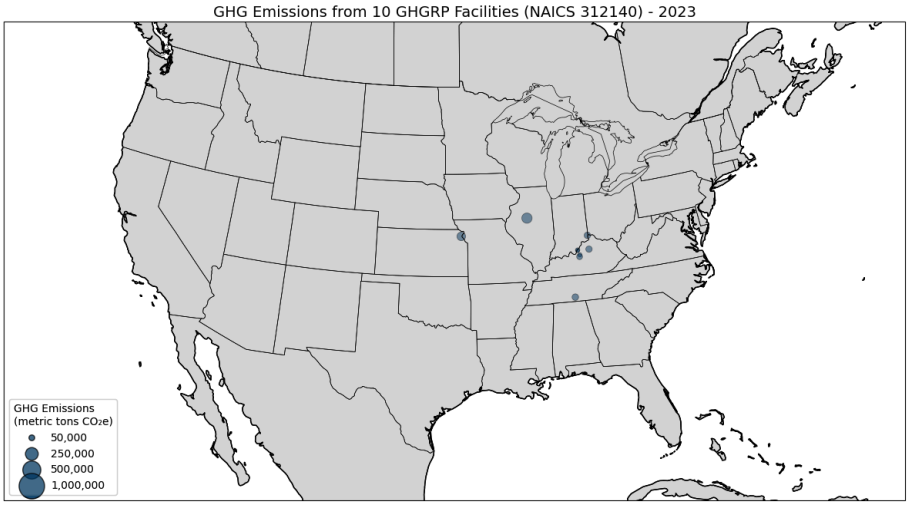
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The 2035 Initiative

NAICS Code: Distilleries (312140)
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NAICS Code: 312140
Link to archetype code:
https://github.com/ISALGroup/archetypes/blob/main/archetypes_list/archetype_distilleries_v2.py
Archetype Name: Whiskey Manufacturing

SUMMARY INFO: American distilleries manufacture alcoholic beverages including whiskey, bourbon, vodka, gin, and rum by blending, fermenting, and distilling grain. The U.S. distilling market has grown in recent decades, increasing its workforce by 214% in the past 20 years,[1] which has largely been driven by small-batch craft spirit production. American whiskey dominates distillery production, composing 63% of market exports, which have grown 280% over the past 20 years.[2] Distillery production is highly impacted by import tariffs in foreign markets, namely from the European Union.[3] American distillers generate over $37.2 billion in annual economic revenue, employ 27,500 workers,[4] and are known for deep regional ties to their areas of production.

Emissions and facility overview: According to the U.S. Census Bureau, there are 1349 establishments associated with NAICS 312140 in the United States, ten of which report annual GHG emissions in the GHGRP.[5] Reported emissions from GHGRP amounted to 642 thousand tons CO2e in 2023. The majority of these plants are concentrated in Kentucky. According to the American Craft Spirits Association, there are 2282 craft distillers in the US, meaning that there is a high potential for emissions reductions from small plants within NAIC code 312140.[6]



[1] U.S. Bureau of Labor Statistics. A Look at a Neat Industry: Distilleries. June 2023.
[2] Distilled Spirits Council of the United States. U.S. Spirits Exports Hit Record High in 2023 Driven by American Whiskeys. February 2024.
[3] Ibid.
[4] VerticalIQ. Distilleries Industry Summary.
[5] 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.
[6] American Craft Spirits Association. Craft Spirits Data Project 2025. 2025.

Sector outputs: The distilleries sector produces potable distilled spirits intended for human consumption such as whiskey, vodka, gin and rum.[7] Out of all of these beverages, whiskey has been the dominant spirit in domestic production.[8] From a mass and energy balance perspective, all spirits are made through the conversion of fermentable sugars to potable ethanol and water. This means, following fermentation, there should be few differences in process depending on the product. However, of the ten facilities within GHGRP, six are associated with well-known Kentucky whiskey companies. For these reasons, we choose whiskey as the main sector output for this model. Distilling also produces byproduct carbon dioxide, spent yeast, and dry distillers grain, a byproduct often sold as animal feed.

Process pathways: While there are multiple ways to make distilled spirits, variation in spirit manufacturing largely comes from one step: the distillation process. There are two approaches to distillation: (1) pot still distillation and (2) continuous distillation. In pot still distillation, distillation occurs through a batch process which occurs in a copper pot still. This produces a lower throughput but is often common in craft processes. Pot still distillation is either double or triple distilled, meaning the spirit is heated, condensed and collected multiple times to produce a different desired character.

In continuous distillation, the distillation process occurs in a distillation column and produces higher volumes of more consistent spirit.[9] This model focuses on continuous distillation as it is more representative of large industrial producers. However, according to Energy Star, continuous column still systems are generally more energy-efficient than pot still systems, while batch processes allow for demand flexibility.[10] Further work is necessary to determine if the benefits of demand flexibility outweigh the efficiency decreases for pot still system electrification. Distillation can also occur once or twice, with many spirits referred to as “single” or “double” distilled.

Variation in spirits manufacturing also arises from different inlet components or “mashes.” For vodka, the mash can be derived from feedstocks including cereal grains or potatoes. Rum mash comes from sugarcane derivatives such as molasses or sugarcane juice, while whiskey is derived from fermented cereal grains such as barley, corn, rye, or wheat. From a life cycle assessment (LCA) perspective, the mash is important for determining lifecycle emissions and energy use, but has limited impact on overall mass or energy balance.

According to GHGRP, one facility within the distilleries subsector has a secondary NAICS code for Ethyl Alcohol manufacturing (325193), meaning this facility may manufacture both potable and non-potable ethanol.[11] No facilities have a secondary NAICS code associated with distilling.

Process Overview: The process flow diagram shown below in Figure 1 summarizes the dominant distillation configuration. As mentioned above, American whiskey is the dominant U.S. distilled spirit by output. The modeled pathway includes mashing, fermentation, distillation, finishing and bottling, with temperatures and energy inputs tracked at each step. The process flow diagram can be further

[7] U.S. Census Bureau. NAICS 312140 – Distilleries (industry definition).
[8] Distilled Spirits Council of the United States. 2024 American Whiskey Category Fact Sheet. 2024.
[9] ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
[10] Ibid.
[11] U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). 2025.

divided into three process lines: (1) the primary line, (2) the product finishing line, and (3) the distillers grain line.

The process begins with a grain "mash bill" input that is mechanically milled to reduce particle size, thereby increasing surface area and facilitating efficient starch conversion in later stages.[12] The mash bill can be a variety of sugar-containing feedstocks, depending on the spirit being produced. Bourbon requires 51% of grain to come from corn.[13] Following milling, water is added to the mash to create a slurry for further processing. The gallonage, or water-to-grist ratio, is a key parameter in distillation and is defined as the ratio of water to grain solids used during mashing and fermentation.[14] Because this ratio determines the total process water required, it serves as a key driver for water demand and thermal demand per input basis.

The mash slurry is then heated in a mash cooker to a temperature range of 66 - 71 ℃ to break apart the long carbohydrates into digestible simple sugars for fermentation.[15] High temperature cooking prior to fermentation is standard for whiskey, with mash typically brought near boiling before cooling and yeast addition.[16] The mash is then cooled to prevent killing the yeast prior to fermentation. Cooling drops the temperature of mash to around 27.5 °C, the optimal temperature for fermentation. Fermentation converts simple sugars into ethanol via enzymatic activity,[17] producing carbon dioxide as a byproduct. In ethyl alcohol manufacturing and breweries, carbon dioxide is often captured, bottled, and sold as carbonation.[18] The stream leaving fermentation is referred to as "beer," a low-weight percentage mixture of ethanol, water, and unreacted solids.

Before distillation, the fermented beer is preheated to 71.1 °C.[19] Preheating reduces the marginal energy needed in the main still or distillation column and is a common efficiency measure, often using heat recovery from the hot stillage or vapor condensate.[20] Beer then enters the distillation column which separates the beer into an ethanol-rich overhead "tops" stream and a water/solids "bottoms" stream, where the vapor-liquid equilibrium sets the temperatures of the top and bottom of the column. Distillation is the most energy-intensive step in the production process. The "tops," or low wines, leaving the distillation column are a 55 wt% mixture of ethanol and water, while the bottoms are determined by the mass balance of unreacted solids, water, and trace amounts of potable ethanol. However, the low wines concentration is process and spirit specific, optimized at the individual facility to operating and spirit conditions.[21]

[12] Liz Rhoades. Grain to Glass: A Technical Overview of the Whiskey Making Process. March 2018.
[13] Liz Rhoades. Grain to Glass: A Technical Overview of the Whiskey Making Process. March 2018.
[14] Inge Russell. Whisky: Technology, Production and Marketing. 2003.
[15] Matt Strickland. Mash Chemistry 101. December 2019.
[16] Liz Rhoades. Grain to Glass: A Technical Overview of the Whiskey Making Process. March 2018.
[17] Kirsty Black and Graeme Walker. Yeast Fermentation for Production of Neutral Distilled Spirits. April 2023.
[18] U.S. Environmental Protection Agency. Mandatory Greenhouse Gas Reporting Rule: EPA's Response to Public Comments Volume No.: 41 Subpart PP—Suppliers of Carbon Dioxide. September 2009.
[19] ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
[20] Ibid.
[21] Ibid.

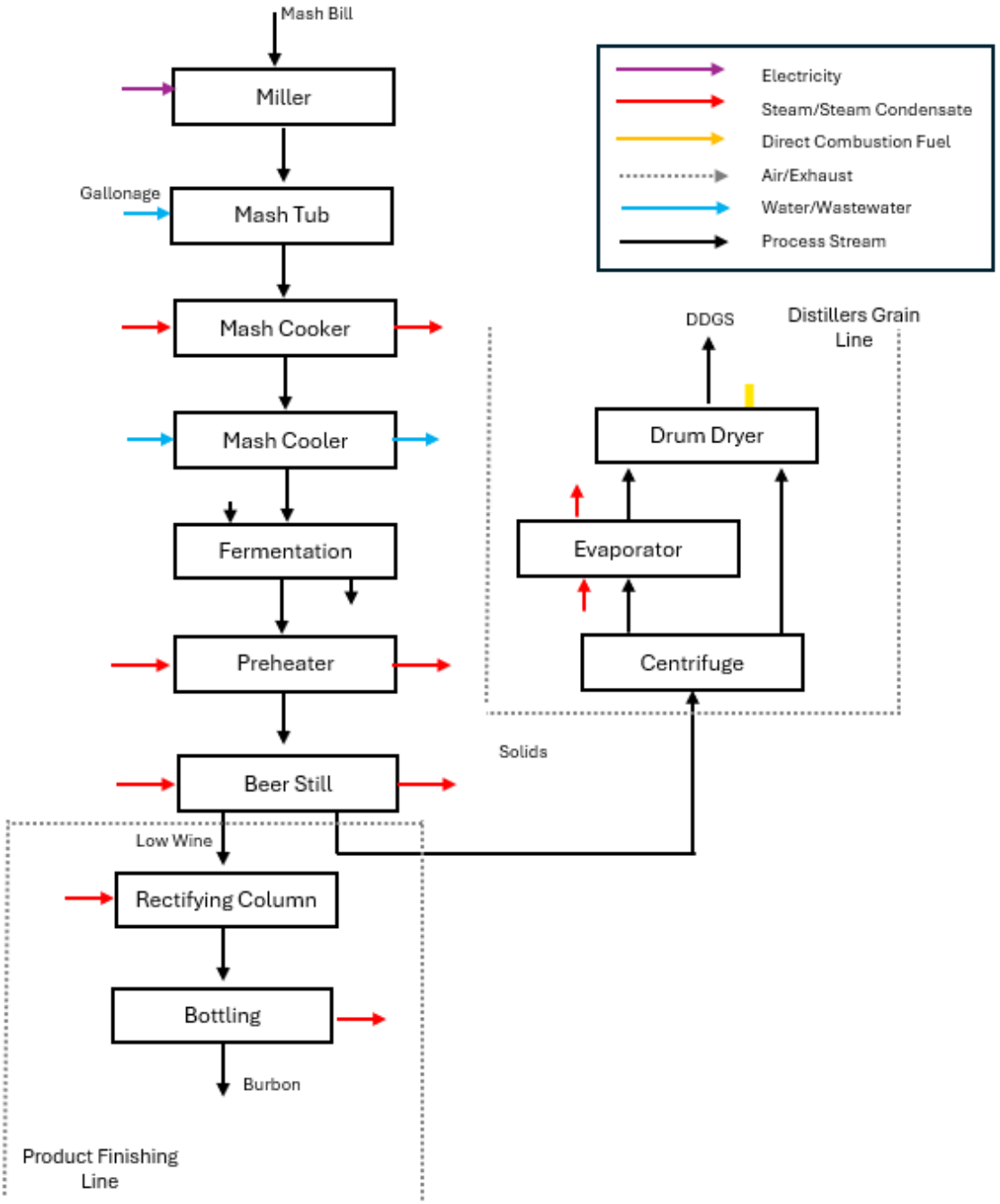


Figure 1: Process Flow Diagram for Bourbon Manufacturing

Product Finishing Line: The "tops" distillate, or low wines, is further refined in the rectifying column, where repeated vapor–liquid contact concentrates ethanol to produce a high-proof spirit stream which ranges in alcohol by volume from 40% to 70%, or 80 to 140 proof. In this step, the low wines are processed under controlled conditions to achieve the target alcohol strength, with additional separation of toxic byproducts such as methanol and higher alcohols. This column works like a repeated "cleaning

loop," where rising vapors and falling liquids repeatedly exchange components. Each cycle strips out more water and unwanted compounds, leaving a cleaner and more concentrated alcohol stream. The target spirit then undergoes bottling, maturation, or blending, depending on the spirit type.[22] Packaging energy is non-trivial but materially smaller than distillation heat loads in typical distilleries.[23]

Distillers Grain Line: The bottoms mixture of spent solids and water is transferred to a centrifuge where the majority of the spent solids are separated. This step separates the leftover solid grain material from the liquid portion of the mash using rapid spinning, which forces dense solids outward and leaves liquid behind. The solids exit the centrifuge as spent cake, a wet, fiber-rich material that contains protein and nutrients. This material is commonly sold as animal feed, making it a valuable coproduct rather than waste.[24] Dry distillers grain ranges in moisture content around 10-15% by mass, and is often sold to farms.

Archetype Unit Process Assumptions: Figure 1 depicts the unit processes, mass flows, and energy flows modeled in our process system archetype. Table 1 below shows the assumptions made within each unit process of the archetype. We assume a constant heat capacity of ethanol at 2.44 $\frac{kJ}{kg℃}$.[25] The range of cereal grain heat capacity span from 1.33 - 2.40 $\frac{kJ}{kg℃}$.[26] We also assume a constant heat capacity for cereal grain at 1.829 $\frac{kJ}{kg℃}$.

Model Comparison: Unlike other subsectors, a distilling model does not exist within *108 Industrial Processes*.[27] Therefore, in order to develop and compare this model to existing studies, we consulted federal distilleries regulations, the *Alcohol Textbook*, and the Energy Star Distilleries Guide.[28] The Energy Star Distilleries Guide represents the best practices for energy efficient manufacturing of distilled spirits. The *Alcohol Textbook*, similar to *108 Industrial Processes*, represents an older manufacturing model of distilled spirits, and therefore represents a lower estimate for spirit manufacturing. We find a 38% increase in thermal intensity on an output basis when comparing the archetype output to Energy Star's thermal demand. Among Energy Star manufacturing plants, eight distilleries have energy efficiency certifications. Therefore, while we believe our archetype to be representative of the industry across the subsector, future work should explore refining thermal energy demand for units outside of the distillation column, preheating and fermentation, which have limited deviation in thermal energy intensity across the archetype and literature. Furthermore, we find sources that show increased electrified technology deployment in distilleries, which likely contributes to the increase in thermal demand within our archetype.[29] Future work should explore where distilleries have already electrified so as to not "double-electrify" these emissions.

[22] Liz Rhoades. Grain to Glass: A Technical Overview of the Whiskey Making Process. March 2018.
[23] ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
[24] Youngmi Kim et al. Composition of corn dry-grind ethanol by-products: DDGS, wet cake, and thin stillage. August 2008.
[25] U.S. Department of Commerce National Institute of Standards and Technology. Ethanol.
[26] Shinoj Subramanian and R. Viswanathan. Thermal Properties of Minor Millet Grains and Flours. March 2003.
[27] Harry L. Brown et al. Energy Analysis of 108 Industrial Processes
[28] National Archives. Subpart L - Production of Distilled Spirits. November 2025., Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003; ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
[29] Renewable Thermal Collaborative. Case Study: Diageo Lebanon Distillery. May 2022.

Limitations and future work: This archetype represents a generalized continuous distillation distillery to manufacture whiskey and therefore does not capture the full diversity of plant designs, operating conditions, and product slates observed across NAICS 312140. In practice, facilities vary widely in scale, equipment configuration, mash bills, proof targets, and aging practices, particularly between small craft distilleries and large industrial producers concentrated in Kentucky. Future work should explore how mash feed affects spirit yield and how variation in gallonage affects the thermal intensities of spirit production.

The model assumes continuous column distillation, which is appropriate for large plants but may misrepresent energy use in facilities relying on pot stills, hybrid systems, or electrified process heat. Given that electrification of unit processes within distillation has occurred, future work should explore where electrification has taken place, to avoid double counting the replacement of electric unit processes with electrified steam. Table 1 also documents two static thermal intensity demands, which are not derived from first-principles thermodynamic relationships but instead reflect aggregated process assumptions and literature. Future work should explore these parameters to develop a more rigorous first-principles formulation grounded in component-level mass and energy balances.

Table 1: Bourbon Manufacturing via Continuous Distillation Archetype Unit Process Assumptio

Unit Process Name	Assumptions	Parameter Basis	Reference
Miller	Electricity Demand: 0.000 kWh/kg		
Mash Tub	Gallonage: 35/56.0	Sector average	American Distilling Institute Forums. Grain/Water Ratio. Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003
Mash Cooker	Unit Temperature: 100 ℃	Literature-derived	Dennis E. Briggs et al. Brewing Science and Practice. 2004. Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003
	Heat Loses: 10%	Engineering Judgement	
	Steam Temperature: 110 ℃	Engineering Judgement	
Mash Cooler	Unit Temperature: 27.5 ℃	Literature-derived	Carlos J A de Souza et al. The influence of presaccharification, fermentation temperature and yeast strain on ethanol production from sugarcane bagasse. April 2012.
	Cooling Water High Temperature: 20	Engineering judgement	

	℃		
	Cooling Water Low Temperature: 5 ℃	Engineering judgement	
Fermentor	Unit Temperature: 29.44 ℃	Literature-derived	Carlos J A de Souza et al. The influence of presaccharification, fermentation temperature and yeast strain on ethanol production from sugarcane bagasse. April 2012.
	Ethanol wt% out: 9.5%	Literature-derived	Carlos J A de Souza et al. The influence of presaccharification, fermentation temperature and yeast strain on ethanol production from sugarcane bagasse. April 2012. ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022. Krzysztof Kucharczyk and Tadeusz Tuszyński. The effect of temperature on fermentation and beer volatiles at an industrial scale. September 2016.
	Ethanol Molar Mass: 46.07	Engineering Judgement	
	Carbon Dioxide Molar Mass: 44.009	Engineering Judgement	
	Yeast to Mash: (1/3800)	Sector average	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Cooling Water Inlet Temperature: 5 ℃	Engineering judgement	
	Reaction Enthalpy = 74 kJ/mol	Literature-derived	FermAxiom BioProcess Development. Ethanol Fermentation Heat Calculator. 2025.
Preheater	Unit Temperature: 71.1 ℃	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Steam Temperature: 100 ℃	Engineering judgement	
	Heat Loses: 10%	Engineering judgement	
Distillation Column	Ethanol wt% Out: 55%	Literature derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Heat Loses: 15%	Engineering judgement	
	Reflux Ratio: 2	Engineering judgement	
	Boiler Percentage: 25%	Engineering judgement	
	Tops Temperature: 78.2 ℃	Literature-derived	DIY Distilling. A Complete Guide To Distillation Temperatures

			(Explained!). November 2023.
	Bottoms Temperature: 95.0 ℃	Literature-derived	DIY Distilling. A Complete Guide To Distillation Temperatures (Explained!). November 2023.
	Heat Capacity Ethanol: 2.44 kJ/kg℃	Literature-derived	U.S. Department of Commerce National Institute of Standards and Technology. Ethanol.
	Heat Capacity Corn: 2.42 kJ/kg℃	Literature-derived	Y. Choi and M.R. Okos. Effect of Food Temperature and Composition on the Thermal Properties of Foods. 1986.
	Heat of Vaporization Ethanol: 855.0 kJ/kg	Literature-derived	U.S. Department of Commerce National Institute of Standards and Technology. Ethanol.
	Distillation Thermal Intensity: 5 MJ/L	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022. Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003
	Steam Temperature: 100 ℃	Engineering judgement	
Rectifier	Unit Temperature: 95℃	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
Bottling	Steam Dermand: 600 kJ/L	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022. Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003
	Steam Temperature: 100 ℃	Engineering judgement	
Centrifuge	Electricity Demand: 0.000 kWh/kg		
	Thin Stillage Solid wt%: 7.5%	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Wet Cake Solid wt%: 65%	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
Evaporator	Stillage solid wt%: 42%	Literature-derived	Amit Arora et al. Microfiltration of thin stillage: Process simulation and economic analyses. January 2011. Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003

	Heat Loses: 10%	Engineering judgement	
	Unit Temperature: 90 ℃	Literature-derived	Katherine Ann Jacques et al. The alcohol textbook: A reference for the beverage, fuel and industrial alcohol industries. 2003
	Steam Temperature: 100 ℃	Engineering judgement	
Drum Dryer	DDGS Moisture Content: 10%	Literature-derived	Iowa Renewable Fuels Association. Distillers Grain FAQs. ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Unit Temperature: 107 ℃	Literature-derived	ENERGY STAR. Energy Efficiency and Cost Saving Opportunities for Distilleries. February 2022.
	Heat Loses: 10%	Engineering judgement	
	Heat Capacity Corn: 2.42 kJ/kg℃	Literature-derived	Y. Choi and M.R. Okos. Effect of Food Temperature and Composition on the Thermal Properties of Foods. 1986.
	Steam Temperature: 117 ℃	Engineering judgement	