

Sugar Beet vs Corn Based Ethanol

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Abstract

Ethanol is currently used to cut emissions in motor fuels and is added to decrease knocking in the engines. Assuming a 20% molar concentration of each component of gasoline, the functional unit obtained is about 1.5 gallons of ethanol to every 1 gallon of gasoline.

To produce 1 billion gallons of ethanol would require 1,876,876.877 acres (1.51 times the current acreage harvested) or 41,666,666.67 tons beets. This comes from 22.2 tons/acre of beets multiplied by 24 gallons/ton to give 532.8 gallons/acre. These 1 billion gallons of ethanol would be able to be mixed with gasoline to form E-10 and represent 1% of the total annual demand for gasoline in America.

Combined farming and processing of the sugar beets requires 511,329845.9 gallons of ethanol equivalent per billion gallons of ethanol produced. Dividing the fossil energy required by the output billion gallons shows that the net energy requirement is .511 times the output energy. In other words the overall process requires 51.1% of the energy leaving 48.9% of the energy produced as net energy obtained.

Producing the same 1 billion gallons of ethanol from corn would require about 2,704,530.08 acres harvested at 147.9 bushels/acre or 369.75 gallons/acre. This is about 3.6% of the entire amount of corn currently harvested in America. Combined farming and processing losses come to 90.35% - giving only 9.65% net energy from the process. This is much worse than the 48.9% net energy obtained from sugar beets and is thereby much worse from an energy efficiency standpoint.

To process both feedstocks into ethanol, first they must be washed in a washer to remove dirt, pesticides, and other impurities. This is done with water in the sugar beet process or by a blower for corn kernels. Then feed is transported from the washer outlet into a system that grinds or cuts the feed to increase contact area before entering the counter-current diffuser for beets or the liquefaction vessel (where saccharification occurs). This is where the sugar is extracted from the beets and the starch from the corn is turned into the sugars to be fermented at the next step. In the fermenter, the sugars are exposed to yeast to produce ethanol that is then purified in a distillation column and a molecular sieve. The waste in both cases could be processed and sold as animal feed for additional energy recovery.

Introduction

Energy has become a common topic for reporters and analysts around the world. Developing nations are requiring more energy and developed nations have ever increasing energy needs to support their growing populations. Transportation accounts for about 30% of the energy needs of the United States – nearly all of this energy is petroleum based. Crude oil prices reached a high of about \$150 per barrelⁱ– translating to close to \$4.00/gallon across the nation. Interest in unconventional fuels has increased in an attempt to decrease the foreign dependence of our energy needs and to decrease the price Americans must pay to continue their heavily car-dependant lifestyle. In addition, Americans are becoming more environmentally conscious and thereby efforts are being made to develop fuels that will produce less carbon dioxide among other pollutants. The burning of gasoline and diesel leads to high carbon dioxide emissions that contribute to global warming through the greenhouse effect.

The foremost alternative fuel being investigated in the United States is ethanol – that is not to say that ethanol is a new fuel. The car that truly started the automobile industry – the Ford Model T was designed to be run on ethanol. Henry Ford has often been quoted as saying that ethanol is “the fuel of the future”ⁱⁱ. Currently, ethanol is used as a fuel additive to decrease emissions through oxygenation and increase the octane (decrease knock) of the blend. Research and further development is going into increasing the ethanol content of blends or using pure ethanol to fuel vehicles – both would require new engines due to common American engine models only being able to handle a 10% mixture of ethanol.

For the purposes of calculations in this paper, gasoline will be assumed to have an equivalent amount of isooctane, isopentane, cyclohexane, benzene, and MTBE. Assuming 20% molar concentration of each component for gasoline, the heat of combustion of gasoline would be - 3,906 kJ/mol. Pure ethanol has a heat of combustion of -1367.6 kJ/mol. A gallon is 3.785 liters and attributing the density and combined molecular weight gives a functional unit of about 1.5 gallons of ethanol to every 1 gallon of gasoline. This functional unit will be used as the main function of fuels is to provide energy and thereby comparing the heats of combustion and the volumes is the most appropriate solution.

Feedstock

The talks of ethanol in America usually centers around the use of corn as the feedstock or sugar cane use in Brazil; however, very rarely do you hear about the production of ethanol from sugar beets in place in France. This paper focuses on the use of sugar beets as the feedstock for ethanol as an alternative to the large amount of literature on corn based ethanol.

First, Fig.1 below shows that the ethanol yield per hectare of land area is highest for the refining of sugar beets in France (about 7000 liters/ha or 749 gal/acre). It goes on to show that corn is the least land efficient.

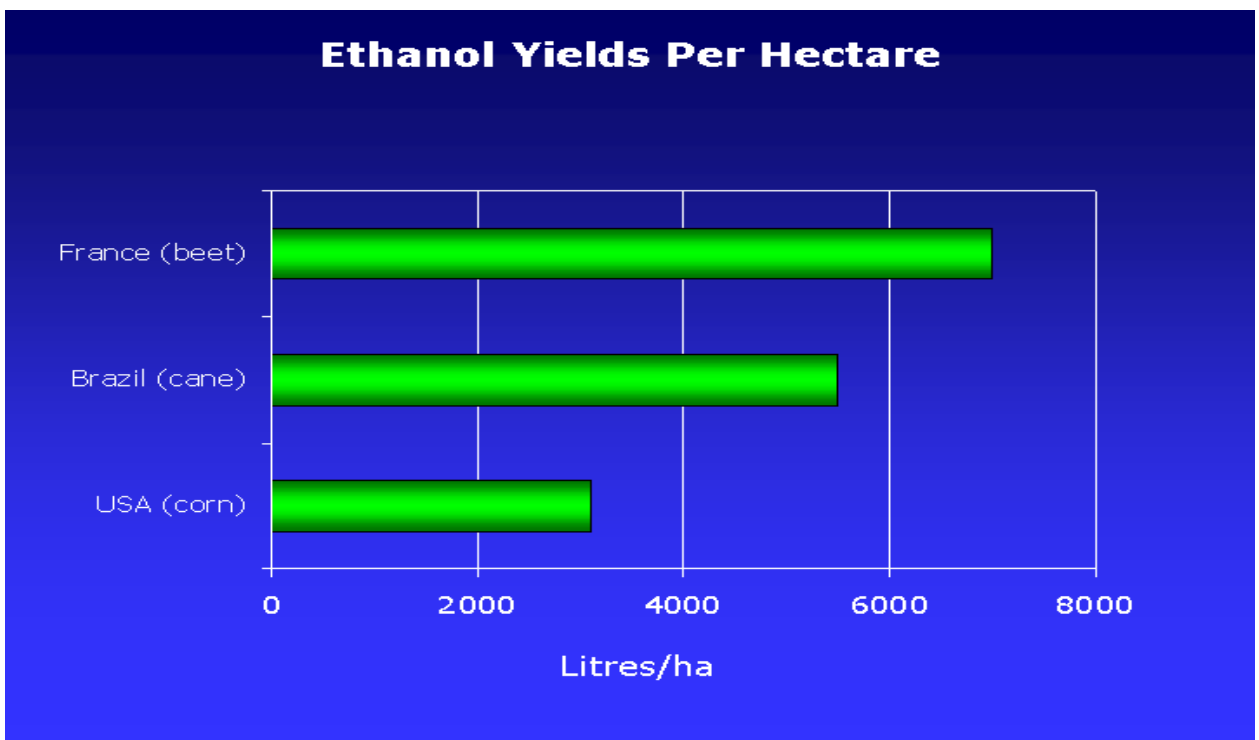


Figure 1. Land Efficiency of Feedstocks

Fig.2 goes on to show that sugar beets produce 100 litres of ethanol per tonne (24 gallons/ton). This is only surpassed by corn; however, the gallons of ethanol per acre from figure 1 showed that this was a land inefficient path.

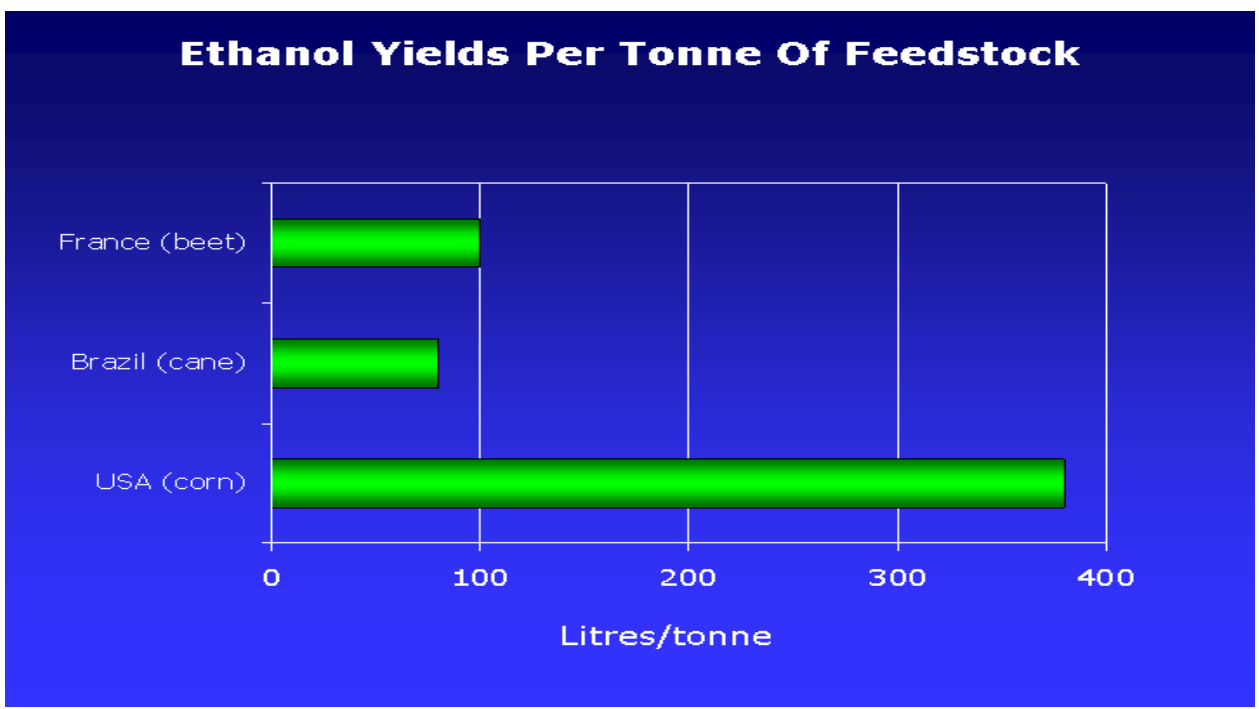


Figure 2. Yields For Bulk Feedstock

Figure 3 below illustrates the main drawback to using sugar beets – it is the most costly feedstock to produce at over 3 times the cost of sugar cane and a penny or two more than the cost per liter of corn based ethanol.

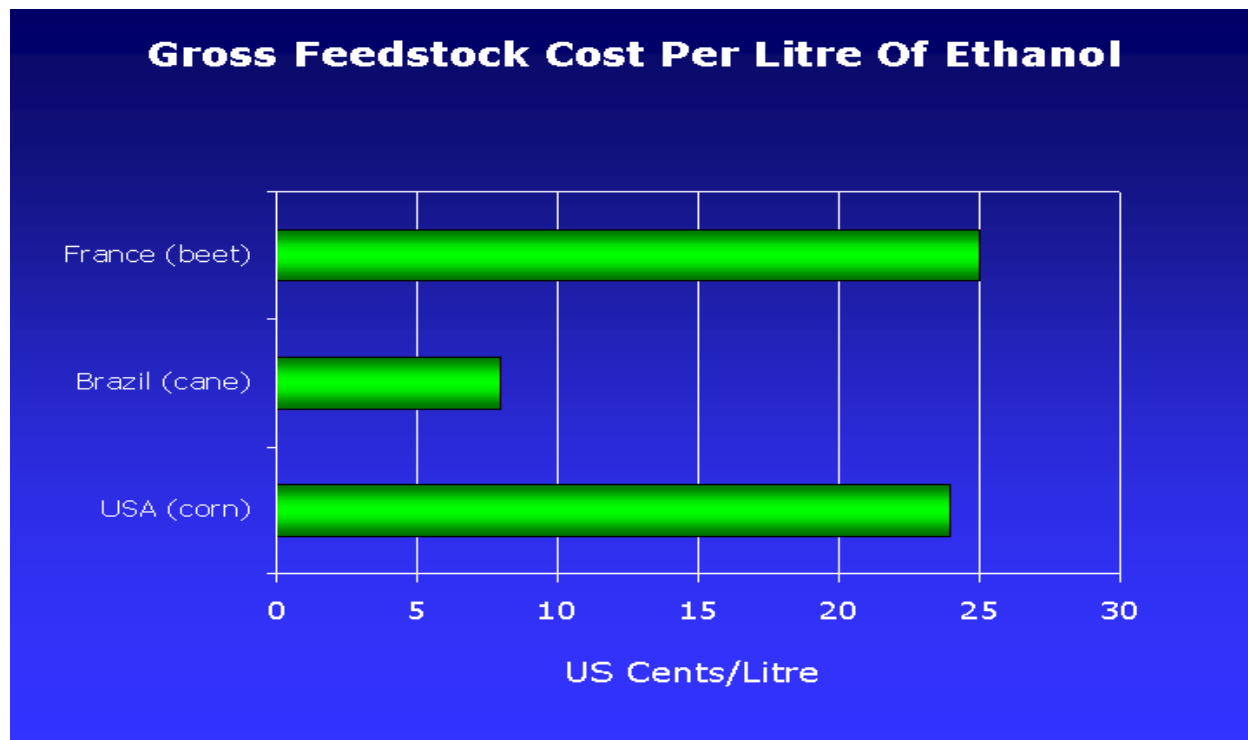


Figure 3. Feedstock Economics

All three previous figuresⁱⁱⁱ demonstrate that sugar beet based ethanol is the most land efficient solution of the feedstocks and the best sugar feed (with corn being a starch feed); however, the feedstock to liter costs are the highest. With the current downward priced gasoline fuel costs this may seem important, but very quickly will the cost per barrel increase and these higher costs will still be profitable. It should be noted that sugar cane to ethanol is not a viable solution for America as the climate required to grow the sugar cane isn't present across the acreage required.

Sugar Beets

Now that the why of choosing sugar beet based ethanol has been addressed, the current amount of sugar beets grown in the United States must be found. Assuming all sugar beet production went to ethanol (leaving sugar cane to produce the sugar for consumption) there are currently 1,243,000 acres being harvested. Yield per acre gives an average of 22.2 tons of beets per acre giving 27,537,000 tons of beets a year^{iv}. Due to the hardy nature of the sugar beet it can be grown annually in most regions of the United States to increase the production of sugar beets if needed – a trait that sugar cane could not share due to its tropical nature.

To produce 1 billion gallons of ethanol would require 1,876,876.877 acres (1.51 times the current acreage harvested) or 41,666,666.67 tons beets. This comes from 22.2 tons/acre of beets

multiplied by the 24 gallons/ton from figure 2 to give 532.8 gallons/acre in America. There was no need to factor additional transportation from the farm site to a refinery as sugar degrades if transported and must be refined as quickly as possible on-site.

After finding the amount of land required, the amount of fertilizer required to produce a billion gallons of ethanol is given in Table 1 below.

Table 1. Beet Land Use Requirements^v

| | Lb/acre | Lb/billion gal ethanol |
|---------------|---------|------------------------|
| N Fertilizer | 121.5 | 228,040,540.6 |
| Potash | 190.8 | 358,108,108.1 |
| Phosphate | 112.5 | 211,148,648.7 |
| Pesticides | 4.77 | 8,952,702.703 |
| Fuel Consumed | 90.9 | 170,608,108.1 |

Process

To process sugar beets into ethanol, plants should be built on-site where the sugar beets are being grown to minimize the degradation of the sugar. First, the beets must be washed in a washer to remove dirt, pesticides, and other impurities. Then the beets are transported from the washer outlet into a shredder to separate the juice and pulp and increase contact area before entering the counter-current diffuser. This is where the sugar is extracted and the syrup obtained is fermented to produce the ethanol. Finally the ethanol stream is sent to a distillation column to purify and remove the ethanol in the condenser while allowing the waste to be removed at the bottoms. The waste is typically pulp and slop that is used for animal feed^{vi}. Fig. 4 below details the process just described.

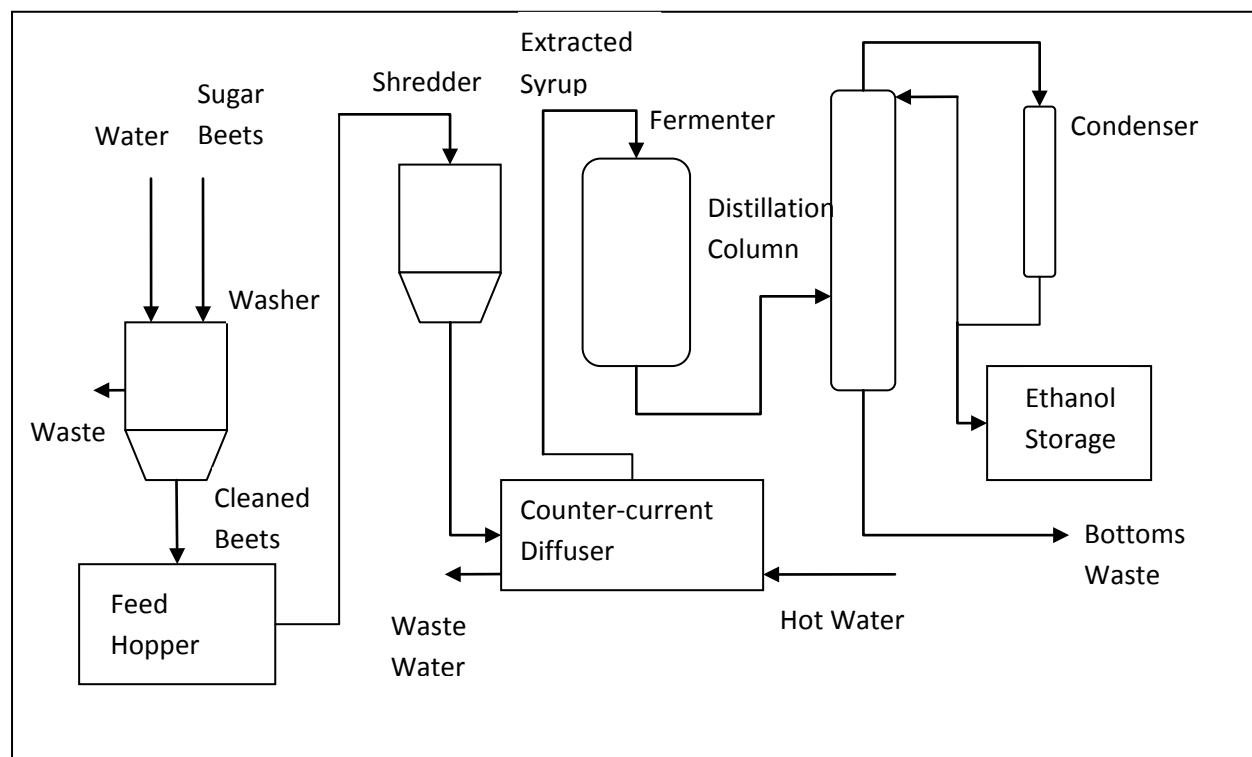


Figure 4. Sugar Beet Process Flow Diagram

The energy requirements of each step of this process are detailed in Table 4 below.

Table 2. Beet Process Flow Energy

| | Heat (MJ/tonne ethanol) | Electricity (kWh/tonne ethanol) |
|------------------|-------------------------|---------------------------------|
| Washing | - | 61 |
| Sugar Extraction | 970 | 139 |
| Fermentation | - | 76 |
| Purification | 5271 | 50 |

To use this table first you must calculate that 1 billion gallons of ethanol is 3291904 tons ethanol (using .789 g/mL density). Then you must convert kWh/tonne to kJ/ton (multiply by 3,265.865) and MJ/tonne to kJ/ton. It will be assumed that all electricity values are three times as high to account for the inefficiency of the power plants in producing electricity. No factor will be added for the heating terms as we will assume that the heating is perfect. The last assumption used is that gasoline has a molecular weight of 87.36 g/mol based on the 20% molar concentration assumed earlier. Calculations are shown in Appendix on how the impact of each step was obtained and Table 5 below shows the results.

Table 3. Beet Process Gasoline Needs

| | Gal Gas/Billion gal Ethanol |
|------------------|-----------------------------|
| Washing | 14823174 |
| Sugar Extraction | 55601468.49 |
| Fermentation | 18468216.79 |
| Purification | 130742599.6 |
| Total | 219635458.9 |

The process requires 219635458.9 gallons gasoline which at the 1.5 functional units is 329453188.3 gallons ethanol. This isn't that bad a result as it means 32.9% of the energy obtained from the process is consumed by the process. The next section will look at the overall energy needs of the production of ethanol and determine if this process is energetically favorable.

Net Energy

From the process in the previous section we've shown that 329,453,188.3 gallons of ethanol is required to produce the 1,000,000,000 gallons of ethanol. This is 32.9% of the energy for the processing of the sugar beets, but this does not account for the growing of the sugar beets on the farm.

Table 1 in section Sugar Beets showed all the lbs of material needed in the growth of the 1 billion gallons of ethanol required tons of beets. Fertilizer energy requirements, Parathion pesticide requirement, and diesel fuel consumed through farm activity are listed in Table 4 below. The assumed density of diesel is 850g/L^{vii} or 7.1 lb/gallons. For abridged calculations refer to the Appendix.

Table 4. Beet Growing Requirements

| | Lb/billion gal ethanol | Gallons Diesel/lb ^{viii} | Gal Gasoline Total |
|---------------|------------------------|-----------------------------------|--------------------|
| N Fertilizer | 228,040,540.6 | 0.2400 | 60717312 |
| Potash | 358,108,108.1 | 0.042 | 16683945.6 |
| Phosphate | 211,148,648.7 | 0.054 | 12642782.4 |
| Pesticides | 8,952,702.703 | 0.4241 | 4520062.334 |
| Fuel Consumed | 170,608,108.1 | 0.1408 | 26687002.71 |

Adding up all the required gallons of gasoline to produce the gallons of ethanol gives a value of 121251105 gallons gasoline which corresponds to 181,876,657.6 gallons ethanol. This means for the farming process 18.19% of the total energy output from the overall process is used.

For the combined farming and processing 511,329845.9 gallons of ethanol equivalent is required per billion gallons of ethanol produced. Dividing the fossil energy required by the output billion gallons shows that the net energy requirement is .511 times the output energy. In other words the overall process requires 51.1% of the energy leaving 48.9% of the energy produced as net energy obtained.

Corn

Corn has recently become much maligned by the press and the scientific community after such intense scrutiny as the solution to America's ethanol needs. For comparison we will use the DOE's 2005 data as used in the sugar beets. 75,107,000 acres harvested at 147.9 bushels/acre gives 11,112,072,000 bushels. The average bushel of corn gives about 2.5 gallons of ethanol^{ix} giving us 27.8 billion gallons of ethanol. Let's scale this back for the purposes of comparison to the sugar beet scale used of 1 billion gallons of ethanol. For this we need 2,704,530.08 acres at the calculated rate of 369.75 gallons/acre. This is a good bit higher than the 275 gallons/acre^x assumption initially assumed.

For the fertilizer needs, corn requires approximately 1.25 lbs. of elemental nitrogen (N), 0.6 lbs. of phosphate (P₂O₅) and 1.4 lbs. of potash (K₂O) for one bushel of corn^{xi}. As 147.9 bushels/acre are obtained the requirements to grow are given in Table 4 below.

Table 5. Corn Land Use Requirements^{xii}

| | /acre | /billion gal ethanol |
|--|--------------|----------------------|
| N Fertilizer | 184.9 lbs | 500,067,611.8 lbs |
| Potash | 207.0 lbs | 559,837,726.6 lbs |
| Phosphate | 88.7 lbs | 239,891,818.1 lbs |
| Pesticides ^{xiii} | 2.5 lbs | 6,761,325.2 lbs |
| Fuel Consumed (gas equiv) ^{xiv} | 14.7 gallons | 39,756,592.2 gallons |

Process

The process to produce ethanol most widely used in America is the dry mill process^{xv} which requires a total energy contribution (including energy loss from inefficiency in electricity generation) of 51,457.18 kJ/gallon ethanol^{xvi}. Wet milling – another process used in America requires 57,225.17 kJ/gallon ethanol and while it gives other products it shall be ignored for its lesser role and its higher energy dependence.

The dry milling process operates much like the process for the conversion of the sugar beets to ethanol with the noted exception that it has to make the conversion of starch to sugar and then to the fermentation step. Kernels start by being cleaned by a blower or a screen and then brought to the hammer mill. The hammer mill crushes and grinds the corn kernels to increase the surface area before the kernels are sent through the cooker to kill bacteria and to begin the liquefaction stage where enzymatic hydrolysis typically occurs. Enzymatic hydrolysis breaks up the starches into their smaller, subunit fermentable sugars in a process known as saccharification. This slurry then travels to the fermenters where yeast is added to the mixture to turn the sugars into the ethanol desired product. After about 52 hours this slurry is passed to the distillation columns to begin the purification stage where typically 190 proof ethanol is desired from the condenser. This 190 proof ethanol and water mixture is then passed through molecular sieves where the water molecules become trapped and nearly pure, 200 proof ethanol is obtained and placed into

ethanol storage^{xvii}. The resulting bottoms is known as DDGS and can be purified and sold as a high protein animal feed.

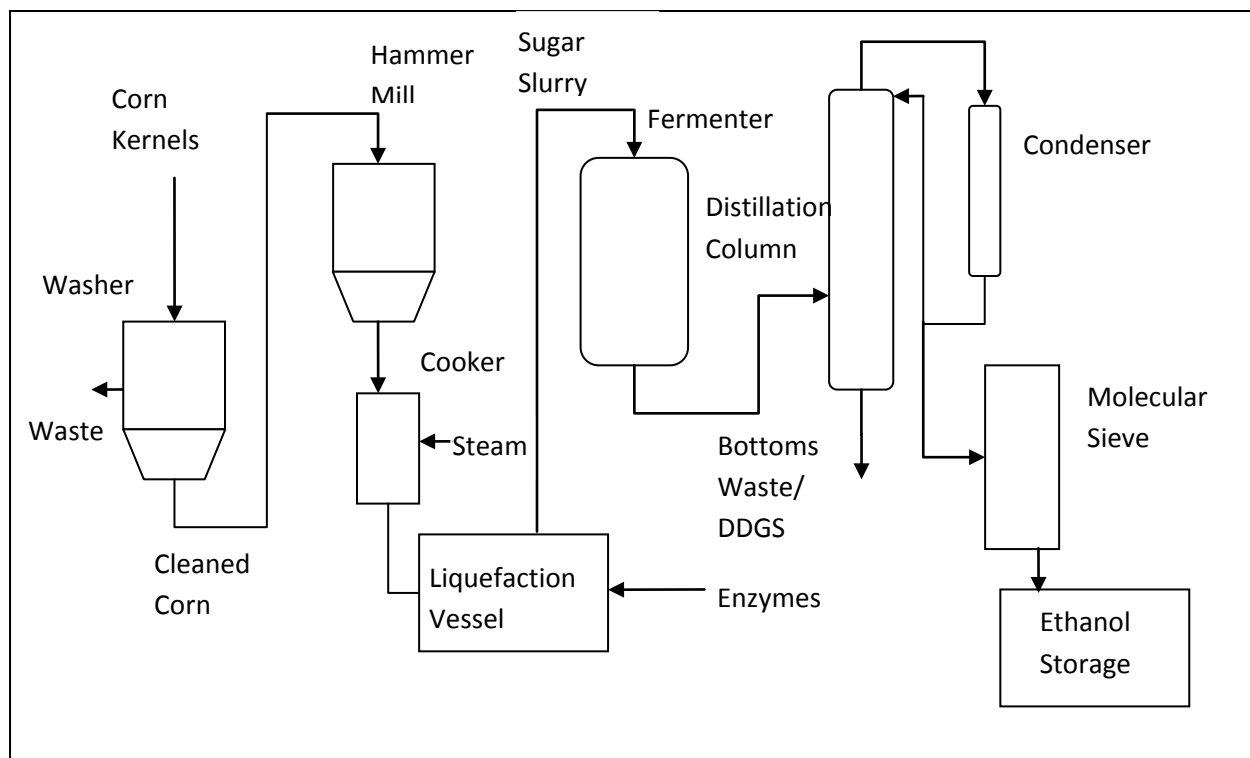


Figure 5. Corn Process Flow Diagram

Excluding any processing of DDGS or benefit derived from it (as was done with sugar beets), this process takes 581,266,021.4 gallons of the one billion galls of ethanol it would produce; 58.1% of the energy it would give.

Net Energy

From the process in the previous section we've shown that 581,266,021.4 gallons of ethanol is required to produce the 1,000,000,000 gallons of ethanol. This is 58.12% of the energy for the processing of the corn, but this does not account for the growing of the corn on the farm.

Table 1 in section Feedstock showed all the lbs of material needed in the growth of the 1 billion gallons of ethanol required per acre. Fertilizer energy requirements, parathion (assumption to equalize it with sugar beets) pesticide requirement, and diesel/gasoline fuel consumed through farm activity are listed in Table 6 below.

Table 6. Corn Growing Requirements

| | /billion gal ethanol | Gallons Diesel/lb ^{xviii} | Gal Gasoline Total |
|---------------|--------------------------|------------------------------------|--------------------|
| N Fertilizer | 500,067,611.8 lbs | 0.2400 | 133170005.3 |
| Potash | 559,837,726.6 lbs | 0.042 | 26090229.54 |
| Phosphate | 239,891,818.1 lbs | 0.054 | 12954158.18 |
| Pesticides | 6,761,325.2 lbs | 0.4241 | 2867478.02 |
| Fuel Consumed | 39,756,592.2 gallons gas | n/a | 39756592.2 |

Adding up all the required gallons of gasoline to produce the ethanol gives a value of 214838463.2 gallons gasoline which corresponds to 322,257,694.9 gallons ethanol. This means for the farming process 32.23% of the total energy output from the overall process is used.

For the combined farming and processing 903,523,716.3 gallons of ethanol equivalent is required per billion gallons of ethanol produced. Dividing the fossil energy required by the output billion gallons shows that the net energy requirement is .904 times the output energy. In other words about 90.35% of the energy obtained from corn based ethanol went into the production of that ethanol. 9.65% net energy is obtained with these assumptions. Knowing that the net energy obtained could be reasoned away with more assumptions, this should help to bolster the belief many hold that “corn from ethanol is a net loser”^{xix}.

Conclusions and Recommendations

From extensive analysis holding all things equal between the feedstocks, sugar beets is a much more efficient feedstock. Sugar beet ethanol loses only 51.1% of the energy it provides, whereas corn loses 90.35% of the energy in the production of the ethanol. While sugar beets are clearly better from an energetic standpoint, the low production of sugar beets needs to be increased to make this a viable solution. It would take 151% of the current annual harvested sugar beets to produce 1 billion gallons of ethanol – roughly enough fuel to be added as E-10 to 1% of the yearly usage of gasoline.

Recommendations for additional analyses would be to factor in the solar energy required to grow the crops as solar energy is a viable energy source, energy required to handle all waste streams, and account for growing differences like irrigation needs.

Appendix – Example Calculations

Process Calculations:

1 billion gallons = 3.785 billion liters * 1000 = 3.785e12 mL (.789) = 2.986e12 grams = 3291904 tons ethanol

Step 1: 61 kWh/tonne * 3265.865 * 3291904 tons = 6.557077739e11 kJ = 167855861.7 mol gas (87.36 g/mol) = 1.466389e10 grams = 1.87e10 mL = 1.87e7 Liters = 4941058 gallons gasoline x3 = 14823174 gallons gasoline

Step 2 Electricity: 2.278688525 (Step 1 electricity) = 33777396.49 gallons gas
 Step 2 Heating: 2.896e12 kJ = 741399625.4 mol gas = 6.476867e10 g = 8.26e7 L = 21824072 gallons gas
 Step 2 Total: 55601468.49

Step 3: 18468216.79 gallons gas

Step 4: 12150142.62 gallons + heating (118592457 gallons) = 130742599.6 gallons gas

Total: 219635458.9 gallons gasoline

Total: 329453188.3 gallons ethanol

Farming Calculations:

1.1096 Gallons Gasoline = 1 Gallon Diesel

Lb N = 2.28E8 = 60717312 gal gasoline

Potash = 3.58e8 = 16683945.6 gal

Phos: 2.11E8 = 12642782.4 gal

Parathion Pesticide: 0.424057 diesel gal/lb = 4520062.334 gallons gas

1.706e8 lbs diesel = 91042983.65 L diesel = 26687002.71 gallons gasoline

Total Farm needs: 121251105 gallons gas = 181,876,657.6 gallons ethanol

Corn Calculations

Process:

48,772 BTU/gallon = 51,457.18 kJ/gallon ethanol = 5.1457e13 kJ/billion gallons ethanol = 1.317e10 mols gasoline/billion gallons = 1.1505e12 grams/billions gallons = 1.4669e12 mL = Total: **387,510,680.9**

gallons gasoline/billion gallons of ethanol

Total: 581,266,021.4 gallons ethanol

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