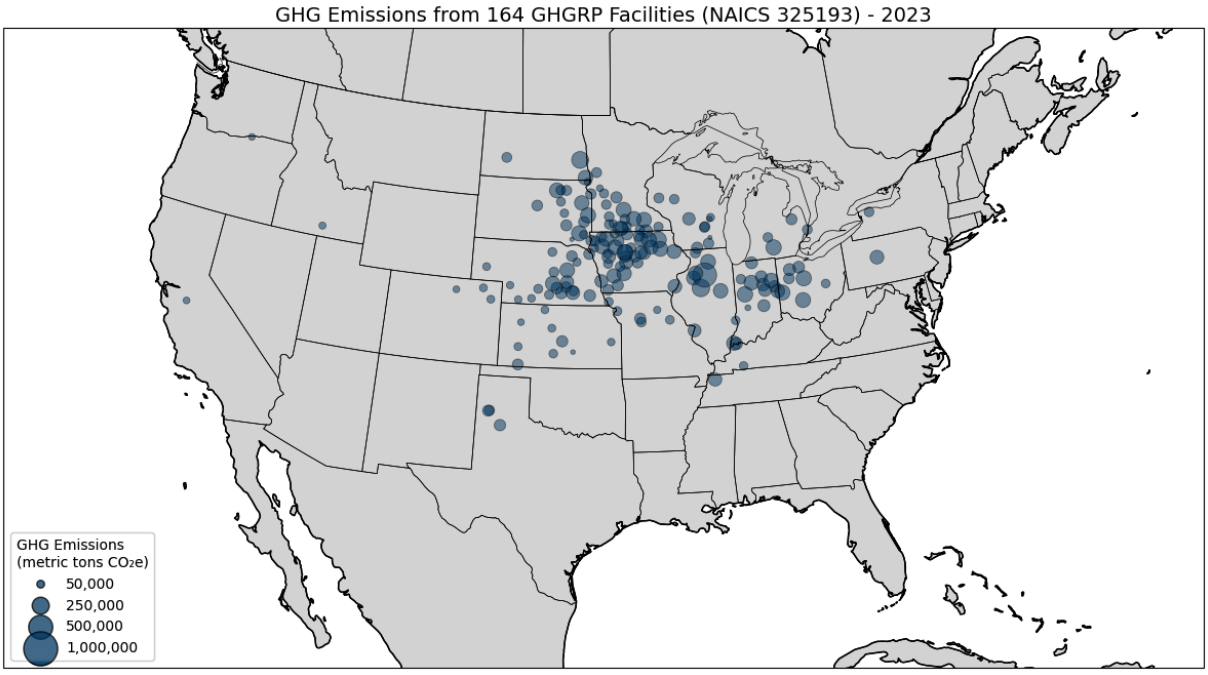
UC SANTA BARBARA
The 2035 Initiative

NAICS Code: Ethyl Alcohol Manufacturing (325193)
DATE UPDATED: 3/4/2026
Authors: Aidan O'Neil*, Antoine Merlo, Madeline Ranalli, and Eric Masanet
ARCHETYPE CODE:
https://github.com/ISALGroup/archetypes/blob/main/archetypes_list/archetype_ethanol_plant_final.py
ARCHETYPE NAME: Ethyl Alcohol Manufacturing

SUMMARY: The U.S. is the largest ethyl alcohol (or ethanol) producer in the world.[1] Ethyl alcohol manufacturing converts milled corn to ethanol–also known as grain alcohol–through fermentation and distillation. Ethyl alcohol is used for many purposes, including as an additive in gasoline, as a biofuel, and as a disinfectant. It is also used as a solvent in various chemicals, plastics, household cleaners, cosmetics, and paint. Ethyl alcohol production is vital to rural economic success, contributing $53 billion to U.S. GDP in 2024 by creating robust, stable markets for American corn. It is also a major employer in midwestern states, directly supporting 56,000 jobs and over 258,000 additional indirect jobs.[2]

Emissions and facility overview: According to the United States Census Bureau, there are 207 establishments associated with NAICS 325193 in the United States, 165 of which report annual GHG emissions in the GHGRP.[3] Reported emissions from GHGRP amounted to 19.7 Mt CO2e in 2023. The majority of these plants are concentrated in Iowa, Minnesota, and Indiana, as shown in the map below.



[1] Renewable Fuels Association. Annual Ethanol Production.
[2] Renewable Fuels Association. Why is Ethanol Important?
[3] U.S. Census Bureau. NAICS Code 325193: Ethyl Alcohol Manufacturing. In North American Industry Classification System (NAICS). 2022; U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). 2025.

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Sector outputs: Unlike NAICS 311211, which produces limited amounts of potable ethanol, the ethanol manufacturing sector produces non-potable ethyl alcohol.[4] A majority of these plants produce ethyl alcohol from corn.[5] However, sorghum, milo and other cereal grains are also used. This study focuses on ethyl alcohol production from corn. Ethyl alcohol manufacturing also generates dried distillers grain as a byproduct.

Process pathways: There are two primary methods to produce ethyl alcohol: wet corn milling and dry corn milling.[6] In the United States, 92% of production is done via dry corn milling,[7] thus the archetypes for NAICS 325193 are based on a dry corn milling process. We model the whole manufacturing process for non-potable ethyl alcohol production.

Dry corn milling converts bushels of corn into ethyl alcohol by mechanically breaking the parts of a corn kernel. Following the breaking of the kernel, all parts of the corn are processed, limiting the need for further separation, but also decreasing the overall mass efficiency of the processing.[8] In some facilities, the corn kernels are further separated to recover corn oil, as not every part of the kernel can be converted to ethyl alcohol.[9] This reduces the mass flow of distillers grain byproducts produced in the byproduct production line.

This archetype does not account for corn oil separation, instead focusing on non-edible corn products. In reality, according to GHGRP, two out of 27 manufacturing facilities within 311211 document 325193 as a secondary NAICS, implying the presence of corn oil processing.[10] Nine facilities also have NAICS code 325193 as a secondary NAICS code. Wet corn milling (311221), distilleries (312140), other starch manufacturing (31122), and basic organic chemicals manufacturing (325199) are all processes that occur at some facilities in combination with ethyl alcohol manufacturing which are excluded from the ethyl alcohol archetype.

Process Overview: Figure 1 documents the full conversion process from corn bushels to ethanol and dry distillers grain. Ethyl alcohol manufacturing is highly linear, meaning that unlike a lot of other sectors, the mass of corn going into the first unit process remains the same throughout further processes without a major break. We divide the process into four major pathways: corn receiving and processing, saccharification and fermentation, ethyl alcohol production, and byproduct production.

After an ethyl alcohol facility receives corn, it first cleans the corn bushels, either via compressed air or water wash to remove dirt and debris. Following cleaning, the corn bushels are milled. During milling, corn falls down into the mill and large mechanical separators remove non-kernel components. Milling equipment, like hammermills, use electricity to crush corn kernels into a fine powder, using screens to

[4] U.S. Census Bureau. NAICS Code 325193: Ethyl Alcohol Manufacturing. In North American Industry Classification System (NAICS). 2022.
[5] Ethanol Producer Magazine. Ethanol plant data & production statistics.
[6] Ethanol Producer Magazine. Ethanol plant data & production statistics.
[7] Irwin, Scott. Trends in the Operational Efficiency of the U.S. Ethanol Industry: 2023 Update. 2024.
[8] Corn Refiners Association. Product Safety and Quality.
[9] The Andersons. Kernel growth stages.
[10] U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP) data for food manufacturing. 2023.

ensure uniformity of a flour size, which is controlled through the use of screens.[11]

Corn flour is then sent to a hydrolysis tank where water is mixed with the corn flour to produce a corn slurry, making the mixture easier to transport. The corn slurry then undergoes preheating in order to reach the temperatures necessary to convert the starch within the kernel into sugars digestible during fermentation. Preheating occurs at roughly 75 ℃. [12]

Liquefaction and saccharification convert the corn slurry from complex sugars naturally present within the corn kernel into simple sugars. During this process, long chain sugars are broken down via heat and enzymes. Liquefaction and saccharification occur at 90 ℃. This takes over three hours and requires minimal additional thermal energy demand due to insulation and preheating. Prior to fermentation, the heat from saccharification needs to be reduced in order for yeast to ferment the sugars. Fermentation occurs at 32 ℃ to avoid killing the yeast bacteria after saccharification. Facilities often use a heat exchanger to recover waste heat from the corn slurry to be used in other parts of the manufacturing process. This occurs in a knockout tank.

During fermentation, yeast and enzymes are added to the corn slurry to convert sugars into ethyl alcohol and carbon dioxide. Carbon dioxide is produced in a one-to-one molar ratio to ethyl alcohol. Fermentation also requires cooling water to maintain unit temperature, due to the exothermic nature of the reaction. Figure 1, shows the additional flow of cooling water to maintain steady temperature. More complex modeling of yeast recycling and carbon dioxide compression does exist, specifically where carbon dioxide pressurizes alcoholic beverages; however, our model does not include this. We find that 25.5% of 311211 facilities within GHGRP report within Subpart PP as suppliers of carbon dioxide. Once fermentation has occurred, facilities now have “beer” which needs to be separated and purified.

Ethyl Alcohol Production Line: Following fermentation, “beer” must be preheated to the inlet temperature before distillation. Beer is the mixture of 28 wt% ethyl alcohol, solids and water produced by fermentation. Preheating occurs at roughly 70 ℃. Then, a distillation system separates ethanol from water and solids in the beer stream.[13] Distillation normally occurs in two columns: the beer column and the rectifying column. In the beer column, ethanol is brought to a 50% by weight, or 100 proof, in the top of the column and excess water and solids fall out the bottom due to their different boiling points. After the beer column, 100 proof, or 50 wt%, ethyl alcohol is further distilled to achieve its maximum boiling composition, or azeotrope, of 95.6% ethanol and 4.4% water. Our process assumes a one-column system as the distillation process unit, shown in Figure 1, where the “bottoms” represent a high mixture of water and solids, and the “tops” represent this azeotropic composition. Distillation requires the most thermal energy demand within ethanol manufacturing. Furthermore, distillation is highly sensitive to operating parameters such as reflux ratio, reboiler duty, and the number of trays, making ethyl alcohol distillation an area for further exploration.

The highly enriched ethyl alcohol “tops” are then sent to a vaporizer where the liquid ethanol mixture is

[11] Homeland Energy Solutions. Ethanol Production 101 - Part 1. October 2015.
[12] Homeland Energy Solutions. Ethanol Production 101 - Part 2. October 2015.
[13] Homeland Energy Solutions. Ethanol Production 101 - Part 3. November 2015.

vaporized into a gaseous stream before being sent to a molecular sieve. In order to vaporize the mixture, process steam is used. Vaporization accounts for 26% of process heating. There, silicate beads are used to remove remaining water, and bring the ethanol stream to 99.7% ethanol, the standard for fuel grade ethanol. This process is physical, requiring no additional process heating.

Byproduct Production Line: The bottoms are sent to a centrifuge, to separate the solid and liquid based product. The remaining solids are the unreacted grains calculated using ethanol yield from a bushel of corn.[14] The centrifuge separates the bottoms into thin stillage and wet cake. Thin stillage is sent to an evaporator to increase the weight percentage of solids to 42%, with a unit temperature of 90 ℃.[15] Then, both the wet cake and stillage is sent to a dryer to reduce the moisture content even further, to 10% for production of dried distillers grain (DDGS). Dry distillers grain is produced in two ways: (1) in a direct-fired process heater or (2) a steam-based dryer. This can be found within GHGRP's unit type data, where grain dryers are documented under product or intermediate dryers.[16] This grain is then sent to farms where it is used as animal feed.

[14] Homeland Energy Solutions. Ethanol Production 101 - Part 4. April 2016.
[15] U.S. Department of Labor, Occupational Safety and Health Administration. Section IV: Chapter 5 - Ethanol processing. OSHA Technical Manual.
[16] U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP) Subpart PP – Suppliers of CO_2.

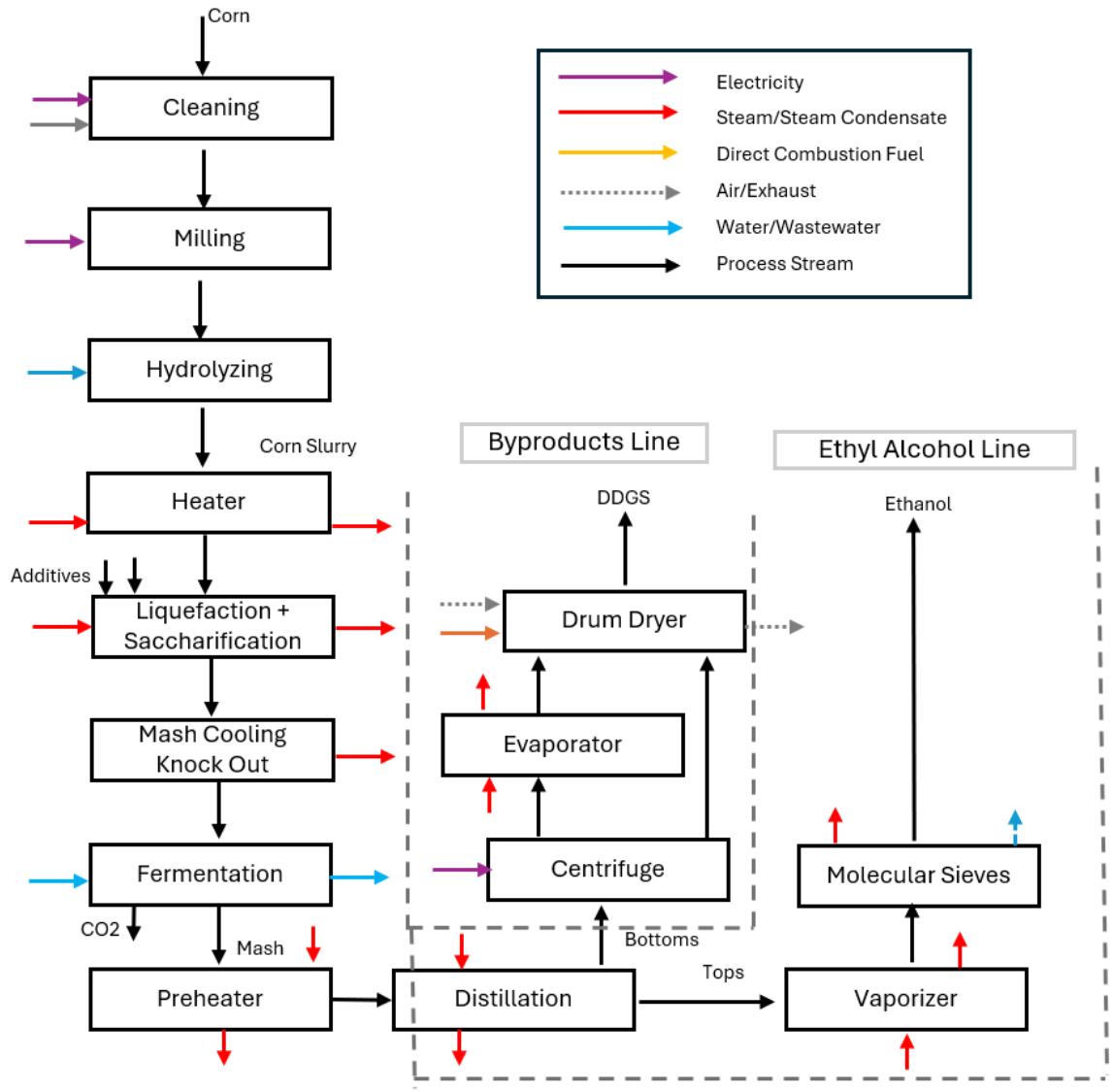


Figure 1: Ethyl Alcohol Archetype Process Flow Diagram

Archetype Unit Process Assumptions: Figure 1 depicts the unit processes, mass flows, and energy flows that are modeled in our process system archetypes. Table 1 below shows the assumptions made within each unit process of the archetype. We assume that density for ethyl alcohol is temperature independent. The density of ethanol is defined as 2.99 kilograms per gallon.

Model Comparison: Brown et al.[17] does not produce a model for ethyl alcohol manufacturing. We compared the output of the first principles archetype to four sources: Lawrence Berkeley National Laboratory's (LBNL) "Energy Efficiency Improvement and Cost Saving Opportunities for the Corn

[17] Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.

Wet Milling Industry,"[18] Gavin Chen's "Production of Ethanol," [19] the United States Department of Agriculture's (USDA) "The Energy Balance of Corn Ethanol: An Update,"[20] and Ethanol Producer Magazine's "Ethanol Plant List."[21] Because LBNL's analysis focused on a wet corn milling process rather than a dry corn milling approach, it was used as a reference for ethanol product yield per bushel of corn. Chen provides another estimate for ethyl alcohol yield per gram of glucose.[22] Table 1 documents our sector-wide assumption for ethanol yield within the fermentation unit process. Neither source was used to estimate thermal energy demand.

To compare the archetype and literature estimates for thermal energy intensity within USDA, we linked production outputs from the Ethanol Producer Magazine to facilities within GHGRP. We chose to use production data from Ethanol Producer Magazine because it provides publicly available, facility-level capacity and output data that can be cross-referenced with GHGRP-reported fuel use and emissions to calculate thermal energy intensity at the facility level. We found that our archetype estimated thermal energy intensity with an average percentage difference of less than 20% relative to the literature derived values and that the estimates fell within the USDA-reported range. Given its grounding in first-principles calculations, its validation against multiple literature sources, and its ability to produce facility-level estimates consistent with USDA-reported ranges, we believe our archetype provides the most current, accurate, and generalizable model of ethyl alcohol manufacturing available.

Limitations and future work: This process system archetype relies on sector-average assumptions for setting parameters such as ethyl alcohol yield per bushel of corn. This does not account for heterogeneity across plants, where market averages might not make sense. The model also excludes coproduct processing of corn oil, which could be present at certain facilities. We expect that these processes would increase overall thermal energy demand, also increasing the percentage of heat coming from other units associated with oil extraction. This model also simplifies distillation into a single column. In practice, a two-column configuration can improve overall thermal efficiency through enhanced heat integration and more effective use of overhead condensation.

Furthermore, this model assumes steady-state continuous operation without accounting for startup, shutdown, or batch effects indicated within the Homeland Energy Solutions process description.[23] Startup and shutdown both affect thermal efficiency, leading to decreased yields and higher energy intensities overall. Future work should explore these parameters as well as variations in seasonality and runtime. Future work should also explore using production estimates, like those in Ethanol Producer Magazine, to tune archetype parameters to an individual facility.

Table 1: Ethyl Alcohol Archetype Unit Process Assumptions

Unit Process	Assumptions	Parameter Basis	Reference

[18] Lawrence Berkeley National Laboratory. Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry. July 2003.
[19] Gavin Chen. Production of Ethanol with Corn Using Dry Milling Method. December 2016.
[20] Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
[21] Ethanol Producer Magazine. Ethanol Plant List.
[22] Gavin Chen. Production of Ethanol with Corn Using Dry Milling Method. December 2016.
[23] Homeland Energy Solutions. Ethanol Production 101 - Part 1. October 2015.

Name			
Cleaning	Compressed Air to Dirty Corn: 1.00	Engineering judgment	
	Electricity Demand: 0.092 kW/kg	Literature-derived	Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
Miller	Electricity Demand: 0.01 kW/kg[24]	Manufacturer-derived	Horning Manufacturing. Roller Mills. 2020.
Hydrolyzer	Water to Corn Ratio: 1/9.94	Literature-derived	
	Ethanol wt%: 29.4%	Sector Average	American Coalition for Ethanol. Corn Ethanol Carbon Intensity Calculator. Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
Heater	Heat Capacity of Corn: 2.42 kJ/kg ℃	Literature-derived	AgEcon. Preserving Grain Quality by Aeration and In-store Drying. October 1985.
	Unit Temperature and Outlet Temperature: 85 ℃	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 2. October 2015.
	Heat Loss: 10%	Engineering judgment	
Liquefaction + Saccharification Tank	Heat Capacity of Corn: 2.42 kJ/kg ℃	Literature-derived	AgEcon. Preserving Grain Quality by Aeration and In-store Drying. October 1985.
	Unit Temperature and Outlet Temperature: 90 ℃	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 2. October 2015.
	Additive Input Ratio: 0.0009	Sector Average	Homeland Energy Solutions. Ethanol Production 101 - Part 2. October 2015.
	Heat Loss: 10%	Engineering judgment	
Knockout Tank	Unit Temperature and Outlet Temperature: 32℃	Literature-derived	Isabela C. Almeida et al. Evaluation of different strains of *Saccharomyces cerevisiae* for ethanol production from high-amylopectin BRS AG rice (*Oryza sativa* L.) February 2022.
	Heat Loss: 10%	Engineering judgment	
Fermentation	Ethanol - CO_2 Molar Ratio: 1.00	Engineering judgement	
	Ethanol Molar Mass: 46.07	Engineering judgement	

[24] Horning Manufacturing. Roller Mills. 2020.

	CO_2 Molar Mass: 44.009	Engineering judgement	
	Heat Loss: 10 %	Engineering judgment	
Preheater	Unit and Outlet Temperature: 71.1℃	Literature-derived	Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
	Heat Loss: 10%	Engineering judgment	
Distillation Column	Ethanol Wt% Out: 95.6%	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 3. November 2015.
	Heat Loss: 15%	Engineering judgment	
	Reflux Ratio: 2	Engineering judgment	
	Boilup Percentage: .25	Engineering judgment	
	Tops Temperature: 78.2℃	Engineering judgment	
	Bottoms Temperature: 95℃	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 3. November 2015.
	Heat Capacity Ethanol: 2.44 kJ/kg ℃	Literature-derived	National Center for Biotechnology Information. PubChem Compound Summary for CID 702, Ethanol. 2026.
	Heat Capacity Corn: 2.42kJ/kg ℃	Literature-derived	AgEcon. Preserving Grain Quality by Aeration and In-store Drying. October 1985.
	Heat of Vaporization Ethanol: 885 kJ/kg	Literature-derived	National Center for Biotechnology Information. PubChem Compound Summary for CID 702, Ethanol. 2026.
Vaporizer	Heat Loss: 10%	Engineering judgment	
	Heat of Vaporization Ethanol: 885 kJ/kg	Literature-derived	National Center for Biotechnology Information. PubChem Compound Summary for CID 702, Ethanol. 2026.
	Heat Capacity Ethanol: 2.44 kJ/kg ℃	Literature-derived	National Center for Biotechnology Information. PubChem Compound Summary for CID 702, Ethanol. 2026.
Molecular Sieves	Heat Loss: 10%	Engineering judgment	
	Ethanol Wt% Out: 99.7%	Sector Average	Homeland Energy Solutions. Ethanol Production 101 - Part 3. November 2015.
Centrifuge	Electricity: 0.01 kW/kg	Manufacturer-derived	Giacomo Carraro et al. Solid-liquid separation of digestate from biogas

			plants: A systematic review of the techniques' performance. April 2024.
	Thin Stillage Solid wt%: 7.5%	Sector Average	Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
	Wet Cake Solid wt%: 65%	Sector Average	Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
Evaporator	Stillage Solid wt%: 42%	Sector Average	Hosein Shapouri et al. The Energy Balance of Corn Ethanol: An Update. USDA. July 2002.
	Unit and Outlet Temperature: 90 ℃	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 4. April 2016.
	Heat Loss: 10%	Engineering judgment	
Drum Dryer	Unit Temperature: 107℃	Literature-derived	Homeland Energy Solutions. Ethanol Production 101 - Part 4. April 2016.
	Heat Loss: 10%	Engineering judgment	
	Dried Distillers Grains (DDGS) Moisture Content: 10%	Sector Average	David W. Olson and Thomas Capehart. Dried Distillers Grains (DDGs) Have Emerged as a Key Ethanol Coproduct. October 2019.
	Heat Capacity Corn: 2.42kJ/kg ℃	Literature-derived	AgEcon. Preserving Grain Quality by Aeration and In-store Drying. October 1985.