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Cellulosic Ethanol: The Benifits, Obstacles, and Implications for Nebraska

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CELLULOSIC ETHANOL:
THE BENEFITS, OBSTACLES, AND IMPLICATIONS FOR NEBRASKA

by

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Abstract

Ethanol is a biofuel that has unique capabilities to mitigate global climate change by reducing greenhouse gas emissions while simultaneously supporting rural economies and decreasing the United States' dependence on foreign oil. Currently, the state of Nebraska depends on corn ethanol, which may be unsustainable. Cellulosic ethanol is a promising alternative but it is not without its problems, including high production costs and potential environmental damage. This thesis is an attempt to understand the benefits, downfalls, and processes of corn-based and cellulosic ethanol and the potential implications to Nebraska. This research should shed some light on the current obstacles and environmental problems involved with production, as well as evaluate the potential economic benefits to Nebraska, while pointing out issues that should be further researched before implementation.

Introduction

The Benefits of Ethanol

Anthropogenic emissions of carbon dioxide and other greenhouse gasses are changing the climate (Storm 2009). If nothing is done, Earth's average global temperature will increase by about 1.8-4° C in this century (Hunt 2008, Storm 2009). The consequences of inaction could be devastating for an agricultural-based state like Nebraska. A change in 3-4° C will likely harm established ecosystems and species currently present in the state (Storm 2009). A transportation fuel that is not made from fossil fuels is seen as part of the solution to reduce anthropogenic carbon dioxide emissions (Peterson and Ingram 2008).

In 2008 (the most recent year for which there is data), the US imported 4.7 billion barrels of oil. Imported oil accounts for 58% of the nation's daily oil use (US Energy Information Administration 2009). Reliance on foreign energy sources undermines the stability of the United States' economy and national security (Sticklen 2008). Breaking free of the dependence on foreign oil is a national security priority, and ethanol is a secure source of domestic energy (Hunt 2008).

In order to address the concerns of both the environment and national security, in 2007 Congress passed the Energy Independence and Security Act (EISA), which required the addition of 36 billion gallons of "renewable fuel," including biofuels like ethanol, to the U.S. fuel supply by 2022 (Hunt 2008). The EISA has been the impetus for much of the recent ethanol production in the US. However, the EISA does not include measures pertaining to the sustainability of biofuel production. Therefore, it is crucial that the issue of sustainability be addressed while implementing alternative ethanol production—it is important to avoid the creation of more problems while attempting to solve others.

The Obstacles to Corn Ethanol Production

Although corn-based ethanol makes up 97% to 99% of all biofuels in the US, the supply of corn is limited, and it also detracts from food corn sources, hitting those that are already malnourished the hardest (Peterson and Ingra 2008, Woodson and Jablonowski 2008, Pimentel 2009, Hertel et al. 2010). In fact, almost 60% of the world's population is malnourished—an all-time high (Pimentel 2009). However, the use of corn to produce ethanol is not entirely to blame. At a global scale, only about 4% of the world's grain is used to make biofuels, but this detraction from the food market coupled with market forces and government subsidies is believed to contribute to huge increases in the price of food (Figure 1) (Hunt 2008, Pimentel 2009).

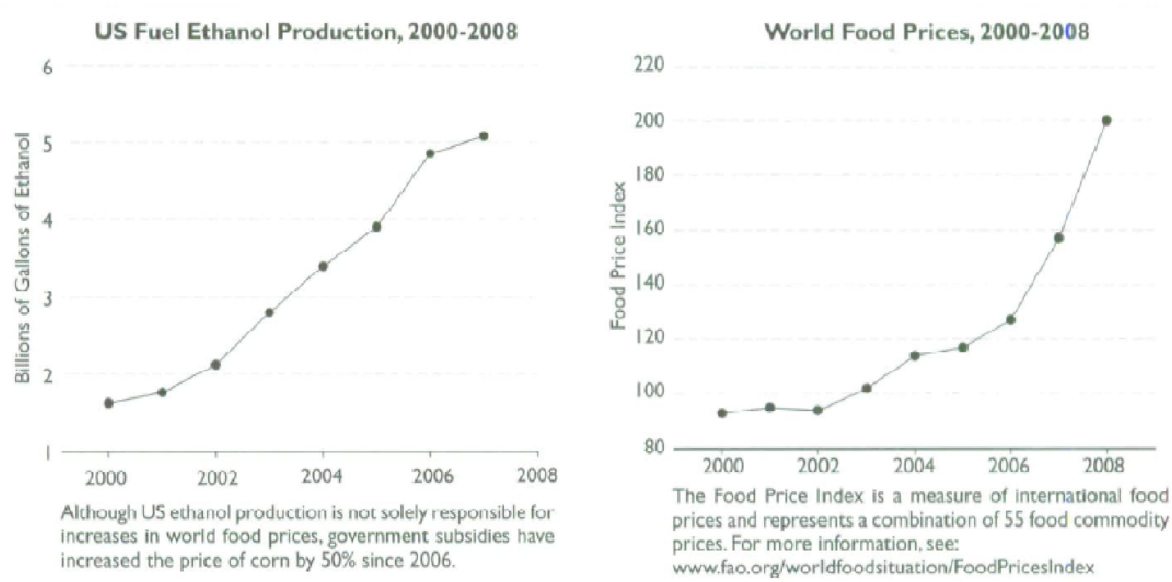

Figure 1. From Pimentel 2009.

However, correlation does not equal causation, as Hunt (2008) has pointed out. Tracking the global price of food is inherently complex. Federal corn ethanol subsidies are not the only reason why corn prices have increased. Farmers must now pay more for fertilizer and diesel because of rising petroleum prices. While increases in the cost of grains is probably a factor, there are other reasons why global food prices have skyrocketed. For example, China and India have shifted towards greater protein consumption, so meat production has increased. More livestock need more food, so there is an increase in the amount of grain going to meat production. It is important to note that 40% of the grain produced globally feeds animals and not people. Even though corn ethanol is not solely to blame for hunger around the world, it is ethically responsible to reduce human suffering whenever possible, and one way to do so is by finding a viable non-food source for ethanol production (Hunt 2008).

According to Schmer et al. (2008), “for an alternative transportation fuel to be a substitute for conventional gasoline, the alternative fuel should (*i*) have superior environmental benefits, (*ii*) be economically competitive, (*iii*) have meaningful supplies to meet energy demands, and (*iv*) have a positive NEV [net energy value].” Corn ethanol fails to fully live up to these four points.

Environmentally, corn has the potential to do more harm than good if not managed properly. Corn production is the cause of the most soil erosion out of all the crops grown in the US and uses the most agricultural chemicals, including nitrogen fertilizers, insecticides, and herbicides (Pimentel 2009). The energy needed to produce industrial agricultural chemicals is derived from fossil fuels that contribute to global warming (Patzek 2004). Some studies show that there is a net increase in greenhouse gas emissions when corn ethanol is produced conventionally because more fossil fuels are required to produce ethanol than its final calorific value yields (Patzek 2004). However, others report that greenhouse gas emissions are reduced by about 18% when corn ethanol is used (Service 2007). Also, the world demand for corn and other grains has initiated the conversion of previously undisturbed land to farmland. In the process, massive amounts of carbon are released since many such pristine ecosystems sequester carbon (Figure 2) (Hunt 2008, Hertel et al. 2010).

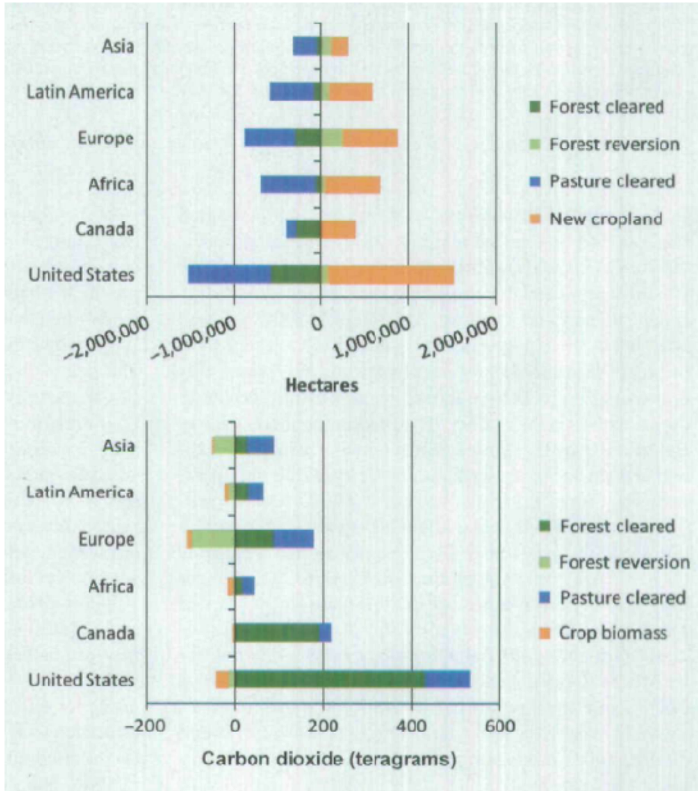

Figure 2. Global land conversion and associated greenhouse gas emissions due to increased corn ethanol production of 50.15 gigaliters per year at 2007 yields, per region (Hertel et al. 2010).

Corn ethanol production also requires a lot of water. Ethanol plants use about three to five liters of water for every liter of ethanol produced (Fargione et al. 2009). Typical ethanol plants use about 500 gallons of water per minute, but current designs are becoming more efficient (Keeney and Muller 2006). Specific water uses and amounts are not publicly available. An interview with Brian Wilcox, who is an engineer in the renewable energy development group at Nebraska Public Power District, revealed that ethanol plants use water to make a slurry from ground-up corn. Distillation of the slurry produces 190-proof ethanol, which is then concentrated to pure ethanol using a dehydration process. Some water is then lost via evaporation, releasing water vapor, a greenhouse gas, to the atmosphere. The water that is retained in the plant is recycled. Even though some of the water is recycled, such massive use of water could still possibly lead to unsustainable exploitation of surface and ground waters (Evans and Cohen

2009). A rise in water use would further degrade aquatic systems by promoting increased runoff of agricultural chemicals (Evans and Cohen 2009).

Economically, corn ethanol is complex because it relies on subsidies. The current federal ethanol subsidy is $.51 per gallon (Tyner 2008). Complicating the picture is the fact that corn ethanol subsidies were set in the Energy Policy Act of 1978, when a barrel of crude oil was $20 (Tyner 2008). Additionally, the corn ethanol subsidy is fixed so it does not adjust accordingly when the price of crude oil changes. One study showed that ethanol production is economically viable without any subsidies when crude oil is more than $100 per barrel (Tyner 2008). Therefore, tax payer money is being wasted on unnecessary subsidies when the cost of crude oil is high. In addition to federal ethanol subsidies, many states, including Nebraska, have implemented their own as well. Currently, Nebraska pays $.18 per gallon to qualifying ethanol producers (Perrin 2005).

Corn-based ethanol alone cannot offset total US oil consumption. In fact, if all the corn in the US was converted to ethanol, it would only replace 4% to 15% of the nation's total oil use (Sticklen 2008, Pimentel 2009). However, the net energy ratio and greenhouse gas emissions can both be improved upon with the utilization of closed-loop biorefinery systems, where products, inputs, and wastes are recycled and reused appropriately (Liska et al. 2009).

Some studies conclude that corn ethanol does not have a positive net energy value (NEV), which is a comparison of the amount of biofuel produced to the amount of petroleum required to produce it (Schmer et al. 2008). According to the negative NEV studies, it takes 46% more fossil fuel energy to produce a liter of ethanol than what it yields so at least part of the oil used to produce corn ethanol must be imported (Pimentel 2009). On the other hand, other researchers have utilized models that result in a positive NEV for corn ethanol (Hill et al. 2006).

It is important to note, however, that these NEVs are relatively small. They show that corn ethanol provides about 25% more energy than what is required for its production. Almost all of the positive gains come from a life-cycle credit for an animal feed co-product that is made during corn ethanol production, as opposed to the ethanol actually containing more energy (Hill et al. 2006). The ambiguity in NEV numbers means that it is vital to develop and implement the most efficient farming and ethanol production methods possible, until it can be said with scientific certainty that corn ethanol has a positive NEV.

An Alternative to Corn

Cellulose is a polysaccharide that is found in the cell walls of plants. Globally, 180 billion tons of cellulose are produced per year, making it the largest organic carbon reservoir on the planet (Sticklen 2008). Cellulosic ethanol is a desirable alternative to corn because it has a higher potential yield. While sugar is fermented in both types of ethanol production, cellulose has a higher glucose content, which makes it easier to form sugar (grain-based ethanol must first be converted from starch to sugar). Cellulose additionally contains both five- and six-carbon sugars, called pentoses and hexoses, which can be utilized by various microorganisms, which are discussed below (Ethanol Across America 2009).

The US produces about 1.3 billion tons of biomass per year, which could replace approximately 30% of the nation’s current petroleum use after being converted to ethanol, with little impact on food or timber harvests (Service 2007, Peterson and Ingra 2008, Schmer et al. 2008). Biomass is typically composed of about 40% to 50% cellulose, 25% to 35% hemicellulose, and 15% to 20% lignin, which are substances that are not broken down by the enzymes used in corn ethanol production (Peterson and Ingra 2008). Cellulosic ethanol can be produced from various energy crops. Native species include switchgrass (*Panicum virgatum*) and big bluestem (*Andropogon gerardii*), while exotic species include *Miscanthus giganteus*, common reed (*Phragmites australis*), reed canary (*Phalaris arundinacea*), hybrid poplar (*Populus* spp.) and camelina (*Camelina sativa*) (Fargione et al. 2009).

Of the common energy crops, switchgrass has probably gotten the most attention recently. Various studies have shown that switchgrass is generally a viable and desirable alternative to corn in ethanol production because it is more energetically efficient and sequesters more carbon. In fact, switchgrass typically produces much more net energy than corn ethanol. Switchgrass monocultures that were agriculturally managed produced a high biomass yield: 93% more than human-made prairies that received lower agricultural inputs (Schmer et al. 2008). An analysis of the amount of energy produced showed that switchgrass had a positive NEV of 343% after biomass ethanol was produced. This value could potentially be increased to 700% or more after further research is done to optimize input-output values (Schmer et al. 2008).

Switchgrass ethanol has been shown to produce zero to slightly positive net greenhouse gas emissions. Compared to gasoline, ethanol derived from switchgrass produces 94% less net greenhouse gas emissions (Schmer et al. 2008). Additionally, switchgrass fields have been shown to increase soil carbon concentrations (Figure 3). Therefore, these bioenergy fields are carbon-negative, sequestering 4.42 Mg C ha^{-1} yr^{-1} in the Northern Plains in one study (Schmer et al. 2008). Management-wise, switchgrass requires fewer agricultural inputs and can be grown on land that would not support traditional cash crops (Schmer et al. 2008). Compared to row crops like corn, perennial cellulosic energy crops like switchgrass can be grown on marginal agricultural land with a reduced risk of erosion (Lynd et al. 1991). Genetic modifications of both feedstocks and conversion species point to a future improvement in net energy yields for switchgrass. In fact, traditional breeding controls alone have already improved the yield of switchgrass from parent types by 20-30% (Schmer et al. 2008).

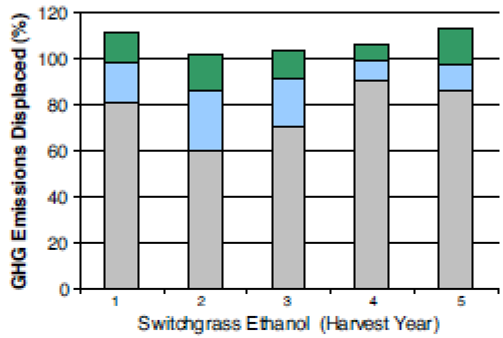

Figure 3. Estimated displacement of greenhouse gas (GHG) emissions by replacing gasoline with switchgrass ethanol. Minimum (grey), mean (blue), and maximum (green) percent GHG displacement for each switchgrass harvest year is based on production data from 10 fields. Estimated GHG values include the amount of CO_2 sequestered in the soil (Schmer et al. 2008).

An area in which there is a lack of research is the threat of wildfires in switchgrass fields. It would be advantageous to study whether the threat of fire increases with the amount of switchgrass biomass in order to reduce any potential risk to human life or property. However, studies have found that the most effective harvesting methods involve two cuttings per season (Thomason et al. 2004). Such frequent harvesting would reduce the build-up of dead plant matter and the litter layer, which would seemingly make wildfires less likely.

One problem with switchgrass is that it would be grown as a monoculture that could become invasive and/or reduce biodiversity (Fargione et al. 2009). Therefore, some researchers have studied the feasibility of using prairie ecosystems for cellulosic ethanol production. Prairie ecosystems can provide a source of energy crops and wildlife habitat while sequestering carbon and reducing soil erosion and chemical runoff. The diversity of species found in prairie ecosystems is advantageous for many reasons. First, these diverse systems increase the amount of carbon held in the soil compared to monocultures. Using local species would also reduce the risk of invasion by exotic species of energy crops. Furthermore, the amount of chemical and energy inputs needed to manage diverse prairie ecosystems is reduced, due to their self-sustaining nature (Fargione et al. 2009).

However, these systems must be harvested periodically in order to reduce the litter layer and encourage new growth. Without some minimal management, grasslands may produce less biomass and lose their habitat for some species. Harvesting considerations must include the height of vegetation, the timing and how it relates to seasonal needs of wildlife, and the proportional amount of plant matter harvested. Studies have shown that generally the most effective way to harvest prairie biomass is in a patchwork fashion, leaving some plots unharvested in order to be utilized by wildlife (Fargione et al. 2009).

In addition, some systems may require the employment of "stubble," the partial harvesting of tall grasses in order to leave a short covering on the ground. Both wildlife and the soil benefit from the use of stubble. Grassland ducks, for example, have a higher nest success in fields with stubble rather than bare soil. Stubble also reduces soil erosion from the wind, and helps to catch and maintain field snow cover and soil moisture, which may increase yields the following growing season (Fargione et al. 2009). However, further research is needed to determine the optimal stubble length that provides enough biomass for efficient ethanol production, yet also leaves enough grass to benefit the ecosystem.

One major problem with cellulosic ethanol is the cost associated with its production (Woodson and Jablonowski 2008). Research is currently underway to reduce the cost of the enzymes used to break down the cellulose, hemicellulose, and lignin found in the cell walls of biofuel crops. Scientists are also employing various genetic engineering techniques to produce microbes that make cheaper cell-wall-deconstructing enzymes (Sticklen 2008). If cellulosic ethanol production becomes commercially viable, it may eventually be economically competitive with gasoline, even without subsidies. Barring any further improvements upon enzymatic technology, however, cellulosic ethanol would be economically competitive with corn ethanol production as long as certain conditions are met: high corn prices, high energy costs, and high environmental damages due to climate change (Woodson and Jablonowski 2008).

Microbes and Cellulosic Ethanol Production

Numerous microorganisms naturally produce substances that are able to be exploited by the ethanol industry. Some microbes form the enzymes needed to break down cellulose, while others produce ethanol as a metabolic by-product. However, no naturally-occurring microbial species produces enough ethanol or enzymes to make either procedure industrially cost-effective. Therefore, attempts have recently been made to genetically engineer bacteria to produce the necessary chemicals at optimal levels. Progress has been slow, but it is occurring.

Enzymes

In order for biomass to be metabolized into ethanol, it must first be broken down into its sugar-based components. One method of doing so uses enzymes. Breaking down the feedstock is what makes cellulosic ethanol more complicated to produce compared to corn. Corn is comprised of starch, a polymer of glucose that is easily broken down by enzymes called amylases. Biomass, on the other hand, is composed of three different molecules: cellulose, the main component of plant cell walls, which is a complex polymer of glucose that contains strong hydrogen bonds; hemicellulose, a branched, amorphous polymer of pentoses and glucose; and lignin, a non-sugar molecule that encapsulates other polymers and provides robust structure (Demirbas 2005, Service 2007, Sticklen 2008, Woodson and Jablonowski 2008).

Biomass must first be pre-treated with extreme heat or chemicals in order to separate the cellulose and hemicellulose from lignin. This process is necessary to make the solid biomass more accessible to further degradation and digestion (Demirbas 2005). Once the lignin is separated, it can be combusted to power the ethanol plant (Woodson and Jablonowski 2008). The cellulose and hemicelluloses can then be broken down into their constituent monomers via enzymatic hydrolysis in order to be digested by ethanologenic microbes (Hill et al. 2006).

Microbes, such as certain bacteria or fungi, are used to produce the enzymes, called cellulases and hemicellulases, needed to hydrolyze the treated cellulose and hemicelluloses. Cellulases are needed to break down cellulose into glucose monomers. Currently, commercial cellulases are available, and are typically produced as a mixture of microbial enzymes. However, enzymatic hydrolysis is the most expensive portion of cellulosic ethanol production, so cheaper cellulases are needed. More work is being done to engineer microbes that produce more efficient cellulases (Woodson and Jablonowski 2008). Hemicellulases remove the hemicellulose that surrounds cellulose, so that cellulase can access it. There are no commercially available hemicellulases that are suitable for cellulosic ethanol production. Therefore, production of a viable hemicellulase is an active area of research for industrial microbiology (Sticklen 2008).

Ethanologens

One of the most ubiquitous and well-studied microbes, *Escherichia coli*, has been the focus of genetic engineering efforts. Taking a look at the process of manipulating *E. coli* is instructive because it reflects the genetic engineering issues found in many different organisms. *E. coli* naturally metabolizes pentose and hexose sugars to form mixed acids and ethanol. However, the acids (like lactic, acetic, formic and succinic) are the major product and ethanol is only a minor by-product (Service 2007, Peterson and Ingra 2008).

In order to overcome low ethanol production, different strains of *E. coli* have been developed. Strain KO11 contains two genes from the ethanologen *Zymomonas mobilis*, which metabolizes glucose (Peterson and Ingra 2008). These genes allow strain KO11 to ferment hexose and pentose into ethanol, which is the major product (Peterson and Ingra 2008). Strain KO11 produced ethanol yields of 95% in complex media (Service 2007, Peterson and Ingra 2008). However, complex media is expensive and contributes to the already-high cost of cellulosic ethanol production. Attempts to produce ethanol in mineral salts media, which is less expensive, resulted in decreased performance and ethanol yields (Peterson and Ingra 2008). Also, the "phenotypic stability" of KO11 is not yet exact, meaning that some samples produce high ethanol yields, while others fail to reach the 95% yield (Peterson and Ingra 2008). A high degree of phenotypic stability is desirable because it reduces production costs. In addition to the economic and inconsistent yield problems, strain KO11 is also intolerant to the ethanol build-up that occurs after fermentation (Peterson and Ingra 2008).

In order to overcome the low ethanol tolerance of strain KO11, *E. coli* strain LY01 was engineered for better ethanol resistance (Peterson and Ingra 2008). This strain was able to withstand brief exposures of ethanol concentrations as high as 100 g/L, but the performance and yields of strain LY01 also decreased in mineral salts media. Therefore, a new strain of *E. coli* was developed to produce ethanol in a simple mineral salts medium (Peterson and Ingra 2008). In order to do so, a derivative of strain KO11 that grew well in mineral salts media was isolated. However, this derivative, now called SZ110, produced lactic acid instead of ethanol. SZ110 was then converted to an ethanologen by using genes from *Z. mobilis*. The new strain, LY168, improves the economic viability of converting cellulose to ethanol (Peterson and Ingra 2008). A high degree of ethanol tolerance reduces the cost of production by minimizing the amount of ethanol distillation, which is an expensive process (Service 2007).

Researchers are also looking at the ethanol-producing possibilities that many other microorganisms have. For example, *Z. mobilis* has been engineered to directly produce ethanol from pentose sugars, along with the hexoses it naturally produces. Some *Z. mobilis* strains have been designed to withstand ethanol concentrations up to 10% (Service 2007). Yeast is the most prevalent microbe in corn ethanol production, because it naturally converts the glucose found in corn to ethanol in an efficient manner. However, it does not naturally metabolize the five-carbon sugars in cellulose. Genetic engineering has resulted in yeast with genes that are able to turn pentoses into ethanol (Service 2007). Additionally, some researchers are attempting to engineer yeasts that produce fermentation enzymes along with cell-wall-digesting enzymes. Utilizing one organism that could break down biomass as well as produce ethanol would lower production costs (Wood 2008).

If the obstacles to cellulosic ethanol production are never overcome, different microbes may still be utilized to produce ethanol. Aquatic microbial oxygenic photoautotrophs (AMOPs), like cyanobacteria, algae, and diatoms, efficiently harness the sun's energy and capture carbon in their biomass. The advantages AMOPs have are numerous. First, the biomass yield of native strains of AMOPs are 5.4 to 10 times greater compared to hybrid corn, and 2.5 to 10 times greater than switchgrass. These values correlate to a 6- to 12-fold increase in the amount of energy yield from AMOPs compared to terrestrial crops (Dismukes et al. 2008). Also, the cellular components of AMPOs are much simpler than those found in corn or biomass. AMOPs do not contain cellulose, hemicellulose, and lignin. Therefore it is much easier to break down the cells in order to form ethanol, which is one of the most monetarily and energetically costly steps in cellulosic ethanol production. In addition, some AMOPs form lipid storage structures. Lipids contain twice as much energy per carbon atom, which also improves the energy efficiency of AMOP ethanol (Dismukes et al. 2008).

Cellulosic Ethanol and the Implications for Nebraska

If the obstacles to affordable cellulosic ethanol are overcome, there are numerous implications for Nebraska that must be understood before implementing its full-scale production. Some are beneficial, and some may be detrimental if the proper precautions are not taken. The major areas that will be impacted are environmental and economical.

Environmental Implications

The expansion of corn ethanol production in Nebraska has impacted different areas of the environment, including wildlife, soil health, pollution, and water. In order to avoid imparting further damage, it is important to understand how these areas have been affected by corn ethanol production. The various subsidies and mandates for corn ethanol have caused an increase in the land used to grow corn, which means that there is less land available for wildlife conservation. Already, more than 850,000 hectares of grassland have been converted to corn fields in the US due to the corn ethanol boom (Fargione et al. 2009). Current analyses show that approximately 385 million to 472 million hectares of abandoned farmland around the world could be converted to biofuel prairie systems, which would provide 1.4 billion to 2.1 billion metric tons of biomass on a yearly basis (Fargione et al. 2009). Lands that are eligible for the Conservation Reserve Program (CRP) may also be allowed to harvest and sell biomass as part of a management protocol that is agreed upon in contract. Properly harvesting biomass from native prairie systems or from CRP lands would increase biodiversity and support wildlife (Fargione et al. 2009).

In addition to using native species, there are other biomass land-use options that are consistent with wildlife conservation, including using agricultural residues and cover crops which are discussed below (Fargione et al. 2009). These methods are beneficial to wildlife conservation because they use land that is already designated for agriculture. Therefore, wildlife habitat does not get converted to farmland for these types of biomass production.

The production of cellulosic ethanol may impact soil health in Nebraska. One proposed source of biomass is corn stover, the leaves and stalks left over after harvest. Using corn stover would increase ethanol production without the input of more agricultural chemicals or energy (other than harvest energy), but it would increase soil erosion while decreasing soil carbon. Fargione et al. (2009) found that 54 million metric tons of corn stover could be removed without adversely affecting erosion amounts. However, this number does not address soil carbon levels, depletion of which would increase CO_2 emissions and reduce yield. Promisingly, a balance may be achieved by utilizing no-till farming along with stover removal. However, much more research is needed in order to discover the optimal balance (Fargione et al. 2009).

It has already been determined that removing corn cobs alone would increase the amount of ethanol made per hectare by 25% without reducing soil carbon (Fargione et al. 2009). In addition, efforts are also underway to explore the feasibility of breeding corn for optimal stover quality—with higher quality, less could be taken from fields to produce the same amount of ethanol (Lewis et al. 2010). This would help alleviate concerns pertaining to soil health.

The effect of cellulosic ethanol on pollution in Nebraska would also need to be monitored. Thanks to subsidies and high corn prices, some farm land that previously rotated between nitrogen-fixing soybeans and corn crops now has only corn. This has lead to decreases in yields and increases in nutrient additions. Higher fertilizer inputs leads to greater nitrogen leaching and lowers the yield per year by 14% (Fargione et al. 2009). However, switching to cellulosic biofuels would help alleviate some of these problems. Grasslands retain soil and nutrients better than corn fields. In fact, nitrate levels leaving CRP grasslands were 98% lower than the amount leaving land continuously planted with corn in one study (Fargione et al. 2009). High nitrate concentrations in water lead to algal blooms and hypoxic dead zones.

When accounting for water inputs, corn ethanol requires an average of 147 liters of irrigation water for every liter of ethanol produced (Fargione et al. 2009). Only about 30% of this water is returned to surface and ground waters through runoff and filtration. However, corn irrigation may become more water efficient with the incorporation of new agricultural technology (e.g. the time-temperature threshold system, see Comis 2009). More research should be conducted to determine the most efficient irrigation practices if biomass that requires water inputs is grown. If cellulosic ethanol becomes wide-spread in the state, it would be advisable to immediately utilize more efficient irrigation practices when they are needed.

Economic Implications

Corn ethanol production currently brings jobs and revenue to rural Nebraska economies, and the implementation of cellulosic ethanol would be expected to expand economic opportunities in these areas. There are now 24 operating ethanol plants in Nebraska—all of them use only corn as their feedstock. A study completed by the Economic Development Department of Nebraska Public Power District (2009) found that current plants have had a positive impact on rural Nebraska economies (Table 1). In fact, corn producers who do not directly sell corn to a local ethanol plant still reap the benefits of higher corn prices that are associated with the presence of the plant (Petersan 2003). Farmers who produce corn near an ethanol plant can expect to earn \$.05 to \$.08 more per bushel of corn, even without selling it directly to the plant (Nebraska Ethanol Board). It is important to note, however, that these studies only look at corn ethanol plants. Similar trends are expected with the building of new cellulosic ethanol—or conversion of existing corn ethanol plants—to cellulosic ethanol plants (Petersan 2003).

Estimated Annual Economic Impacts Associated With the Operation of Completed Nebraska Ethanol Plants*

Increased Economic Effect on:	Direct Effects*	Total Impacts**
Total Ethanol Production	1,717 million gal.	
Economic base (Output)	$2,884.6 million	$3,051.6 million
Jobs	999	3,237
Household income	$119.7million	$213.2 million
Tax revenues	$50.9 million	$63.3 million
Retail Sales (Households)	N/A	$143.6 million
Grain prices	N/A	$0.05-0.10/bushel

* Includes the estimated direct inputs, including labor, required to produce 1,717 million gallons of ethanol.

** Includes the estimated direct and secondary (indirect and induced) economic effects associated with the operation of the 24 completed Nebraska ethanol production facilities, as of February 2009.

Table 1. Breakdown of the sectors of rural Nebraska economies that are impacted by ethanol plants. From Economic Development Department of Nebraska Public Power District (2009).

The switch to cellulosic ethanol would also provide landowners with additional opportunities to earn income. Grassland owners could utilize carbon markets to make money from the credits that would come from carbon sequestration and/or greenhouse gas emission offsets. In fact, a fully implemented cap-and-trade program would create a $2.7 billion per year global market for carbon trading, at $49 per Mg CO_2 (Liska et al. 2009). Ethanol plants and landowners would be able to tap into this additional revenue source as long as the biorefineries were efficient enough to verifiably reduce greenhouse gas emissions compared to gasoline. Grassland owners can also receive additional income by participating in the CRP-Management Access Program (CRP-MAP). This program allows Nebraskans to earn up to $5 per acre that they open to the public for hunting and trapping access during the appropriate hunting season

(NGPC 2010). As discussed previously, CRP landowners with harvesting practices in their contracts would also be able to earn additional income by selling the harvested biomass.

Conclusions

Using gasoline as a transportation fuel is exacerbating global climate change and undermining the United States' national security. Biofuels like ethanol are a secure source of energy that may reduce CO_2 emission while also bolstering rural economies. However, the mismanagement of corn ethanol since the 1970's has created environmental problems that must be avoided in the future. Although the production cost of cellulosic ethanol is still too high to make production economically viable, research into lowering those costs continues and looks promising. The eventual implementation of cellulosic ethanol has numerous environmental and economic implications for the state of Nebraska. There are several areas of further research that could contribute to the sustainability of cellulosic ethanol production before fully implementing production in Nebraska. The four major areas follow:

- *Increasing ethanol tolerance of ethanologens and reducing the cost of the media used*. The high cost of cellulosic ethanol production is the reason why it has yet to be wide-spread. Increasing the ethanol tolerance of the ethanologens will reduce the cost of production because the batches of microbes would have to be replaced less often. Engineering microbes to use a simple, cheaper medium will also lower the cost of production.
- *Optimal input-output values pertaining to perennial biofuel crop management.* Finding the best balance of chemical and energetic inputs to the amount of biomass harvested is important because it will increase the efficiency of the biofuel while lessening its contribution to pollution and energy waste.

- *Impact of biomass land use on wildlife & biodiversity: can the two coexist?* There are many options when it comes to biomass production, including land use practices that may help maintain biodiversity and conserve wildlife. However, it has yet to be seen if these forms of biomass are as efficient as their counterparts, which could be coupled with the research on biomass input-output levels.
- *Removal of corn stover: how much can and should be removed without causing soil erosion and water pollution?* Corn stover has the potential to greatly improve cellulosic ethanol yields. However, the removal of stover must be seriously studied in order to not exacerbate the problems of soil erosion, soil carbon levels, and water pollution.

Addressing these issues in a timely manner will help to prevent creating more problems than what are being solved. Ensuring that cellulosic ethanol production is sustainable will bolster Nebraska's economy and conserve the physical and biological environment for future generations.

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