

Growing America's fuel: an analysis of corn and cellulosic ethanol feasibility in the United States

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Abstract Recent excitement over ethanol in the United States has been unmatched by other alternative energy sources. To a certain extent, the mention of ethanol by President Bush in the past four State of the Union Addresses has politicized the debate and generated a high level of support for increased ethanol production in both Congress and the private sector. In December 2007, President Bush signed into law the Energy Independence and Security Act, which increased the renewable fuel standard that was mandated under the Energy Policy Act of 2005 to 36 billion gallons by 2022. “Growing fuel” has appealed to politicians, the American public, and powerful agricultural interests all for different reasons. Whether or not the large-scale ethanol production and distribution of ethanol is efficient is not easily understood. Corn-based ethanol is so heavily subsidized through federal tax credits and even state credits that its true cost is hard to determine (Gardner in *J Agric Food Ind Organ* 5:4, 2007). The high corrosiveness of ethanol and its tendency to absorb water damages existing fuel infrastructure and requires special equipment and supply chains for transportation (Rusco and Walls in *Biofuels*, petroleum refining and the shipping of motor fuels. Institute for Advanced Policy Research, Technical Paper TP-05008, 2008). Perhaps, most importantly, the agricultural availability for energy crops is intertwined closely with food crops; corn prices are influenced by the converging demands of ethanol, feed crops and human consumption. After examining the feasibility of recent goals for alternative fuels in the context of corn and cellulosic ethanol production, we are unable to validate that

corn-based ethanol is worthy of continued pursuit as a viable, comprehensive alternative to gasoline. On the other hand, we find the argument for cellulosic production more compelling due to the ubiquitous availability of amounts and variety of feedstock, combined with a high potential for far reaching and decentralized refineries. Our work indicates that a transition to advanced, cellulosic feedstocks for ethanol is absolutely necessary for increased biofuel production and reduced petroleum use to occur. However, in light of the lack of commercial availability of key components needed for cellulosic ethanol production, we conclude that the feasibility of cellulosic ethanol as a mainstream fuel will require many changes in technology and federal funding. Thus, we conclude that, in the short term, ethanol cannot meet the energy security and environmental goals of a gasoline alternative.

Keywords Corn ethanol · Cellulosic ethanol · Transportation fuel · Feedstock · Renewable fuels standard · Energy

Introduction

Domestic energy policy heretofore has been only marginally successful in identifying alternatives to petroleum as a transportation fuel. Diversifying our fuel sources, combined with increased domestic production, would help to mitigate risks against supply side disruptions and price spikes. Reducing our dependence on foreign oil coming from unstable regions of the world also would enhance U.S. national security. These factors, combined with the emerging scientific consensus on climate change, have led to policies to increase the production of ethanol and other potential biofuels.

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Broadly, biofuels can be derived from any form of biomass (known as feedstock), and can take the form of many different fuels. Two well-known biofuels currently in production include biodiesel derived from soybeans or rapeseed, and ethanol derived from corn, sugarcane or cellulosic sources. This paper focuses on the current situation involving corn ethanol and presents the result of an analysis that examined the feasibility of increasing U.S. ethanol production using only corn (which currently constitutes about 95% of the feedstock (Schnepf 2006), as well as the feasibility of utilizing cellulosic sources, which currently are not used for commercial ethanol production. Additionally, it examines the potential effectiveness of corn and cellulosic feedstocks in moving our Nation toward the goals of gasoline displacement and energy security, greenhouse gas emission reduction and environmental sustainability.

Corn ethanol production and use today

In 1970s, ethanol production in the US was encouraged in response to the oil embargoes of 1973 and 1979, and then again under the Clean Air Act Amendments of 1990 which, via the Reformulated Gasoline (RFG) program, was a major driver of the corn ethanol industry's development. Before the Energy Policy Act of 2005 (EPA 05), corn ethanol was used mainly as a gasoline additive to satisfy oxygenate requirements for RFG (Yacobucci 2007). EPA 05 boosted production further by including in the legislation a production goal—called a renewable fuel standard (RFS)—of 7.5 billion gallons by 2012.

EPA 05, combined with various state laws and incentives, already has had a major impact on ethanol demand. The ethanol production industry currently is experiencing a major boom: demand has jumped from 2.0 billion gallons in the year 2002 to 5.4 billion gallons in 2006 (Renewable Fuels Association 2007). Projected production for the 2007/2008 marketing year is 11.7 billion gallons, which would achieve the 2005 RFS mandate 4 years early (Renewable Fuels Association 2007). Production will increase even further under the Energy Independence and Security Act of 2007. The law mandates 36 billion gallons of renewable fuels by 2022, with the caveat that 21 billion gallons must be produced from non-corn feedstocks.

Despite a large growth in the industry, ethanol production is still largely concentrated within a small region of the US and among a small number of businesses. It is not surprising that the top corn-growing states in the country also are the top ethanol producers, since there are less logistical challenges in ethanol production close to the feedstock supply (Rusco and Walls 2008). Roughly 75% of

all ethanol output occurs in five states: Iowa, Nebraska, Illinois, Minnesota, and South Dakota (Yacobucci 2007).

This geographic concentration of production has resulted in a similar pattern of consumption; the majority of cars filling up on ethanol are in the metropolitan areas of the Midwest. The shipping cost of ethanol, which, due to the lack of a pipeline system, is disproportionately high when compared with gasoline, is one of the largest obstacles for expanded ethanol use on the East and West Coasts. Ethanol-blended gasoline is corrosive to the pipelines that are part of the current petroleum infrastructure and so the transport of the fuel must be by truck, rail or barge. This has contributed to increased research and development of cellulosic feedstocks, which have the potential for higher geographic variety and therefore could result in production facilities in more areas of the US than just the Midwest.

Historically, ethanol production has been concentrated among a few large producers. While production concentration has declined in recent years, critics still argue that, in this context, tax incentives for ethanol production are equivalent to “corporate welfare” for a small number of companies (Hymel 2002). In 2006, the top ten corn ethanol production companies accounted for about 46% of the total output, but production among the top ten is not equally distributed (Renewable Fuels Association 2007). The top producer, Archer Daniels Midland, produces approximately 1.07 billion gallons per year, over four times the capacity of the second company in line, BioEnergy Corporation (Renewable Fuels Association 2007). Despite this, the Federal Trade Commission found this concentration to be on the decline and concluded that the current market structure would not result in power for a small group of firms to manipulate prices (Federal Trade Commission 2006).

The reality of a corn ethanol RFS

President Obama has not outlined a detailed plan for the future of ethanol. A plan to invest \$150 billion to reduce our dependency on foreign oil is available on the White House website. His predecessor was more specific. In his 2007 State of the Union Address, President Bush called for a reduction in gasoline consumption by 20% in 10 years. As part of accomplishing this goal, the former President proposed increasing the current RFS to 35 billion gallons by 2017. This increase would account for 75% of the 20% gasoline reduction goal. In order to achieve this goal, ethanol would need to be relied on heavily and critics point out that with only corn ethanol, it would be difficult. In order to meet this increase, alternative sources of biofuel would need to be tapped into. Two alternative fuels, cellulosic ethanol and biobutanol, might help bridge the gap

but neither have commercial production nor are expected to be produced commercially for 10 years (Pimentel and Patzek 2005; Miller 2007).

U.S. ethanol production used about 17% of the domestic corn crop in 2006 (Yacobucci and Schnepf 2007). If only corn ethanol were used in the expansion of the RFS called for by President Bush, it would require more corn than the US currently grows. Converting more cropland to corn, and shifting corn utilization to ethanol and away from other uses, would have severe consequences for other agricultural markets, livestock, food prices and land.

In terms of actual cropland, in 2006 an estimated 71 million acres of corn were harvested for all uses. This is on the larger end of historical corn crop production. Since 1950, the U.S. corn-harvest acreage has never reached 76 million acres (Yacobucci and Schnepf 2007). In order to substitute for roughly 20% of our petroleum imports, the US would require a staggering 137 million acres of corn cropland to produce approximately 56.4 billion gallons of ethanol (Yacobucci and Schnepf 2007). These data demonstrate that generating enough ethanol to run our automotive fleet is unlikely.

Corn ethanol as a gasoline substitute

About 99% of the corn ethanol consumed in the US is in the form of “gasohol,” a term for gasoline blended with 10% ethanol (also known as E-10). Only 1% is consumed as E-85 (USEIA 2009). In total, the combination of the two substituted for just 3.6% of 2006 gasoline consumption, which was approximately 141 billion gallons (USEIA 2009).

There are several major reasons why more E-85 is not being consumed. One reason concerns pricing. Even with tax incentives, ethanol is more expensive than gasoline on a per gallon basis, although the current tax incentive of 51 cents per gallon puts ethanol approximately on a par with gasoline (Chicago Board of Trade 2007). Additionally, ethanol has a lower energy content per gallon than gasoline, meaning that vehicles running on E-85 (and E-10, to some extent) need to be refueled significantly more often than is the case with conventional fuel. Thirdly, E-85 can only be used in vehicles specifically designed to run on it. These vehicles are commonly referred to as “flexible fuel vehicles,” because they can run on pure gasoline or E-85. Compared to traditionally fueled vehicles, there are relatively few flex-fuel vehicles being manufactured, and even fewer that actually run on E-85. The National Ethanol Vehicle Coalition (2009) estimates that there are approximately six million flex-fuel vehicles on the road, when compared with over 200 million cars and trucks that can run only on gasoline or diesel. Furthermore, of the six

million flex-fuel vehicles, only about 2.5% actually run on E-85 (USEIA 2009). One reason for such a low consumption rate of E-85 by flex-fuel vehicles is a lack of availability of E-85 pumping stations. In 2006 there only 556 E-85 stations were operating across the country, as compared with 120,000 gasoline stations; 65% of these were located in the top five ethanol-producing states of Iowa, Nebraska, Illinois, Minnesota, and South Dakota (Yacobucci and Schnepf 2007). Currently 1991 E-85 stations are now available with only 40% of them in the top five ethanol-producing states (National Ethanol Vehicle Coalition 2009); indicating improved distribution outside of these areas. However, 66% of the stations remain in the Midwest. And while the number of E-85 stations has tripled nationwide, it represents only 0.016% of all pumping stations, a slight increase from the 0.005% available in 2006 (National Ethanol Vehicle Coalition 2009).

Moving forward with cellulosic

Corn ethanol infrastructure, most importantly a pipeline system for transportation, must be further developed before ethanol can ever begin to make a serious dent in our gasoline consumption. Even after that happens, the amount of gasoline displaced will still be seriously hindered by the availability land for corn crops. As mentioned earlier, a 20% displacement of gasoline by corn ethanol only is largely infeasible, and even if the total 2006 corn crop (10.5 billion bushels) were dedicated to ethanol production the result would replace only about 13.4% of the estimated 2006 gasoline consumption of 141 billion gallons (Yacobucci and Schnepf 2007). Thus, it is clear that transition to advanced, cellulosic feedstocks for ethanol is absolutely necessary for increased biofuel production and consequent reduced petroleum use.

Cellulosic ethanol is an alternative fuel that is derived from cellulose instead of starch. Cellulose is the most common organic compound on earth; therefore, there is much excitement that energy can be derived from it in the form of a liquid fuel. Cellulose is found in non-food plant material such as agricultural wastes, wood chips or dedicated energy crops such as switchgrass and other prairie grasses (Lin and Tanaka 2006).

Cellulosic ethanol is considered a “second-generation biofuel,” which means that a wide range of materials, including waste, can be used in its production. Because a large variety of materials can be used, cellulosic ethanol can be produced almost anywhere, offering the potential to overcome the problem of centralized corn ethanol production in the Midwest. In addition, cellulosic ethanol may offer better engine performance (Yacobucci and Schnepf 2007). Because of the higher energy content of cellulosic

feedstocks vis-à-vis corn feedstocks, producing cellulosic ethanol requires less cropland than corn for equivalent amounts of energy (Righelato and Spracklen 2007). Finally, when commercialized, the cost of second-generation biofuels have the potential to be price competitive with gasoline and diesel, making them possibly the most cost-effective future route to renewable, low-carbon energy for vehicle transport (Greene 2004). Supporters promote cellulosic feedstock production as a carbon sink. Whether or not greenhouse gas emissions are reduced is unclear. Lynd (2006) offers support in this regard while Searchinger (2008) argues the use of croplands for biofuels increases greenhouse gases through emissions from land-use changes.

Barriers to cellulosic ethanol production

The nation's demand for biofuels currently is met primarily with the conversion of corn to ethanol. Despite the promising qualities of cellulosic ethanol, at the present time no commercial refineries or demonstration plants for cellulosic feedstocks are up and running in the United States. (There is one cellulosic ethanol demonstration plant in Canada.) While Greene (2004) estimated the price of cellulosic ethanol to be as low as \$0.59–\$0.91 per gallon by 2012 (assuming mature technology), refining and production costs are still holding back output. Cellulosic production costs are significantly higher than that of corn ethanol and other alternative fuels, mainly due to the fact that existing refining processes are very expensive and involve many steps. McAloon et al. (2000) have shown the steps involved to break down the material to a fermentable stage are estimated to cause about a 70% increase in production costs compared with corn ethanol.

Like ethanol derived from corn, cellulosic feedstock faces the obstacles of land availability, transport and adequacy as a gasoline substitute. On the other hand, the US has a higher capacity for cellulosic ethanol than corn ethanol according to the Government Accountability Office (2007). However, despite this edge on corn, the availability of consistent cellulosic feedstock remains in question. For example, the USDA recently predicted an upper range of production at around 1.3 billion tons of cellulosic biomass (Bailey 2007). Long term, this would still not be enough to completely substitute for our gasoline demand; 1.3 billion tons would produce enough ethanol to replace a little over 30% of our projected petroleum consumption in 2030 (Perlack et al. 2005).

All types of ethanol are more corrosive than gasoline and are therefore more difficult to distribute. On top of the added production costs, cellulosic ethanol requires storage in specialized tanks that cost around \$100,000 each

(McAloon et al. 2000). On the other hand, the issue of transport for cellulosic feedstocks is not as large as it is for corn, due to the fact that cellulosic production in more regions of the country is possible, thus reducing shipment costs. Since no cellulosic ethanol is on the market at the present time, their extent of technological challenge that extensive use of cellulosic ethanol would pose to auto manufacturing is not clear. It is possible, for example, that even current flex-fuel vehicles designed to run on corn-based E-85 may need to be retrofitted to run on a cellulosic blends.

Current funding and legislation for cellulosic advancement

While significant cost and technology barriers exist, government, academia and business interests involved in the renewable fuel industry all recognize the necessity of bringing cellulosic feedstocks into production. In recent years, there have been several large pushes for increased funding into cellulosic R&D to bring refinery technology up to speed.

In his January 2007 State of the Union address, President Bush called for \$2 billion to build cellulosic ethanol plants to compliment his goal of 35 billion gallons of annual alternative fuel use by 2017. To begin implementation of the Administration's plan, the Department of Energy in February 2007 announced a \$385 million program for cellulosic demonstration plants in six states (Kansas, Florida, California, South Dakota, Virginia, and Colorado). Under the program, six companies were slated to receive federal funding through fiscal year 2010 to convert a variety of biomass types into cellulosic ethanol. Combined with an industry cost share, as much as \$1.2 billion will be invested in the six biorefineries for cellulosic production (Department of Energy 2007).

Recognizing the potential superior performance and sustainability of cellulosic ethanol production, Congress mandated that 21 billion gallons of the 2007 RFS must come from advanced feedstocks. This represents significant progress toward a cellulosic ethanol mandate that likely will spur innovation as producers approach the 15 billion gallon corn ethanol limit. Additionally, substantial cooperation between the government and academia to continue research into second-generation fuels is evident. Lave et al. (2006) agree that ethanol is needed in order to keep national gasoline consumption from rising. The USDA and several land grant universities have partnered in the Sun Grant Initiative, which is founded on the assumption that agriculture can reduce our oil dependence through biofuel production.

Ensuring no food competition

Riots in Mexico over tortilla price rises drew attention to the impact of ethanol production on food prices. Recent global food shortages have further vilified energy crops and led some to second guess the government's enthusiastic policy toward biofuels and such an aggressive RFS. Although corn ethanol is the most obvious food crop competitor, the problem cannot be solved by completely growing other energy crops. Ethanol production can cause food prices to rise (Fales et al. 2007); for example, acreage dedicated to growing switchgrass is acreage not dedicated to growing food. Ethanol can be harvested from oil produced by algae, while very expensive, it can be done on non-agricultural lands and lands with saline soils, which would not create competition with agriculture (Briggs 2008). Until we expand agricultural lands or increase productivity per acre, we may see food prices rise regardless of whether we make ethanol from corn or from cellulosic materials. The best way to avoid the food versus fuel problem is to convert bagasse, or non-food material, into ethanol. Fortunately, this can be accomplished by separating the cellulose molecules from lignin, the sticky substance that holds the plant together. The feedstock (biomass) is heated and treated with enzymes, producing a material similar to molasses. This material is then introduced to yeast and distilled, yielding ethanol. This process converts 45% of the biomass energy into ethanol (Farrell et al. 2006). Since crude oil production can convert close to 85% of the biomass energy into usable fuel, the current method of cellulosic ethanol production will have to be improved to become competitive with gasoline on that production criterion.

One alternative is to gasify biomass, pass it over a catalyst, then turn it into liquid ethanol. According to Philips et al. (2007) of the National Renewable Energy Laboratory, cellulosic ethanol produced in this way could become competitive with corn ethanol by 2012. Biomass gasification involves cutting and drying a feedstock, like corn stover or poplar wood. The material is put into a gasifier unit where it is converted into carbon monoxide, hydrogen, methane and carbon dioxide. The gas is filtered and then passed over a catalyst such as platinum or molybdenum. The gas is converted into methanol, alcohol and ethanol liquids, which are then separated. The methanol can be cycled back into the system for reuse while the ethanol and alcohol are end products. The Energy Information Administration (2007) indicates that the cost of the catalyst as a major drawback to this method. Philips et al. (2007) believe gasification might be cost competitive with ethanol by 2012 but that commercial production would not occur until 2030.

While there are many high hopes for cellulosic ethanol, so far this biofuel has yet to deliver. The best strategy to increase cellulosic production is the continuance of substantial R&D programs such as the Department of Energy's current \$385 million grant program. Federal grant money, combined with effective legislation that recognizes the differences among corn ethanol and advanced feedstocks (such as the 2007 energy bill RFS), along with financial initiatives to encourage production and protect private investment, is needed to spur the commercialization of this fuel.

Corn versus cellulosic: impacts on the climate and environment

As the US moves forward toward a new energy future, it is critically important that policies to increase energy security and reduce oil consumption also address the urgent problem of global climate change by reducing greenhouse gas emissions. At the same time, it is important to analyze the environmental impacts of an RFS on sensitive lands. The 2007 RFS recognizes the pressures that a large increase in crop production could have on farms, forests, and protected lands, and so includes some safeguards to minimize environmental harm.

Intuitively, using ethanol and other biofuels as transportation fuels seems preferable from an environmental standpoint to burning non-renewable fossil fuels. The question is whether the impact of production and combustion biofuels is less than that of petroleum-based fuels. Our work indicates that, by evaluating environmental costs and benefits early on, we can work toward producing ethanol in a sustainable way that will have positive returns for both the economy and the environment.

While it generally is accepted that, when compared with corn, cellulosic feedstocks have better energy conversion ratios (Appendix), cause reduced CO₂ emissions, and create less damaging land and water impacts, a debate has surfaced over the net energy benefits of ethanol as a substitute for gasoline in transportation fuels. For scientists such as Dr. Michael Wang of Argonne National Labs, energy balance value alone, even if negative (meaning more energy goes into production than comes out), is not necessarily meaningful in evaluating the benefit of ethanol or any other energy product. Wang (2005) suggests that a product's energy balance must be compared with that of the product it replaces for proper evaluation. On the other hand, Pimentel (2007) argues conversely that net energy is a critical calculation and if the equation comes out negative, the energy source should be ruled out. For its part, the USDA says that ethanol yields a net energy gain (Bailey 2007).

In evaluating the energy balance of a fuel, it is important to analyze all inputs and all processes involved in the production process. These include things like transportation and distribution, farm equipment operation, and the energy needed to produce fertilizers. There have been numerous studies on the net energy yield of corn ethanol, some finding a negative yield and others a positive yield. Farrell et al. (2006) found that corn-based ethanol does have a slight positive yield. The studies that reported a negative energy yield failed to account for the co-products of ethanol that have economic value and can replace other products on the market that would require energy to manufacture (Farrell et al. 2006).

There is less controversy surrounding cellulosic energy conversion ratios. A fuel-cycle study by Argonne National Laboratory, for example, found that relative to gasoline, a cellulose-based version of E85 could reduce fossil fuel energy consumption by as much as 70% per mile (Wang et al. 1999). Similarly, there is almost no debate around biodiesel, which has been accepted as net energy positive, even by the loudest critics of biofuels. The reason is due mainly to the natural ability of soybeans to fix nitrogen. Pimentel et al. (2002) indicate that the costliest input to corn-based ethanol production is nitrogen fertilizer. Soybeans can be grown without this input and also leave the soil nitrogen rich, which is beneficial to follow on crops the next season (Bailey 2007).

Another major concern involves greenhouse gas emissions. In evaluating this critical factor, it is essential that a lifecycle analysis be used. Wang et al. (1999) and Farrell et al. (2006) report varying results for real emission benefits of corn ethanol, ranging from about 10–20% reductions compared with gasoline (based on a blend of E85). In contrast to corn feedstock, Demirbas (2005) found that, if used at 100% concentrations, second-generation biofuels could reduce well-to-wheels CO₂ emissions by up to 90%. Searchinger (2008) argues this is not the case at and that land-use changes to accommodate fuel crops will increase emissions. Included in the 2007 RFS is a guarantee that positive results for the climate will come along with increased ethanol use. Under the law, conventional biofuels (corn ethanol) must generate 20% fewer greenhouse gases than gasoline and cellulosic fuels must generate 60% less. These targets account for the full lifecycle impacts of biofuels production, including land conversion.

Land conversion is an important factor to include in lifecycle analysis because crops and soils have the ability to sequester and store carbon. Therefore, land-use changes and harvesting techniques also must be considered when evaluating emissions. Any changes from forestland into crop land for fuels will mean a sharp rise in emissions. In fact, a recent study found that, if carbon emission mitigation were the only goal, restoring forests and continuing the

use of gasoline as a primary transportation fuel would be more effective than substituting gasoline with biofuels. In other words, the carbon sequestered by restoring (and conserving) forests is greater than carbon emissions that could be avoided by the use of both cellulosic and corn feedstock (Righelato and Spracklen 2007).

No matter which crop is grown, there is a sizable potential for adverse impacts on land such as soil erosion, increased water use for irrigation and habitat degradation. Some of the worst environmental impacts can be mitigated by safeguards put in place at the time of an ethanol mandate. For example, crop rotations can increase natural soil nutrients and decrease the need for fertilizers. This would lower energy inputs while also reducing harmful agricultural run-off. The Natural Resource Defense Council worked to improve the 2007 RFS by recommending inclusion of “no grow areas” in the legislation. By including this provision, the RFS increases crop production while also protecting fragile ecosystems and marginal areas, wetlands, forests and habitat preserves, and establishing buffer zones for stream and river beds to protect watersheds.

Cellulosic feedstocks provide a conflicting message regarding environmental values. Exploiting the cellulose in corn plants, instead of only the kernels, could in theory double the yield, according to some USDA and DOE studies. But removal of cellulosic material from corn fields resulted in yield declines in years to come (Varvel et al. 2008) and increased the amount of necessary cropland and fertilizers used for continued corn production. Reducing or eliminating chemical fertilizers reduces the largest energy input for corn-based ethanol production (Yacobucci and Schnepf 2007). The production of cellulosic ethanol may have a deleterious effect on corn-based ethanol production and provides another example of why the feasibility of efficient ethanol production on a wide scale is even harder to determine.

Conclusion

Through an analysis of the literature, we have found that the President’s goals as outlined in the 2007 State of the Union address for expanding our renewable fuel use to 35 billion gallons by 2017 are unattainable by using today’s ethanol production practices. Attempting to reduce our gasoline consumption via ethanol only would require an enormous shift in agricultural production and land use, and could greatly impair fresh water supplies and soil resources. Concerns surrounding sufficient ethanol production needed to displace gasoline, including the myriad challenges in distributing it, resultant marginal greenhouse gas reductions, lack of price competitiveness without subsidies,

and controversial net energy gains, appear to make such a goal unattainable.

In summary, while ethanol, particularly cellulosic ethanol, offers the promise to be a significant component of our energy future, it fails the litmus test as a panacea to our energy problems for a range of reasons: (1) the production of ethanol places an enormous strain on agricultural production and land use, depletes fresh water supplies and soil resources, (2) distribution of ethanol is hampered by a high level of corrosiveness that damages existing infrastructure, (3) without subsidies, ethanol costs more to produce than gasoline, (4) there is a strong body of conflicting data with regard to its net energy output, and (5) ethanol's potential contribution to greenhouse gas impacts are debatable.

Cellulosic ethanol may be able to help meet the President's goals, but breakthroughs must be made. Most importantly, ethanol's commercial distribution obstacles should be addressed. The principal factors making ethanol an interesting possibility is the ubiquitous amounts and variety of feedstock with the potential for refineries to be developed in many areas of the country.

Reducing our gasoline consumption will need to be met through conservation and a range of substitutes, in addition to ethanol. Ethanol is an important fuel additive for air quality control and as a replacement to other gasoline alternatives. It does not appear, however, to be a feasible gasoline replacement on its own.

Corn-based ethanol under current conditions will only be able to replace about 10% of today's gasoline demand (Miller 2007). The discussion when expanded into cellulosic shows some promise, but tangible results are still far down the road and are unlikely to contribute to the short-term goals of the President without significant technological breakthroughs. While the USDA remains optimistic about the role of ethanol in our energy future, that agency's judgment appears to be influenced by its mission is to support and promote the rural economy of America, as contrasted with making America energy independent. Our Nation is in need of a cheap and effective transportation fuel other than gasoline, and it does not appear that ethanol will be the sole replacement.

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Appendix

It is generally accepted that, when compared with corn, cellulosic feedstocks have better energy conversion ratios (Table 1), cause reduced CO₂ emissions, and create less damaging land and water impacts.

Table 1 Comparison of various ethanol types and gasoline

	Corn ethanol	Cane ethanol	Gasoline	Cellulosic ethanol
Energy output	8	1.3	1	2–36
CO ₂ emission	16.2 lbs/gal	9 lbs/gal	20.4 lbs/gal	1.9 lbs/gal
US Consumer price	\$2.62/gal	\$2.92/gal	\$3.97/gal	Unavailable
	Gasoline equivalent \$3.71/gal	Gasoline equivalent \$3.88/gal		
US production price	w/subsidies \$1.09/gal w/out subsidies \$7.88/gal	Unavailable, not in commercial production domestically	\$1.25/gal	Unavailable, not in commercial production domestically
Percentage of US auto fuel	3%	<1%	97%	<1%
US production (gallons)	4.8 billion, should peak at 9 billion	None, Brazil production is about 4 billion	3.2 billion	Zero, could peak at 60 billion
Ignition temp	High	High	Lower	High
Water use in production	Growth of corn, refining diesel for tractors	Growth of cane	Refining of crude	Varies greatly
Production per acre	400 gallons	660 gallons	N/A	1,000 gallons

Table sources: Worldwatch Institute, US DOE–EIA, US EPA

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