A Review: Comprehensive Comparison of Corn-Based & Cellulosic-Based Ethanol as a Biofuel Source

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ABSTRACT

In order to examine the net benefits of corn-based ethanol compared to cellulosic-based ethanol, a comprehensive study was conducted utilizing a wide collection of independent studies. The investigation included energy inputs from farming, harvesting, production and all other major outputs. Through analysis, it was determined that cellulosic-based ethanol far exceeds corn in energy balance, pollution reduction, and farm availability. The benefits of corn-based ethanol do not seem to be sufficient to warrant its widespread use, particularly when its negative impacts are considered.

Keywords: ethanol, cellulosic, corn, net energy ratio, cropland

1 INTRODUCTION

In the next 20 years, it is anticipated that the energy use in the world will increase by 57% with the U.S. leading in the consumption of fossil fuels [1]. A growing concern over global warming and climate change in the scientific community has motivated research into renewable energy as 11 out of the past 12 years have been recorded as the hottest since 1850, when instrumental records became available. Corn-based ethanol is currently the leading crop choice for ethanol fuels in the transportation sector despite growing questions over its potential harm to the environment and its great use of fertilizers and water. The net energy gain of corn-based ethanol has also been debated. The purpose of this study is to synthesize the state of the art with regard to the benefits and costs of corn-based ethanol by a side-by-side comparison with cellulosic ethanol and thereby resolve the debate over whether corn-based ethanol should be used as a widespread replacement for oil-based transportation fuel.

2 ENERGY ANALYSIS

The following three metrics are used in this paper to evaluate the potential to replace fossil fuels with ethanol fuels.

1. The net energy ratio (energy input/energy output)
2. The net energy benefit (energy output-energy input)
3. The amount of land required to replace traditional fuels in the U.S. with biofuels

In addition, comments will be made on the potential for either corn ethanol or cellulosic ethanol to reduce greenhouse gas emissions.

3 CORN-BASED ETHANOL

The first study to be considered here was conducted in the U.S. and Brazil in a comparison between corn-based ethanol (U.S.) and sugarcane ethanol (Brazil) [2]. Table 1 shows the results for the total energy inputs (harvesting and production), the net energy ratio, and the required percentage of U.S. farmland to replace petroleum fuels with corn ethanol. The net energy ratio is recorded as 1.1; so that 1 unit of invested energy results in 1.1 unit of harvested energy. This source also estimated that the required corn cropland to replace petroleum as a transportation fuel would have to increase by 600 percent and all cultivated corn would have to be dedicated to ethanol production. The conclusion of the authors is that it would be very difficult to replace petroleum fuels with corn ethanol due to the small energy yield and the unreasonable amount of land required to grow the corn. In addition, [2] mention the dangers of soil erosion, depletion of minerals and water requirements. Taken together, the results from [2] are not positive with regard to the potential of corn-based ethanol as a transportation fuel substitute.

Total Energy Input	**65.02 (GJ/ha)**
Net Energy Ratio	**1.1**
% cropland required	**600**

Table 1: Metrics summary [2]

The next study was very detailed in the recording and analysis of all energy inputs and outputs for corn ethanol production. The authors of [3] used current farming technology in their comparison of corn-based ethanol and biodiesel made from soybeans. As seen in Table 2, only a 6 percent increase in energy was reported for corn-based ethanol. This energy yield increased to 28 percent when the co-products (husks, stalks, refuge) of corn were added to the process. Concurrently, [3] concluded that an increase of 833 percent in corn cropland would be necessary to replace petroleum fuels for transportation. Due to the infeasibility of full-scale corn ethanol production, the limited energy gain, and the small improvements on environmental impacts, the authors declared corn ethanol as a non-viable option. On the other hand, they promoted further analysis and investigations into cellulosic ethanol.

Total energy req.	**0.94MJ/MJ ethanol**
Net Energy Ratio	**1.06**
Net Energy Ratio (including co-products)	**1.28**
% cropland required	**833**

Table 2: Metrics summary [3]

In the following study [4], a very detailed analysis of corn-ethanol production was conducted investigating the major production stages using thermodynamic analysis. The work included fertilizer inputs, farming techniques, the ages of the processing plants and the geographical characteristics of different regions. In addition, the author compared the independent works of others with his own. Again, this author concluded that corn-based ethanol is not a viable fuel source. Key results from the study are shown in Table 3 that indicates one of the most unfavorable calculations for an energy ratio with no energy gain from corn ethanol production. The degree of large government subsidies and the local environmental problems caused by the plants is another incentive against corn ethanol that is discussed as well. The author further concludes that corn-based ethanol increases emissions to the environment and is, therefore, not an attractive alternative to oil-based fuels.

Total Energy Input	**80 (GJ/ha)**
Net Energy Ratio	**0.93**
% cropland required	**~900**

Table 3: Metrics summary [4]

In Table 4, the results of a fourth study are shown [5]. Year-to-year crop yields and the geographic characteristics on the yields and energy inputs were analyzed. The analysis covered a nine-state region with two key results; one energy ratio including co-products and one without. The higher number of 1.34 for a net energy ratio is also influenced by the sophistication and efficiency of the machinery used in ethanol production. Yet despite this factor, the amount of cropland required is still too great to accommodate corn-based ethanol production.

Total Energy Input	**77238 (Btu/gal)**
Net Energy Ratio	**1.08**
Net Energy Ratio (including co-products)	**1.34**
% cropland required	**~720**

Table 4: Metrics summary [5]

The final investigations that focused on corn-based ethanol are those of Pimentel. This author completed a series of studies, the most recent of which is utilized in the present investigation. The studies set forth by Pimentel are set apart from those previously discussed. In these articles, the author includes all the energy required that goes into constructing the refining plants and farm machinery. Although these are large one-time costs to the production process, they still have a strong impact on the total energy yield and ratio. Overall, the production of corn-based ethanol is declared an energy-loosing process, with one of the largest approximations for the percentage of cropland required to replace petroleum fuels.

Total Energy inputs	**85 (GJ/ha)**
Net Energy Ratio	**0.88**
% cropland required	**2018.18**

Table 5: Metrics summary [6, 7]

An overview of all the collected data shows a strong consensus that corn-ethanol yields only a slight increase or decrease in energy. The potential for an increase in greenhouse gases poses a threat to the environment as well, serving as one more reason to avoid corn. Finally, all sources agree that there is not enough cropland in the U.S. to grow the required quantity of corn that would be needed to displace petroleum fuels in the transportation sector. At best, corn-based ethanol could be used to replace a small portion of oil-based transportation fuels.

4 CELLULOSIC-BASED ETHANOL

The potential for low-impact perennial crops as an ethanol source has received increasing interest in the nation. These crops include, but are not limited to; switchgrass, poplars, forestry residuals and other lignocellulosic sources. These crops are considered low-impact because they require far less farming inputs and less water compared to corn and can be grown on marginal farmland.

Based on data taken from large-scale plots on ten farms throughout the U.S., the reported results in [8] detailed the energy yields, benefits and emission reduction for cellulosic-based ethanol. There are two prominent differences when comparing this study with those from corn ethanol. The total energy input for the production of cellulose is significantly lower than the values for corn.

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This means a greater return, which can be seen in the Table 6. There, it is seen that the energy gain from the system is 540 percent, which is significantly larger than that for corn. The only factor that has not changed is the required percentage of cropland to replace petroleum fuels. Another benefit to the process is that carbon dioxide emissions from the production and combustion of cellulosics were reduced by 94 percent compared to the equivalent use of oil-based fuels

Total Energy Input	**5.2 (GJ/ha)**
Net Energy Ratio	**5.40**
% cropland required	**800**

Table 6: Metrics summary [8]

Finally, the investigation of [9] considered here produced several key comparisons between cellulose and corn. Based on these values, perennial farming is seen to be much more effective and beneficial than farming corn for fuel. As mentioned previously, the net energy ratio for cellulosic-based ethanol is much higher than that for corn ethanol. Cellulosic ethanols also require far fewer energy inputs due to its ease and success growing on marginal cropland. Another important characteristic that is worth mentioning is the reduction in carbon dioxide for both plants. Considering the growing danger of global warming and the efforts being made to reduce the greenhouse gases in the world, this must be considered a very important factor. The reason for the larger cropland requirement is easily explained as a handicap the other studies did not include. This analysis included the energy required to support all of the farming operations that go into the production of the ethanol. Essentially, the extra farmland indicated in Table 7 is required to provide the fuel for the machines harvesting the biomass materials.

	Corn	**Perennials**
Net Energy inputs (GJ/ha)	**75**	**5**
Net Energy Ratio	**1.25**	**5.44**
CO_2 reductions (kg CO_2/ha)	**1000**	**6000**
% cropland required to displace all petroleum fuels	**1325**	**1410**

Table 7: Energy budget for ethanol production [9]

A very recent article [10] looks at the health risks and costs associated with biofuel and gasoline corn production, which confirms the findings of this study. The study of [10] analyzed data from numerous potential heat sources, but for the purpose of this paper only corn ethanol, cellulosic ethanol from switchgrass and diverse prairie grasses will be discussed. The paper found that corn ethanol has a higher cost for toxic and dangerous GHG and particle emissions compared to cellulosic ethanol and gasoline. This is true regardless of the heat source used in production. Likewise, in all cases of emission sequestering, cellulosic ethanol had the lowest costs for GHG and particle emissions. Based on this analysis, corn-based ethanol inflicts the greatest financial burden on the nation's economy. In addition, cellulosic ethanol required fewer inputs compared to corn.

5 CONCLUSION

Increased demand and a decreasing supply of non-renewable energies guarantees the need for alternatives sources of transportation fuel. "In 2007, petroleum products accounted for >95% of U.S. transportation energy" [10]. Corn-based ethanol has been the leading U.S. biofuel source for many years with cellulosic-ethanol recently being seen as another viable source. Through a comparison of cellulosic- and corn-based ethanol, two important outcomes were the goals of this paper.

1. Investigate the development of a renewable energy source.
2. Determine the potential of biofuel production with regard to emissions and energy gain.

In all the investigations considered here, there is a consensus that the benefits from corn-based ethanol are minimal at best with a trace impact on emission reduction and energy gain. However, cellulosic-based ethanol has greater potential as a clean fuel source for the transportation sector. There was a mutual agreement among researchers of cellulosic ethanol that not only is the net energy gain much greater than corn, but the emission reduction could significantly reduce the levels of greenhouse gases. In addition, there are current articles and journals that continue to be published which only enhance and supplement the results from the studies presented in this paper.

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