

Reducing the Carbon Footprint of Fuel Ethanol

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1. Abstract

There is currently a huge movement towards research and future implementation of renewable fuel sources such as biofuels to combat the increasing rate of global warming partially due to the combustion of petroleum-based fuel sources. This was one of the major inspirations for my College of Engineering Senior Design group project. My team and I analyzed an ethanol plant in which dried corn is refined to produce fuel-grade ethanol, which is a fuel source that has the potential to completely replace gasoline and produces less greenhouse gas emissions when combusted. Unfortunately, one of the major drawbacks to the typical refinement of ethanol is the large amount of CO₂ emissions that are produced as a byproduct of the refining process. As a result, my senior design team researched possible alternatives that could be implemented into an ethanol plant to mitigate these carbon emissions. More specifically, my team looked at three plausible options: electric heat, carbon capture and gas stripping. These alternatives were extensively researched and compared to our base case, which models the process operations and carbon emissions of a typical ethanol plant, to determine the extent that negative environmental consequences were mitigated. Moreover, my personal contributions to this senior design project included an extensive analysis of the plant's economics relating to material costs, operating costs, and product revenue along with an in-depth risk analysis of the process hazards associated with the plant.

2. Introduction

The continued use of nonrenewable fuel sources – especially those produced by the oil and gas industry – has become a major controversy around the world. Recently, there has been a huge push towards clean energy and renewable fuel sources to not only mitigate the rising amounts of greenhouse gases entering the atmosphere, but also to combat global warming. The oil and gas industry uses crude oil to produce many popular products such as diesel fuel, gasoline, jet fuel, heating oil and many different types of plastics and lubricants. “Global carbon emissions from fossil fuels have significantly increased since 1990. Since 1970, CO₂ emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing [to] about 78% of the total greenhouse gas emissions increase from 1970 to 2011” (Global 2021). In 2020, an average of 18.12 million barrels of petroleum are consumed per day in the United States alone (Frequently 2021). These numbers will only continue to rise as the global population increases, thus increasing the demand for petroleum-based products. As a result, it is imperative that alternative and more sustainable fuel sources be researched in order to lessen this demand of petroleum-based products.

With this in mind, my engineering senior design team and I decided to research one of the many alternatives to petroleum-based fuels and design an entire plant that could produce this fuel on a mass production level. We decided to focus on the corn to ethanol process that refines dried corn into fuel grade ethanol, which is a more emission-friendly fuel source. Because many biofuels such as corn-derived fuel ethanol produce large amounts of carbon emissions due to carbon dioxide (CO₂) gas being a major byproduct of the fermentation process, my senior design group also researched ways to reduce these carbon emissions to make this process more environmentally conscious. My personal contributions to this project, however, were to calculate all economics associated with the plant – utility and operating costs, equipment costs, capital investment costs, and net profit – along with conducting an analysis of all process safety hazards associated with the plant and the process itself.

3. Process Overview

3.1 General Refining Process and Base Case

Dried corn is disintegrated and mixed with hot water to form a corn mash. This mash is mixed with sulfuric acid and an enzyme known as alpha amylase before it undergoes a process known as liquefaction. During this process, the long starch chains within the corn are cleaved into smaller chains due to a partial hydrolysis reaction in order to promote the occurrence of future reactions. After liquefaction has occurred, the corn mixture undergoes the process of saccharification. During this process, the smaller starch chains are further cleaved into smaller molecules known as glucose through another hydrolysis reaction (Busboom et al. 2021). Once saccharification has gone to completion after approximately 8 hours, yeast is added to the cooled glucose mixture to promote fermentation. The fermentation reaction produces the desired product of ethanol along with a byproduct of CO₂ gas.

What exits the fermenter is a mixture of ethanol, water, acid, solid corn and CO₂ gas. Because ethanol is the desired product from this process, it must be separated from this mixture. To do this, the mixture is sent to two different distillation columns whose job is to separate the different components of the mixture based on its phases – solid, liquid, vapor – and the relative volatilities of the components within the mixture. The solids are removed from the bottom of the distillation column and are sent to undergo further processing in order to be sold as dried distiller's grains (DDG) and make extra profit. Next, CO₂ is removed from the mixture out the top of the column because it can easily be boiled off as vapor due to it having a boiling point lower than that of water and ethanol. The remaining water and ethanol mixture is sent to the second mixture where the two components are separated based on boiling points. Because ethanol has a lower boiling point than water, the ethanol turns into vapor and boils out of the water and out the top of the column.

Although the ethanol is fairly pure, it still contains some water. To fully remove the remaining water, this mixture is sent through two absorbers that allow the water and ethanol to be separated based on their molecular sizes (Busboom et al. 2021). Due to the water molecules being larger than that of ethanol, the water is trapped in the absorbers whereas the ethanol can flow completely through. This ethanol product is 99.2% pure, and it is mixed with naphtha to denature it before it is sent to storage where it will be held until it is sold. This entire process, generally referred to as the base case, is summarized in Figures 1 and 2 below which are snapshots of the Aspen Plus simulation that my group created to model this entire ethanol refining process.

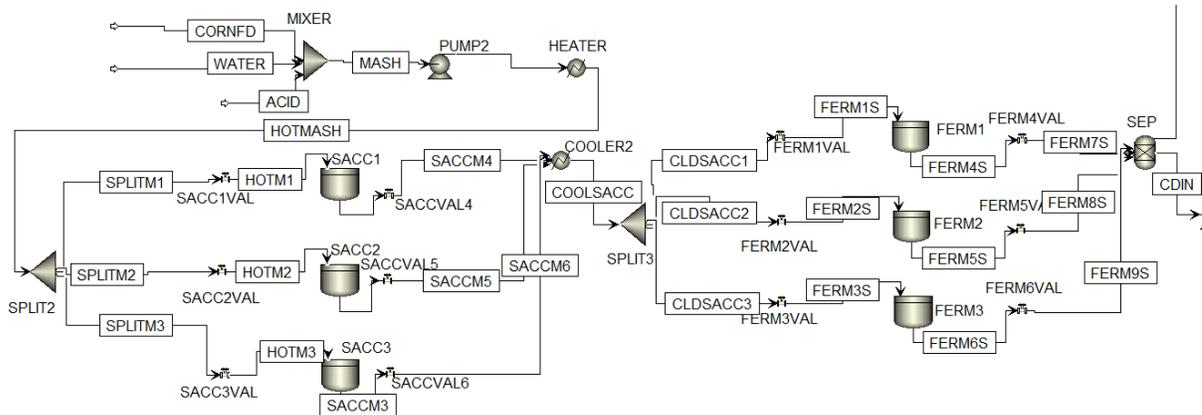


Figure 1: Schematic of the First Half of the Corn to Ethanol Refining Process (Solids Processing, Saccharification and Fermentation)

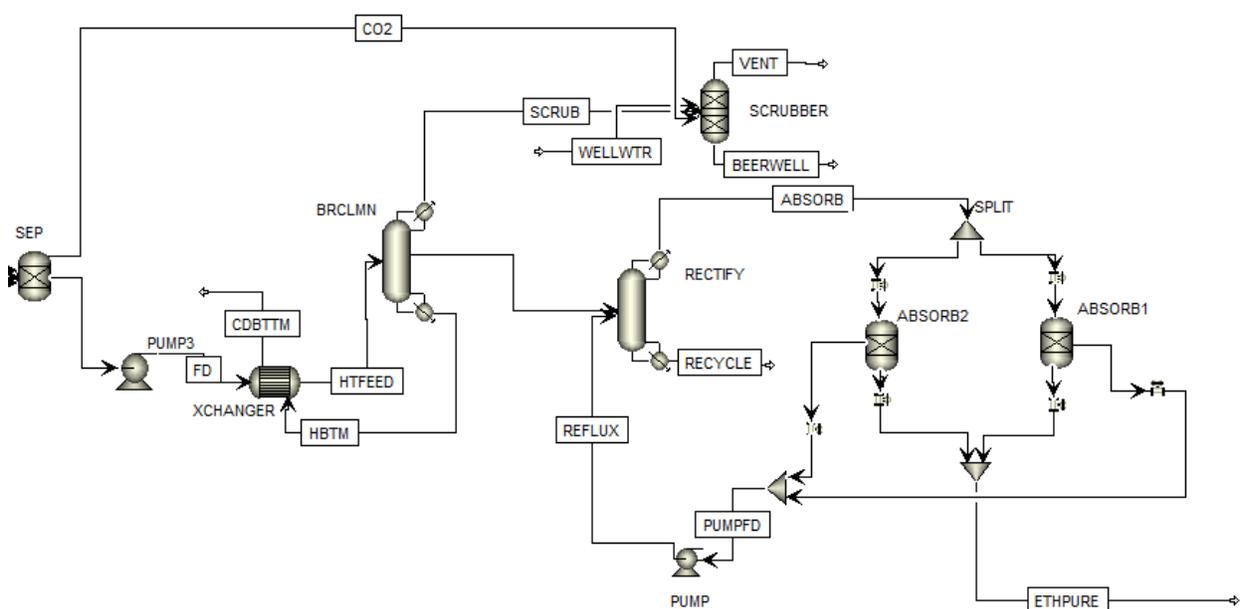


Figure 2: Schematic of the Second Half of the Corn to Ethanol Refining Process (Separations)

3.2 Emissions

Unfortunately, one of the major concerns regarding the corn to ethanol process is the immense amount of CO₂ that is produced as a result of this process. Emissions are mainly produced through usage of natural gas fired burners and the fermentation process. The natural gas fired burners produce 202,683 tons/year of CO₂ emissions and the fermentation process produces 2,829,869 tons/year of emissions. Therefore, the annual emissions that this plant releases to the atmosphere – assuming that no systems are installed to prevent atmospheric release – are 3,032,551 tons/year.

Releasing 3 million tons/year of CO₂ into the atmosphere can have catastrophic negative effects on the environment. “For a typical world-scale 300,000 barrel per day [petroleum] refinery, this will lead to CO₂ emissions ranging from 0.8 up to 4.2 million tons of CO₂ per year” (Straelen

2009). Based on these numbers, our ethanol plant is no more environmentally friendly than a petroleum refinery is. Therefore, it is imperative that ways to mitigate or prevent this CO₂ from escaping into the atmosphere be investigated. My senior design group looked at three different alternatives that could be made to a typical corn to ethanol plant to reduce its carbon footprint. These methods were electric heat as opposed to natural gas, carbon capture technology and gas stripping as opposed to a distillation column.

4. Alternative Cases

4.1 Electric Heat

The first alternative that my group looked at in hopes of reducing plant emissions is to replace the natural gas fired heaters with electric heaters. Making this change reduced the overall equipment cost of the plant from \$17,645,856.94 to \$16,695,416.14 due to the electric heaters being far less expensive than the natural gas fired heaters. This is because the two natural gas fired heaters had a combined cost of \$1,010,316.09 whereas the two electric heaters had a combined cost of only \$92,496.90.

Not only was the overall equipment cost cheaper with electric heaters, the 202,683 tons/year of CO₂ emissions produced from the natural gas fired heaters would be completely eliminated. Unfortunately, this would not decrease the CO₂ emissions created by fermentation due to fermentation being a naturally occurring process. In order for those emissions to be reduced, a system such as carbon capture – which is discussed next – should be implemented.

However, utilizing electric heat instead of natural gas is not as great as it seems. It is estimated that the plant consumes 3,378,045 MMBtu/year, or 990,048,300 kWh/year of energy (Busboom et al. 2021). Assuming that the cost of electricity in South Dakota – which is the state we chose to build our hypothetical plant in – is \$0.0735/kWh, the cost of the electricity needed to run the plant is \$72,768,600/year (South Dakota 2020). Overall utility expenses using natural gas (electricity, cooling water, steam and natural gas) were only \$28,106,276.95/year with electricity expenses only totaling to \$224,532. The utilities for electric heat (electricity, cooling water and steam) had a total estimated cost of \$86,528,258.02/year, which is an increase of 307%.

Increasing the plant's utility cost to \$86,528,258.02/year causes the plant's annual expenses to increase from \$152,770,000 to 213,570,000 per year, which exceeds the plant's predicted yearly revenue. As a result, the plant would never make a profit, and would continuously fall into debt each year that it operated. However, if the market price of ethanol was increased from \$1.41/gallon to \$2.98/gallon and a carbon tax of \$302/ton CO₂ was implemented on natural gas usage, it would make the electric heat case a more viable option. Although implementing electric heaters improved plant emissions and seemed great in theory, it was proven to be an economically viable option with the current government regulations.

4.2 Carbon Capture

Carbon capture is of particular interest to my group's senior design project because it would drastically reduce the amount of carbon released to the atmosphere. This system works by filtering carbon compounds out of the flue gas that is produced by the natural gas fired heaters. First, the flue gas is sent to an absorption column where it interacts with any number of CO₂ soluble gases. Monoethanolamine (MEA) is used in this column. This liquid flows down through

the column while the flue gases simultaneously flow up the column. When the liquid MEA contacts the gaseous flue gas, it interacts with the CO₂ in the gas and bonds to it. This process removes the CO₂ in the gas and makes it soluble in the MEA liquid, which is then sent to another distillation column in order to completely remove the CO₂.

In the second column, the solution containing both MEA and CO₂ flows down from the top of the tower. As it falls down, the solution is spread out with packing material within the column. The packing is connected to a steam heat source and warms the CO₂-rich solution. This heat causes the CO₂ to dissociate from the MEA solution. The CO₂ is in a gaseous state and flows back up the tower into the condenser. The MEA solution (free of CO₂) is then recycled back into the first tower to collect more CO₂ from the flue gas. The CO₂ is pressurized in the condenser and is removed as pure CO₂ gas. This gas can either be sold industrially and offset the plant's material expenses as a byproduct credit, or it can be sequestered underground where it will not be able to escape into the atmosphere.

Implementing this technology into the ethanol plant's refining process drastically reduces the amount of CO₂ emissions released into the atmosphere. Because the CO₂ is captured and not vented into atmosphere, the carbon emissions from burning natural gas drop to a nearly non-existent level. Being able to lower the plant's CO₂ emissions and therefore making a renewable fuel source a more appealing alternative is exactly the goal of my team's senior design project. Although carbon capture seems like a perfect solution to the plant's emissions problem, it is expensive and relatively new technology, so research and development is still necessary in order to make it a more viable and practical option for reducing a plant's carbon footprint.

4.3 Gas Stripping

The last alternative that my senior design group analyzed is a process known as gas stripping in which the CO₂ produced during fermentation is syphoned off and then later used to separate the ethanol product from water. The gas stripping method would slightly modify the separation process that was discussed earlier in section "3.1 General Refining Process and Base Case" of this essay. Instead of entering a distillation column, the ethanol, water, acid and corn mixture that exits the fermenter is sent to a flash unit. In this flash unit, the CO₂ that was syphoned off the fermenter would be pushed through the flash vessel so the CO₂ could mix with and evaporate the ethanol out of solution, leaving excess reactants and water to be disposed of. The mixture of ethanol vapor and CO₂ is sent to a cooling unit so the gradual condensation of ethanol back into liquid form can occur. Once the condensation of ethanol begins to occur, it is then sent to a second cooling tower that operates at a cooler temperature to completely condense the ethanol before it is recovered in a second flash tank. The CO₂ being used as a stripping gas is removed from this ethanol and water mixture and will either be sent to a scrubber or possibly to a carbon capture system, if ever implemented (Busboom et al. 2021). The remaining ethanol and water mixture will be sent to a distillation column to separate the ethanol from the water. Figure 3 below provides a general schematic of this process:

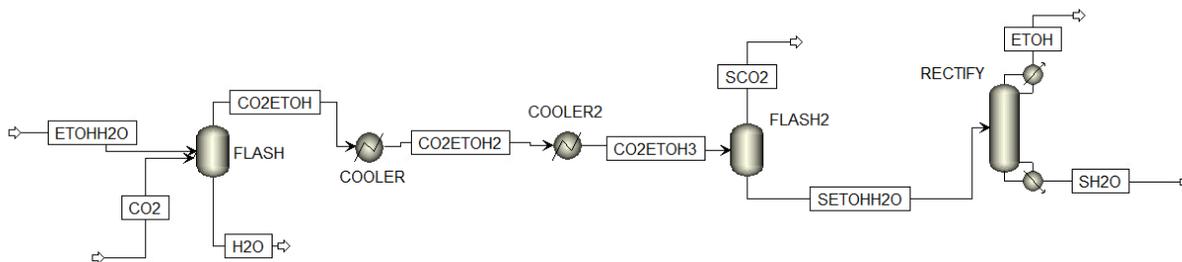


Figure 3: A Schematic of the Gas Stripping Process

Utilizing the gas stripping method would allow for one distillation column to be removed, and in its place two flash units and two coolers would be added, which are far cheaper pieces of equipment than a distillation column. In addition, gas stripping was determined to have lower utility costs than the original two distillation column method. It was calculated that annual utilities using the distillation method cost \$23,726,844.37 whereas the utilities utilizing the gas stripping method only cost \$2,630,012.11. The reason why the utility costs are so high for the distillation method is because distillation columns require a large input of energy to operate. Distillation is widely used in industry and “...accounts for over 35% of the energy used in U.S. chemical manufacturing” (Constable 2016). As a result, if more plants moved toward a process like gas stripping that consumes less energy than distillation, it could have positive environmental impacts across the U.S. and therefore lower the amount of energy consumed by chemical manufacturing.

However, although the utilities were drastically lower for the gas stripping method, it comes at a cost. Utilizing the distillation method allowed for 28,163 kg/hr of ethanol to be produced with a purity of 99.2% whereas the gas stripping method only produced 4,000 kg/hr of ethanol at a lower purity of 86.8%. If gas stripping is predicted to produce only 1/7th of the amount of ethanol that distillation can, this would result in a significant loss of revenue to the plant. Because the emissions from both gas stripping and distillation are relatively the same, it can be concluded that gas stripping is not an economically viable option and the benefits to distillation outweigh its large operating costs.

5. My Contributions

My major contributions to my group’s senior design project mainly included an extensive economic analysis of the plant and its basic operations, along with a discussion on the major process safety hazards within the plant and how to mitigate those hazards.

5.1 Economics

Once our plant was created using a modeling software known as Aspen Plus, it was my job to go through and determine prices such as the total equipment cost, utility and operating costs, direct and indirect plant costs, and overall net profit to determine if this plant is economically feasible. All economic calculations were based on an assumed 350-day operating year and that the plant contained natural gas fired heaters (i.e., none of the alternative cases discussed above were factored into these calculated costs).

Material Costs

I created a production cost estimate to determine the material costs and profits associated with the operation of the plant. The ethanol plant's gross cost of raw materials includes the cost of shelled corn and fuel-grade naphtha, which is \$127,220,000/year. The plant was designed to profit off selling its byproducts such as dried distillers' grains (DDGs) and carbon dioxide. Selling these byproducts results in a \$46.35 million credit a year on average, which brings the cost of raw materials down to \$80,870,000/year (net cost). In addition to purchasing DDGs and fuel-grade naphtha, the plant also must purchase catalysts and chemicals such as sulfuric acid, alpha-amylase and glucoamylase enzymes to aid in the refining process, which have a total cost of \$3,180,224.82/year. Yeast is not included into this annual price because we are assuming we will be able to produce our own yeast within our facility so we would not have an annual cost of yeast after our initial purchase of it, which is taken into account in our working capital investment (Busboom et al. 2021). Combing the net cost of raw materials with the catalyst and chemical expenses results in a total annual materials cost of \$84,062,424.82/year. I determined these prices by researching the market cost of each material in conjunction with the annual amount of material needed for the refining process, which are summarized in Table 1 below.

Table 1: Summary of Raw Materials, Byproducts and Catalysts and Chemicals

Raw Materials						
Material	Market Price	Unit	Amount	Unit	Annual Price	Unit
Shelled Corn	6.71	c/lb.	1,720,000,000	lbs.	\$115,412,000.00	\$/yr.
Fuel-Grade Naphtha	88	c/kg	13,400,000	kg	\$11,792,000.00	\$/yr.
Gross Cost of Raw Materials					\$127,204,000.00	\$/yr.
Byproducts						
Material	Market Price	Unit	Amount	Unit	Byproduct Credit	Unit
DDGs	8.61	c/lb.	538,000,000	lbs.	\$46,321,800.00	\$/yr.
Net Cost of Raw Materials					\$80,882,200.00	\$/yr.
Catalysts and Chemicals						
Material	Market Price	Unit	Amount	Unit	Annual Price	Unit
Yeast	\$0	\$/g	6043.18	g	\$0	\$/yr.
H ₂ SO ₄	\$0.17	\$/kg	0.521	kg/s	\$2,678,356.80	\$/yr.
a-amylase	\$1.80	\$/kg	0.00855	kg/s	\$465,393.60	\$/yr.
glucoamylase	\$6.30	\$/g	5789.59	g	\$36,474.42	\$/yr.
Total Cost of Catalysts and Chemicals					\$3,180,224.82	\$/yr.
Total Cost of Raw Materials, Catalysts and Chemicals					\$84,062,424.82	\$/yr.

Each of these materials are necessary to produce fuel-grade ethanol, and all amounts of these materials were estimated using the created Aspen Plus simulation. Because the plant is estimated

to produce 86 million gallons of ethanol and it sells at a market price of \$1.41/gallon, I calculated that the plant should have an annual revenue of \$121,260,000 from ethanol production alone (United 1).

Operating Costs

Operating costs encompass two major expenses: labor costs and utility costs. I’ve estimated our plant’s labor costs to be around \$3,000,000/yr minimum. However, this cost is just an estimation because I only appraised the salaries of employees who are responsible for the safe operation of the plant such as an operations manager, two chemical engineers, a maintenance supervisor, and so forth. There are most likely many other positions that would be involved such as a human resources department or contract workers for possible turnarounds, so our estimated price for labor is likely to be much larger. However, it’s difficult to determine this cost because it’s hard to accurately predict the exact size of the plant and the number of employees that are necessary for the smooth and safe operation of this plant. Table 2 summarizes how the \$3 million/year predicted labor costs were determined.

Table 2: Salary Breakdown of Different Plant Employees

Worker	Annual Salary	Number of Personnel	Total Annual Cost
Operations Manager	\$77,760.00	1	\$77,760.00
Plant Engineer	\$77,760.00	1	\$77,760.00
Maintenance Supervisor	\$72,000.00	1	\$72,000.00
Lab Manager	\$68,160.00	1	\$68,160.00
Shift Supervisor	\$58,560.00	4	\$234,240.00
Lab Technician	\$32,500.00	1	\$32,500.00
Maintenance Techs.	\$42,000.00	7	\$294,000.00
Shift Operators	\$38,400.00	18	\$691,200.00
Yard Employees	\$26,000.00	28	\$728,000.00
General Manager	\$96,000.00	1	\$96,000.00
Clerks and Secretaries	\$39,360.00	5	\$196,800.00
Chemical Engineer	\$69,120.00	2	\$138,240.00
Safety Manager	\$70,080.00	1	\$70,080.00
Production Manager	\$84,480.00	1	\$84,480.00
Total			\$2,861,220.00

The major utilities associated with the ethanol plant include electricity along with steam and cooling water for heating and cooling purposes. I determined the utility cost to be \$13,662,600/yr – assuming natural gas fired heaters – based upon steam and cooling water usage data from the modeled plant in Aspen Plus and the price of electricity for a commercial business in South Dakota, which is the state my team hypothetically chose to build the plant in. The breakdown of these utility costs are shown in Table 3 below.

Table 3: Breakdown of Electricity, Steam and Cooling Water Utility Costs

Base Case Utilities				
Material	Cost	Unit	Annual Price	Unit
Electricity	26.73	\$/hr	\$ 224,532.00	\$/yr.
Cooling Water	134.39	\$/hr	\$ 1,128,876.00	\$/yr.
Steam	1,476.94	\$/hr	\$ 12,406,296.00	\$/yr.
Natural Gas	3,2815.29	\$/day	\$ 11,485,351.50	\$/yr.
Total			\$ 25,245,055.50	\$/yr.

Because the facility uses natural gas fired heaters and burners, there will be an annual expense to the plant to purchase natural gas. I calculated that plant requires a total heat duty of 7,721.2 MMBtu/day and assuming that the heaters operate at an efficiency of 80%, the plant will therefore consume 9,651.6 MMBtu/day to account for burner inefficiency. I estimated the cost of natural gas to be \$11,485,352.95/year. Adding utility costs, labor costs and natural gas expenses together – and assuming no carbon tax is being imposed by the government – the plant’s total annual operating costs will be \$28,106,276.95/year.

Equipment Costs

I determined the plant’s equipment costs by using the different equipment pricing plots in the Peters and Timmerhaus textbook based on equipment information given to us from the Aspen Plus simulation. In some cases, the equipment size was either too big or too small for the ranges on the plots to determine the price for certain pieces of equipment, so I had to use the following equation to scale up the cost:

$$cost\ a = cost\ b * \left[\frac{size\ a}{size\ b} \right]^{0.6} \quad \text{(Equation 1)}$$

Where:

Cost a = the actual price of the equipment

Cost b = the reference price

Size a = the actual size or capacity of the equipment being cost estimated

Size b = the reference size

Because the prices in the plots from the Peters and Timmerhaus textbook were current as of 2002, I had to scale the prices up to 2018 to account for inflation. 2018 was chosen because that was the most current CE index I was able to find in order to perform this calculation and adjust equipment prices accordingly. This process was done for every single piece of equipment shown in Figures 1 and 2 above. I calculated the total purchased equipment delivered cost for the entire plant – solids processing, saccharification and fermentation, and separations – to be \$17,645,856.94. This price takes into account the estimated 9% delivery fee for each piece of process equipment. Table 4 below shows a breakdown of the equipment costs for each major section of the plant.

Table 4: Summary of the Equipment Costs for Each Major Plant Section

Equipment Costs	
Equipment Section	Cost
Solids Handling	\$ 14,124,675.18
Saccharification and Fermentation	\$ 1,627,748.86
Separations	\$ 1,893,432.90
Total	\$ 17,645,856.94

Direct and Indirect Plant Costs

Using Table 6-9 from the *Plant Design and Economics for Chemical Engineers'* textbook, I was able to calculate the direct and indirect plant costs for a solid-fluid processes plant (Peters 2006). The direct plant costs encompass purchased equipment price, installation, instrumentation and controls, piping, electrical systems, buildings, yard improvements, and service facilities whereas the indirect plant costs include the cost of engineering and supervision, construction expenses, legal expenses, contractor's fee, and contingency (Busboom et al. 2021). In order to determine each component of a direct or indirect plant cost, the price of each piece of equipment was multiplied by a ratio specified for that specific component and divided by 100 (Busboom et al. 2021). For example, if the piping price for one of the heaters needs to be determined, then the total equipment price for that heater needs to be multiplied by a ratio of 31/100 (Busboom et al. 2021). Figure 4 below shows the ratio values used to determine the direct and indirect plant costs.

	Ratio
FOB	91
Delivery	9
Direct Costs	
Purchased equipment delivered	100
Purchased equipment installation	39
Instrumentation and controls	26
Piping	31
Electrical systems	10
Buildings	29
Yard Improvements	12
Service facilities	55
Total direct plant cost	302
Indirect Costs	
Engineering and supervision	32
Construction expenses	34
Legal expenses	4
Contractor's Fee	19
Contingency	37
Total indirect plant cost	126
Fixed-capital investment	428
Working capital (15% of total capital)	75
Total capital investment	503

Figure 4: Costing Ratios of a Solid-Fluid Processing Plant

Using the process described above, I calculated the total direct plant cost to be \$53,290,487.96 and the total indirect plant cost to be \$22,233,779.75. Adding these two values together produces a fixed capital investment of \$75,524,267.71. The working capital investment is assumed to be 15% of the fixed capital investment and it is estimated to be \$13,234,392.71. Next, adding the working capital investment to the fixed capital investment gives us a total capital investment of \$88,758,660.41. This total capital investment price is the total cost it would take to build the plant completely from scratch.

Predicted Revenue and Gross Profit

To reiterate, I determined the plant's predicted revenue of fuel grade ethanol to be \$121,260,000/year. Using this information, I created a cash flow sheet to determine when the plant will pay off its capital investment and begin making profit. The net revenue, capital investment costs and all plant expenses – utilities, labor costs, etc. – were taken into account on the cash flow table. Total annual expenses were determined to be \$152,770,000; the tax rate was assumed to be 21%, the discount factor investment rate is 10%, and the fixed capital investment amount was split evenly over years -1 and 0 (Busboom et al. 2021). 0 is used to denote the year the plant actually begins to operate, so any negative year refers to plant construction. A MACRS depreciation rate for a 20-year recovery period was used to determine the depreciation factor (i.e., the rate at which the equipment in the plant is assumed to depreciate at) (Busboom et al. 2021). The MACRS depreciation rate can be found in Table 7-9 in the Peters and Timmerhaus textbook (Peters 2006).

Using the cash flow sheet, it is estimated by the payback period that we will have paid off our initial capital investment and will start making money by year 9. Starting in year two, I calculated that the plant would have a yearly gross profit of \$14,840,000 each year and by year 25, it will have a cumulative cash flow of \$222,560,000. Our internal rate of return, which estimates the profitability of potential investments, is 12%. This means that my team's hypothetical ethanol plant would theoretically be a good investment.

5.2 Process Safety

Process safety is one of the most important guidelines to consider when creating or operating any type of industrial machinery to ensure both the safety of the employees and the preservation of the environment. It is defined as “a discipline that focuses on the prevention of fires, explosions, and accidental chemical releases at chemical process facilities” along with the “prevention of, preparedness for, mitigation of, response to, or restoration from catastrophic releases of chemicals or energy from a process associated with a facility” (Introduction 2016). Being mindful and proactive about process safety will not only prevent environmental and safety hazards from occurring, but also will mitigate the effects of these hazards if they happen to occur.

My major contribution to process safety was to create a risk matrix and perform risk ranking assessments of identified hazards within the plant. “...in the process industries, understanding the risk associated with an activity requires answering the following questions:

- What can go wrong? (human injury, environmental damage, or economic loss)
- How bad could it be? (magnitude of the loss or injury)
- How often it might happen? (likelihood of the loss or injury) (Introduction 2016)”

In order to answer these questions regarding the corn to ethanol plant, I created a risk matrix that would evaluate the risks associated with each aspect of the plant and its corresponding operations (Busboom et al. 2021). A risk matrix assesses the level of risk associated with a situation or scenario based on its business impact, environmental, and safety and health consequences, and its likelihood of occurrence (Busboom et al. 2021). Based on this consequence's likelihood and the severity, the risk is categorized from the risk matrix on a zero to five scale with 'zero' being most tolerable and 'five' being most intolerable (Busboom et al. 2021).

In order to risk rank the entire plant using the risk matrix, all plant-wide hazards were first identified and ranked as either low, medium or high risk (Busboom et al. 2021). Those hazards that were identified as high risk, such as rotating equipment, over-pressurized pipes, control malfunctions, fall risks, etc. – were then assessed using the risk matrix to determine its risk category. For example, the risk of injury from rotating equipment in the fermentation and saccharification section of the plant was determined to be high because it could result in serious injury or even death, along with damage to the process equipment and business operations. Using the risk matrix – which is too large to include in this paper – the likelihood of this scenario occurring was deemed to be a '4' (probable) with a consequence of a '3' (critical). This produces an overall risk score of a '2', which is categorized as undesirable and proper precautions and safety measures should be taken in order to prevent this event from happening.

In the entire plant, I only identified 22 out of 72 possible scenarios as being high risk. Performing a risk ranking on the 22 identified high risk scenarios resulted in an average score from the risk matrix of a '1.6'. Because the highest possible score from the risk matrix is a '5', this shows that overall risk associated with the plant and its operations is relatively low. No score higher than a '3' was ever produced when using the risk matrix to risk rank the 22 high risk scenarios. The plant being relatively low risk makes sense because most of the operating pressures and temperatures utilized within the plant fail to exceed levels that could cause serious damage or injury. The biggest risk associated with the plant is environmental damage due to ethanol leaks (it's flammable) or bodily injury due to improper handling of rotating equipment. Although this hypothetical plant is relatively safe and low-risk, measures should continuously be taken to further improve the safety of the plant.

6. Conclusion

In conclusion, with a huge push towards renewable fuel sources, the refinement of corn into fuel-grade ethanol looks like a very promising alternative. Ethanol is far more environmentally friendly than petroleum-derived fuels such as gasoline and diesel, and it should therefore be further researched in order to help combat global warming. Making changes to the ethanol refining process by implementing technology such as carbon capture and gas stripping can drastically reduce the plant's overall carbon footprint. Through the analysis of different alternatives that could be implemented to the ethanol refining process, it can be concluded that the option that provides the most environmental benefits is the implementation of a carbon capture system. Although electric heat and gas stripping provide some environmental benefits, they just are not economically feasible and would most likely put the plant out of business. This project not only allowed me to apply many aspects of my education, but it also allowed me to learn how processes can be improved to better fit environmental needs. It was a very rewarding

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27e95805f5fe&sid=3765c5848d3e634fc84b59d02ea07d8fcb3bgxrqa&type=client.

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