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Life Cycle Analysis for a Technical, Environmental, and Economic Comparison between Corn and Shale Gas Ethanol

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Biogenic ethanol from corn has proven effective as an oxygenate that improves gasoline engine performance. However, the US Renewable Fuel Portfolio legislation was written before shale gas became a huge technically recoverable resource in the US. This work investigates tapping this large methane resource as an alternative to biogenic ethanol. Recent technological advances have enabled inexpensive production of natural gas from shale that could be used for ethanol production instead of corn. This research compares these two options from several perspectives. Ethanol from corn is controversial because corn is a fundamental source for both human ingestion and as animal feed. As such, the ultimate objective has been to develop technologies for cellulosic ethanol produced from the plant residual biomass instead of the fruit or grains from the plant. However, so far these new technologies result in a much more expensive biofuel. Without cost-effective cellulosic ethanol, the amount of ethanol production is limited. The abundance of natural gas from shale could offer an alternative feedstock for ethanol production. Recent drops in natural gas price only improve the competitiveness of ethanol from natural gas over biofuels. In the current work, a comparison between two synthesis routes for fuel ethanol was conducted. The first route is the process chain using corn as the feedstock. The second is an alternative processing route using shale gas as the feedstock. The method applied is a life cycle comparison considering each of the following four environmental elements: water, atmosphere, land, and energy. While there are important impacts related to the interaction of these elements, this research will mainly focus on each element in segregation. The comparison shows that shale gas could be competitive to corn as feedstock for ethanol production. The results provide valuable arguments and tools for political discussions and decision making that could be useful for future energy policy development.

1. Introduction

This research was based on an idea to use the surplus in shale gas, and to examine the viability of another ethanol pathway. The motivation lies in the changes in the economy and the environment; for example; in 2012 there was a big percentage of oil imports in the US about 320 M barrels, and oil price was over $100 USD/barrel. The shale gas boom started and now the country has a shale gas surplus, this led to a reduction in imports of 20 M barrels in comparison to 2012 and lower oil prices that stay in an average of $50 USD/barrel nowadays. The greenhouse gas emissions were a concern in 2012 and still a concern today, the Renewable Fuel Standard (RFS) May 2015 rule, creates incentives for E85 and E15 (E 85 is the blend of 85 % ethanol and 15 % gasoline). The controversy around food versus fuel continues in the US and around the globe because of the usage of millions of acres for fuel crops instead of food supply.

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2. Methodology

The methodology used was a Life Cycle Analysis (LCA) where authors considered four components: 1. Water, 2. Atmosphere, 3. Land and 4. Energy implications. The first step was a literature review, consecutively Aspen Plus V8.8 was used to simulate both processes. The life cycle was applied for each of the components and the boundaries for the system were defined. The data obtained from the simulation was used for calculations of each component.

3. Ethanol Production Process

In this section, the methods considered in this study to produce ethanol from corn and ethanol from shale gas are described.

3.1 Ethanol from Corn

The first process is ethanol from corn, and the main two sub processes are wet mill and dry grind or dry mill. The main difference in these two sub processes, as its name entails, is that wet mill uses water in the first step, and the dry grind uses corn in a dry form. The dry grind over the wet mill was selected due to the fact that most ethanol plants in the United States, about 88 % (Wood, 2014), use this method, and it also requires less capital investment, and less workforce to operate the plant.

This process is designed to obtain the maximum amount of ethanol according to (Bothast and Schlicher, 2005). The operating conditions were based on (Mosier and Ileleji, 2012), characteristics such as enzymes quantity and quality were obtained from (Chaplin, 2014), and the process for the main stages were based on (Kwiatkowski et al., 2006).

The whole process can be divided into six main stages. The first one is milling, where the corn grains are milled, then mixed with water and enzymes. Second, liquefaction; the mixture is cooked, adding enzymes. The third step is saccharification where the slurry is cooled down, and more enzymes are added to break down the glucose. The fermentation stage is to let the glucose converts into ethanol by adding yeast. The fifth one is where the components are separated by evaporation, and it is called purification. The last step is Dried Distillers Grains with Soluble (DDGS) separation and drying, here the solids are separated using centrifugation and the drying process occurs through an evaporator. Figure 1, shows the simulation results from Aspen for the dry mill process.

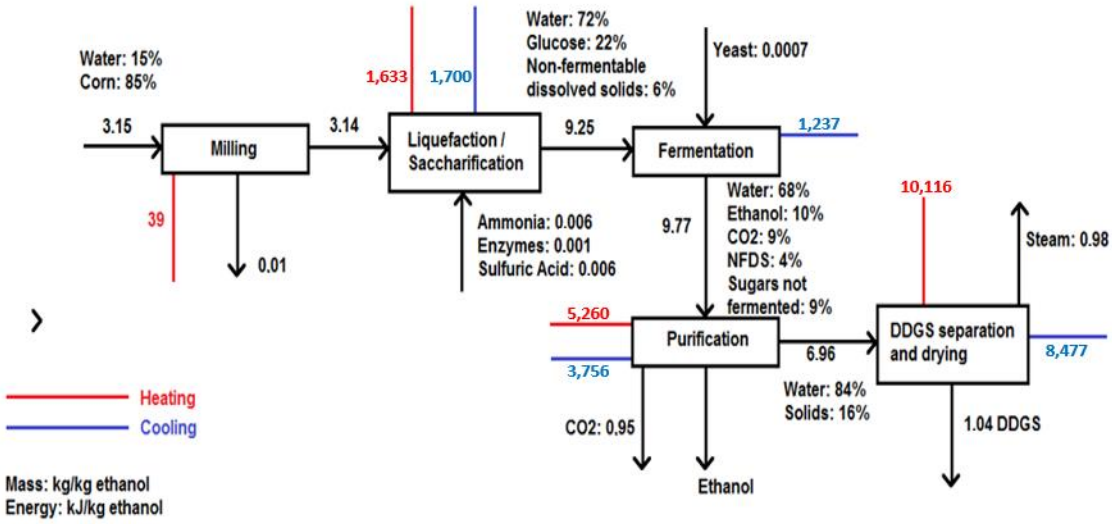

Figure 1: Mass and energy diagram for ethanol from corn

3.2 Ethanol from shale gas

There are three commercial companies with claims over the gas reforming technology for ethanol production, such as Celanse with the TCX® Technology through catalytic and thermochemical pathway (Celanese and BUS, 2011); Coskata through the biochemical pathway (Coskata, 2008) using carbon-containing feedstocks in order to produce a variety of alternative fuels; and Lanzatech (Lanzatech, 2008) using a fermentation process to transform CO and CO_2 from steel plants into ethanol.

Since none of the three commercial processes mentioned above provide enough published information for this research, the process diagrams and conditions, chemical and biochemical reactions data for this study were taken from open literature. The production process was obtained from (Jechura, 2015), syngas production information was taken from (Farniaei, Abbasi, Rahnama, Rahimpour, and Shariati, 2014), methane reforming from (Simpson and Lutz, 2007), and simulation aspects were based on (Gangadharan et al., 2012).
For the simulation of the fermentation process of syngas useful information was obtained from (Younesi et al., 2006). The fermentation reactions were based on (Kasteren et.al., 2005) and more recently (Liu et al., 2014), the gasifier and bioreactor information was based on (Rao, 2005)
Figure 2 depicts the block diagram for conversion process. The process has three main stages, reforming, fermentation and purification. The reforming stage is where the transformation of natural gas into synthesis gas occurs when changing the molecular structure with high temperatures. The second step is fermentation and it happens when the bacteria convert the syngas into a fermented mixture. The third and final step is purification that will separate the components and obtain the desired fuel grade ethanol.

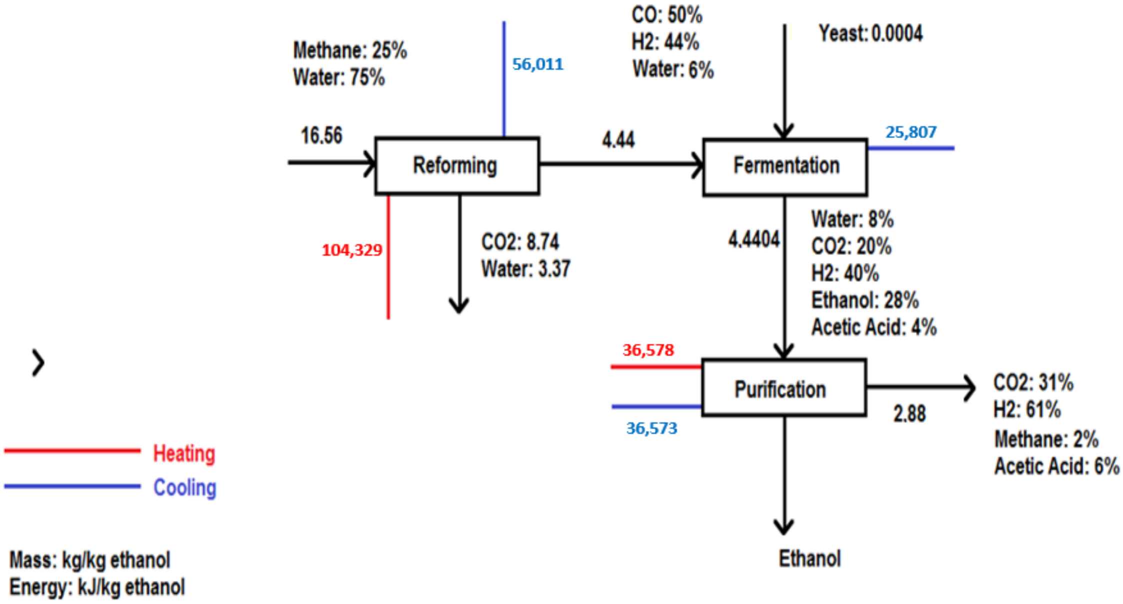

Figure 2: Mass and energy diagram for ethanol from shale gas

4. Life Cycle Analysis

In this section, a Life Cycle Analysis (LCA) of both ways to produce ethanol was performed, the boundaries were set and determined that each of the components behave independently. The analysis is done considering the implications on water, atmosphere, land, and energy for ethanol from corn and ethanol from shale gas using the processes described in the previous section (Quizena Fernandez, 2016).

4.1 Atmosphere

For the atmospheric emissions, calculations for the steps of pre-production, production, transmission and combustion of fuels for both corn and shale gas processes were taken into consideration. The total emission calculated for corn accounted as 76 gCO_2e/MJ, compared to 97.81 gCO_2e/MJ for ethanol from shale gas. The atmospheric aspects of ethanol production show a difference in emissions of 1.29 times greater for ethanol from shale gas.

4.2 Water

The data in Figure 3, represents the results obtained from the Aspen simulation and calculations. The total water was calculated considering the requirements for drilling, hydraulic fracture, and ethanol production process for the shale gas scenario, resulting a total of 9.1 kg of water per kg of ethanol. For the ethanol from corn calculations the water required in the conversion process was considered, as well as the water for corn crops growth, with a total water of 2,110 kg water/kg ethanol.

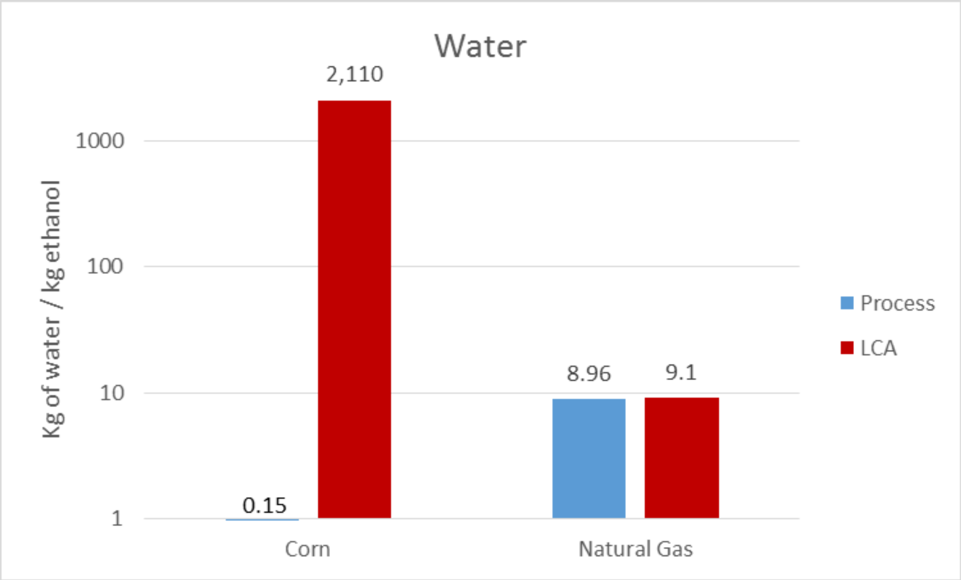

Figure 3: Water implications for the conversion process (blue) and the entire LCA (red)

4.3 Land

In terms of land usage, was estimated that 1 acre can produce 407.19 gallons (1.541 L) of ethanol from corn; and 589,545 gallons (2.23 x 10^6 L) of ethanol from shale gas. In order to make this comparison, was calculated how many acres are needed to produce the same amount of ethanol from corn, and this is 1,447.83 acres (586 ha). This land estimation results are represented in Figure 4.

Another important aspect, is the fact that the drainage area per acre for shale gas is through multiple wells using only one pad of horizontal wells which account for a 1 % surface footprint.

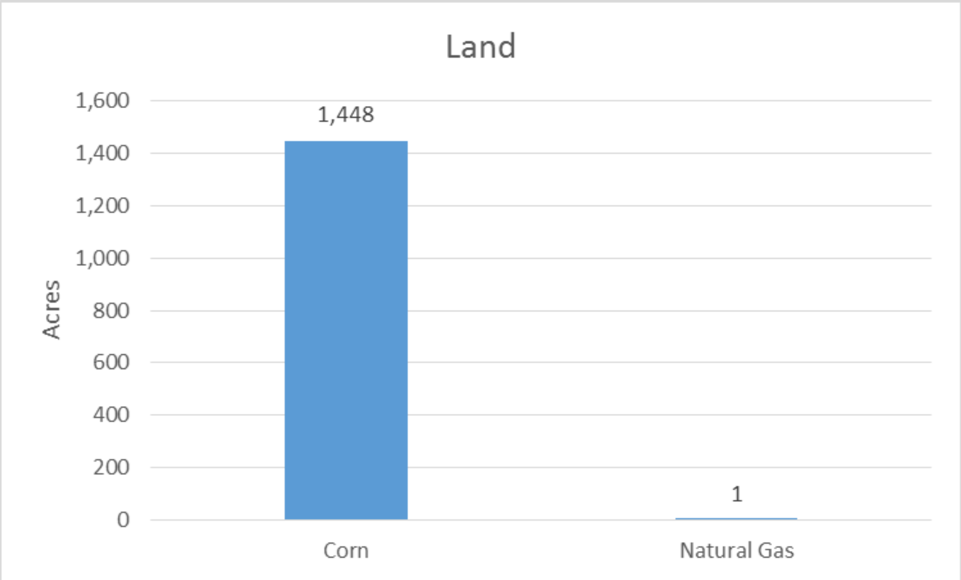

Figure 4: Land implications

4.4 Energy

The energy aspects of corn and shale gas processes where based as well in the Aspen simulation and used to calculate the total energy not only for the conversion process, but for the whole cycle of all production chain including harvesting step in case of bioethanol from corn. The data from the simulation was used with a multiplying factor (Yaritani and Matsushima, 2014) found in literature called energy return on investment to calculate the energy from shale gas. To calculate the energy from corn an estimate from the Department of

Energy was used. Figure 5 summarizes the energy required in terms of energy efficiency in order to produce ethanol from corn versus ethanol from shale gas. The efficiency of the conversion process itself, is better for corn, but the complete life cycle shows a better efficiency for ethanol from shale gas.

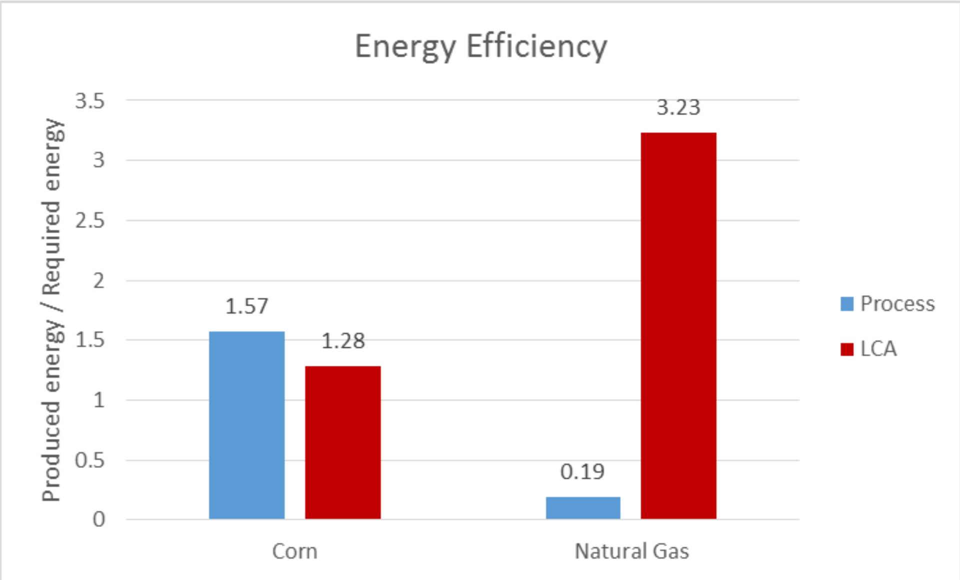

Figure 5: Energy efficiency comparison for the conversion process (blue) and the entire LCA (red)

5. Economic Comparison

This comparison was based on the natural gas study for the prices of ethanol for the shale gas conversion (Light, 2014) where the lowest price is for Coskata's technology at about USD$ 1,25/gallon of product ethanol, a feedstock gas price of USD$4/MBTU, and a Return on Investment (ROI) of 46 %. Celanese has the second place in terms of cost with their TCX technology with USD2.35/gallon of ethanol, and a considerably lower ROI. For ethanol from corn for a 40 M gallon plant with the dry-mill process according to (Whims, 2002) represents a return on investment of 45.6 %, and the wet mill process shows a lower ROI. For this study, the highest values of ROI from both processes were used, Coskata against the dry-mill resulting in a very similar return on investment, and a difference of only 0.4 % better for corn. One aspect that should be taken into consideration is that ethanol from corn has been the only process accepted by mandate to blend with gasoline, and it is necessary also include the "learning curve" of a new technology in order to be in equal basis because the production of ethanol from corn has been lowering its costs due to improving technology over the last decades, and ethanol from shale gas is only under serious consideration after the shale gas boom in the US.

6. Conclusions

The data obtained shows that ethanol from shale gas process was more efficient than bioethanol from corn in three of the four aspects evaluated throughout the present study. The greatest difference was obtained in land usage; ethanol from corn represent a footprint of 14,000 times more than for shale gas. Secondly, the water required to produce 1 gallon of ethanol is 200 more for corn due mainly to harvesting and the production process. The third aspect is the energy efficiency which is 2.5 times less for corn especially due to the energy consumption during the cultivation and harvesting process. This difference could be even higher if some processes from companies with new technological claims for shale gas ethanol are consider. It can be note that in terms of emissions the conversion process of shale gas into ethanol generated more CO_2, the overall LCA shows a difference of 1.3 times better (less CO_2) for corn ethanol due to CO_2 sequestrations related with corn growth. The difference is not as big as could be expected due to CO_2 production during the cultivation and harvesting process. Similar ROI shows a viable option in the actual technology conditions for shale gas ethanol to be competitive with ethanol from corn. Meanwhile authors have to state that there is a lot of room for improvement and deeper study of each of the four selected components in the LCA, considering the limitations related with the uncertainty in open information and initial data quality, which could be overcome with new researches in the area of data recollection and validation in the part of corn cultivation and harvesting and more precise data about emerging technologies for natural gas to ethanol production.

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