]
Cement	8 kg[i]	8[i]	10.60[d]
Steam	2,546,000 kcal[j]	2,546[j]	21.16[k]
Electricity	392 kWh[j]	1,011[j]	27.44[l]
95% ethanol to 99.5%	9 kcal/L[m]	9[m]	40.00
Sewage effluent	20 kg BOD[n]	69[h]	6.0
Total		6,597	$453.21

The complete energy inputs required for the production of corn ethanol come to 6,597 kilocalories x 1000. When the total energy content in one liter of ethanol fuel resulting from the process (5,130 kilocalories x 1000) is divided by the total energy inputs, a final energy input/output ratio of 1:0.78 results. This leads to a 22% net energy deficit (Pimentel, 2005). The extreme differences in the input/output ratios of these two studies come as a result of the incompleteness of Shapouri's energy input considerations. Shapouri's study omits the energy required for the production and repairing of equipment in the farming and fermentation-distillation processes, which are both large energy inputs due to the mechanized agriculture techniques of modern America. Only nine states were used in Shapouri's study, whereas data from all fifty US states were used in Pimentel's study. Also, the total energy costs for steam energy and electricity were underestimated in Shapouri's study, which are two of the three largest contributors of the total energy input for corn ethanol production (Pimentel, 2005). Since Shapouri's analysis does represent the forefront in the general understanding of corn ethanol production, it is necessary to refute his misleading account and present the more accurate energy analysis of the production process.

ENVIRONMENTAL AND SOCIAL COSTS

No energy was allocated in either Shapouri or Pimentel's study concerning the negative environmental or social considerations of ethanol production. However, when considering the completeness of Pimentel's study and the resulting negative energy return, the energy requirements for future impact remediation should most likely create an increased negative return.

The chemicals needed to created crops with the highest yield possible, including fertilizers and pesticides, can have potentially irreversible effects on the surrounding natural systems. The universal agricultural requirements for a complete fertilizer include varying proportions of nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Depending on the crop requirements, the ratio of the three essential fertilizer parts can differ to suit that crop's needs for optimum growth. Corn, particularly corn hybrids, requires more nitrogen fertilizer than any other plant crop (Worldwatch, 2007). For corn crops planted in 2005, 96 percent received nitrogen applications with an average of 138 pounds of nitrogen applied per acre; 81 percent of corn acreage received applications of phosphate with an average of 58 pounds per acre; 65 percent of corn acreage received applications of potash with an average of 84 pounds per acre (USDA). Because of the variation of soil texture, structure, and deficiencies, other nutrients are added as needed; however, these are dealt with on a more local level. The amount of fertilizer that is not absorbed into the crop is washed into the surrounding surface and groundwater systems by rainfall and excess irrigation water. This influx of nutrition into a surface water system can cause eutrophication, which results from an imbalance of nutrient input/output, and can result in the premature death of that system. Nutrient overload can also affect the water quality of groundwater utilized for human consumption.

Corn also requires more pesticides than any other US crop (Pimentel, 2005). While many other types of pesticides are available, US corn crops planted on a wide scale require pesticides in the forms of both herbicides and insecticides. Herbicides, with the most popular being Atrazine, were applied to 97 percent of the 2005 corn acreage at an average of 1.133 pound per acre (USDA). The excess pesticides from typical spray application methods can be introduced into surface and groundwater systems in much the same way as excess fertilizer, causing contamination of those systems and potentially endangering the health of the water's consumer.

There is also the issue of further agricultural expansion. Because of corn's necessity for extremely fertile growing land and the already wide utilization of the best US agricultural land available, corn ethanol's demand will most likely require the use of forest-covered land. In order to make this land usable for corn agriculture, all growing foliage must be cut, thereby releasing the years of carbon stored within the foliage. After the creation of the agricultural land through the planting of corn crops, the land would become a net producer of carbon dioxide instead of its previous carbon dioxide-storing forest state (Grunwald, 2008).

One of the most potentially detrimental environmental effects of corn ethanol production is the continued increase in aquifer utilization. The majority of ethanol corn crops are situated in the United States "Corn Belt," a region that covers 11 states and extends from Ohio to South Dakota. Irrigation for crops in the Corn Belt region east of the Missouri River is generally not necessary due to favorable rains. However, irrigation is required east of the Missouri River in the agriculturally-rich Great Plains states. Around 96% of the current corn crop devoted to ethanol production is not irrigated, most likely due to their situation in the naturally-watered US agricultural sector. However, with prime land acreage in the US already in use for crops, those regions that require irrigation would have to be exploited if corn ethanol production were to increase. Water use estimates are difficult to obtain, however the 2003 USDA Farm and Ranch Survey states that irrigation-dependent corn grain uses an average of 1.2 acre-feet of water per year, which results in an average corn yield of 178 bushels per acre. This corresponds to around 785 gallons of water per gallon of ethanol during the crop growth process alone, with no consideration to the water required during the continued steps of the ethanol production process

(Aden, 2007). Water use in agriculture varies according to local and regional considerations, but almost all agricultural water is extracted from aquifer sources, which are being "permanently" drained at a rate higher than the aquifers' recharge rates. Once aquifers are drained, they will require decades to centuries to recharge, making water an essentially non-renewable resource.

There also exist many social detriments in using corn for ethanol biofuel production. Nearly all biofuel programs in the United States and abroad exist because of government subsidies and tax incentives to large agribusinesses. In order to offset this government spending, taxes to the common public must be increased. It has been estimated that various subsidies and tax incentives for ethanol production will cost US taxpayers approximately 6.3-8.7 billion dollars each year between 2006 and 2012. This is mostly due to the price-per-gallon tax credit given to refiners who meet the expectations of the federal Renewable Fuels Standard mandate (Moore, 2007).

The diversion of large amounts of corn for use as a biofuel crop could also increase food prices, affect US corn exports, and bring up ethical concerns in diverting needed food resources to fuel production. Corn is present in a vast number of food products, particularly is the case of meat production. The majority of the US corn yields are used for animal feed for livestock. Increases in corn prices brought about by demands for corn ethanol could escalate the price of beef significantly, along with all other products that use corn. The US leads the corn export market with 71% of all corn exports, with the top three leading importers of US corn being Japan, Mexico, and Taiwan (USDA). These countries would also have to face the effects of higher prices on corn. Though not automatically evident in an economic sense, the ethical concerns in diverting a food source for use in fuel production appears morally skewed and could potentially create significant tensions between the United States and foreign countries who experience a greater degree of food shortages.

SWITCHGRASS

It has been established that the production of corn ethanol does result in a negative energy return and many potentially devastating future environmental and social effects, thereby making corn ethanol an unfeasible and unsustainable substitute for transportation fuel in the United States. However, a second crop that has received recent attention in the biofuel market is switchgrass.

The future of biofuel technology may potentially lie in cellulosic biofuel development. Cellulosic biofuels utilize plants or parts of plants that are less desirable and are usually discarded. Switchgrass (*Panicum virgatum*) is a North American native summer perennial grass. It is a natural component of prairie ecosystems of central and southeastern United States, and formerly covered most of the Great Plains area. The two main types of switchgrass are upland and lowland types. Upland types typically grow up to 6 feet tall and are better acclimatized to well-drained soils, whereas lowland types can grow up to 12 feet tall and are found on heavier soils in bottomland sites. It is very tolerant of soils that too nutrient poor for other plant or crop species, drought, and flood (Bransby).

The use of switchgrass and other such prairie grasses are extremely appealing for ethanol biofuel technology in the United States for a number of reasons. The use of plants or parts of plants that would otherwise be disposed of obviously is more efficient and will not directly compete with world food supplies. When grown in a crop setting, the hardiness of switchgrass in particular would decrease the need for irrigation and fertilizers required for the optimum growth of other biofuel crops such as corn and sugarcane. It is also resistant to many plant pests and diseases because of its native history in the area (Bransby). The recent focus of the Department of Energy's Bioenergy Feedstock Development Program toward switchgrass came as a result of these combined reasons.

Along with his analysis of corn as a biofuel crop, David Pimentel also completed a total analysis of the use of switchgrass in this same manner (Table 3).

Table 3. Average Inputs and Energy Inputs Per Hectare Per Year for Switchgrass Production

Input	Quantity	10^3 kcal	Dollars
Labor	5 hr[a]	20[b]	$65[c]
Machinery	30 kg[d]	555	50[a]
Diesel	100 L[e]	1,000	50
Nitrogen	50 kg[e]	800	28[e]
Seeds	1.6 kg[f]	100[a]	3[f]
Herbicides	3 kg[g]	300[h]	30[a]
Total	10,000 kg yield[i]	2,755	$230[j]
	40 million kcal yield	input/output ratio	1:14.4[k]

An input/output ratio of 1:14.4 is determined in the same manner as his corn study, by dividing the total energy content of the crop per hectare by the energy required to grow and harvest the crop. This in turn leads to a net energy gain of over 1300% for this first step in the procedure. However, once again, the analysis has only taken into account the energy required for switchgrass growth alone.

However, Pimentel does continue his analysis of switchgrass into the ethanol production phase as well (Table 4).

Table 4. Inputs Per 1000 l of 99.5% Ethanol Produced From U.S. Switchgrass

Inputs	Quantities	kcal × 1000[a]	Costs
Switchgrass	2,500 kg[b]	694[c]	$250[o]
Transport, switchgrass	2,500 kg[d]	300	15
Water	125,000 kg[e]	70[f]	20[m]
Stainless steel	3 kg[g]	45[g]	11[g]
Steel	4 kg[g]	46[g]	11[g]
Cement	8 kg[g]	15[g]	11[g]
Grind switchgrass	2,500 kg	100[h]	8[h]
Sulfuric acid	118 kg[i]	0	83[n]
Steam production	8.1 tons[i]	4,404	36
Electricity	660 kWh[i]	1,703	46
Ethanol conversion to 99.5%	9 kcal/L[j]	9	40
Sewage effluent	20 kg (BOD)[k]	69[l]	6
Total		7,455	$537

After dividing the energy content of ethanol fuel by the total energy expended to get one liter of switchgrass-derived ethanol, an energy input/output of 1:0.69 can be obtained. This results in a 31% negative energy return after the completed switchgrass ethanol production process (Pimentel, 2005).

Such an energy deficit for switchgrass, particularly when compared with that of the high net energy gain after the initial crop growing process, may not seem feasible. The dramatic difference between the input/output ratios can be understood through a better understanding of the inputs of the two steps. During the growth process, there is very little energy required for the growth and maintenance of switchgrass due to its hardy nature. It requires less pesticides, fertilizers, and water when compared with more intensive crops such as corn, and produces a significant crop yield. However, the end net energy loss comes as a result of the energy required to break down the switchgrass cellulose into a usable fuel, which is evident in steam production and electricity generation stated in Table 4. Instead of the more simple grinding, enzymatic breakdown, and fermentation process that is required for corn ethanol production, cellulose breakdown technology currently incorporates thermo-chemical and biochemical conversion pathways (Worldwatch, 2007).

The use of cellulose-based ethanol is continuing to receive much support in the biofuel research sector even with its current energy deficit. This is due to the positive aspects concerning its lack of competition with food resources, the ability to use poorer soils, and its decreased need for irrigation and chemical application. The technology for the production process, however, requires significant technological advances for future use.

SUGARCANE

BRAZILIAN SUGARCANE EXPERIENCE

Sugarcane (*Saccharum*) is the possibly the most significant biofuel crop that exists today. This crop alone supplies more than 40 percent of the world's ethanol fuel supply and, along with corn, is considered another "first-generation" biofuel feedstock (Worldwatch, 2007). Perhaps the most successful example of biofuel utilization and infrastructure is the sugarcane ethanol program in Brazil, South America.

Brazil has been the leading producer of ethanol for over 30 years, with actual sugarcane sugar being a residual of ethanol production. As was the case with the US, Brazil was required to find alternatives to the petroleum deficiencies of the early 1970's, thereby turning to ethanol production using tropical sugarcane and creating the National Alcohol Program known as Proalcool (Lagercranz, 2006). Through a combination of government support, subsidizing, infrastructure, and petroleum reserves, Brazil has become relatively energy self-sufficient. The Brazilian government has also forged ahead in the national production of flexible fuel vehicles, which can run on gasoline, ethanol, or any combination of the two. Since the prices of both gasoline and ethanol fluctuate regularly, Brazilian citizens with flex fuel vehicles do not have to make predictions on which fuel will be cheaper, but can use whichever is most economical at the time.

SUGARCANE IN AMERICA?

Though sugarcane has been a relative success in Brazil, there are some issues for its prospective use as a biofuel crop in the United States. One potential issue with using sugarcane as a stateside base crop for ethanol production is the limited amount of area within the US that can produce sugarcane. Sugarcane requires warm weather, a long growing season, and significant amounts of rainfall (around 850 mm per year) and grows best in tropical regions because of these specific requirements (Worldwatch, 2007). The top four producers of sugarcane in 2004 in descending order were Brazil, India, China, and Thailand, all of which are situated between the world's tropics. Other major producers are located in other parts of Latin American (23%) and Africa (28%) (Worldwatch, 2007). Due to the United States' geographic location and climate, only four states produce any valuable amounts of sugarcane. Florida ranked highest in 2007 in sugarcane production with around 14.6 million tons, followed by Louisiana with 12.6 million tons, Texas with 1.84 million tons, and Hawaii with 1.78 million tons (USDA). While these figures may seem like large amounts, they are completely overshadowed by the shear volume of production Brazil, whose production weight in 2002 totaled nearly 300 million metric tons of sugarcane annually, with more than 50% of that stock being utilized for the countries ethanol biofuel needs (USDA). When the total US sugarcane crop acreage is divided by the total US land acreage currently in use for agricultural purposes, sugarcane only amounts to around 0.27% of the current total agricultural land use. Expansion of sugarcane production in these four producing states is a veritable impossibility due to the current agricultural land use already taking place for the production of more economically-viable tropical climate crops.

It is also difficult to quantify the energy requirements of sugarcane ethanol production in the United States due to the inability for comparison with Brazilian ethanol production. Agricultural practices in Brazil are still mainly based upon manual labor for planting and harvesting of crops. These practices require significantly less amounts of energy and monetary costs when compared with the practices of more developed nations such as the United States. Therefore, the statistics and resources concerning energy input/output of sugarcane ethanol production in Brazil would have fewer energy inputs than the production of the same type of ethanol in the US, and cannot be used for modeling comparisons.

FUTURE FUEL PROSPECTS

It is painfully evident that the United States' biofuel sector is currently following the wrong path in its attempts at success. The use of corn as a biofuel crop provided a foothold for biofuel research in America, but the combination of the fuel's energy deficit, along with potentially detrimental environmental effects and societal impacts make it unfeasible and uneconomical. The idea of using a cellulose-based biofuel is appealing, but the energy required for the current cellulose breakdown technology makes it even more unfeasible than corn ethanol. Sugarcane ethanol may be potentially successful in tropical Brazil due to climate and governmental support. But due to the temperate climate and lack of US energy analyses, any possibility of sugarcane ethanol use in the US appears unrealistic. However, it is possible to change the trajectory of the liquid fuel solution to preserve the future of America's fuel energy dependence.

One possible solution is the burning of biomass waste products, coal, or the expanding of nuclear power plants to generate electricity. This electricity could then be utilized to power vehicles installed with electrically-generated battery systems instead of the internal combustion engine that exists in most America vehicles of today. The positives of this sort of fuel system would include the practically consistent stateside supply of fuel from local coal, nuclear energy, or waste products, along with the utilization of the economically feasible methods of material combustion that are already in place. The problem with this method is the lack of current infrastructure in terms of mass transport, distribution, and vehicle compatibility with electrical fuel. The vast majority of vehicle fueling stations would require significant transformations in order to distribute electricity to vehicles. Also, while vehicles are beginning to become more computer-based as opposed to combustion-based, the creation of the fleet of electrically-fueled vehicle for US needs would still necessitate many years and potentially billions of dollars of infrastructure overhaul.

Another potential transportation fuel option would be the creation of a methanol-based system. Methanol, or wood alcohol, is a raw material that can be used to produce dimethyl ether, which is a diesel biofuel that could be utilized by diesel-powered or flexible fuel vehicles (Zubrin, 26). A methanol economy has much of the same issues in terms of lack of infrastructure and availability as that of an ethanol-based or electricity fuel system, along with the lower energy content of the fuel as with ethanol, particularly when compared with the energy content of petroleum. The appeal of a methanol-based system would be its potential for stateside fuel independence, the use of any and all biomass for production, and the presence of appropriate technology for the growth of a methanol system. Flex-fuel technology is already present and is continuing to grow , with some 6 million vehicles being produced between 1998 and 2006 that had the capability of using alcohol/gasoline combinations in various amounts (Zubrin, 27). In 1984, Dutch inventor G. A. Schwippert developed an optical sensor that could determine the type of alcohol/gasoline combination being used in an engine. This sensor was then continued by Roberta Nichols' Ford engineering team to indicate to the vehicle's computer system the instructions on how much fuel and air to utilize to make the vehicle's engine work properly (Zubrin, 104). The continuing production and expanded operations in a methanol system could indeed potentially be a significant player in the search for the best alternative transportation fuel.

Whichever the fuel alternative that is best for use in the United States, government support, infrastructure, and continued technological improvements in the alternative fuel research field must be present. The continued expansion of the biofuel market in a private, research-based sector can only benefit our understanding of proper fuel alternatives. However, because of the lack of nationwide infrastructure and proper technological advancements needed to make any alternative fuel system economical and energetically feasible, these types of alternative fuels, including biofuels, are not ready for mass use in the United States.

The need of energy for the maintenance of our society as we know it and the growing fuel-dependent world will continue the forging of new breakthroughs in the transportation fuel sector. In the current age, we should prolong the utilization of petroleum fuels for our energy needs, while at the same time practicing responsible fuel usage and looking to the future of biofuel and other alternative fuel technologies that will continue to be made.

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