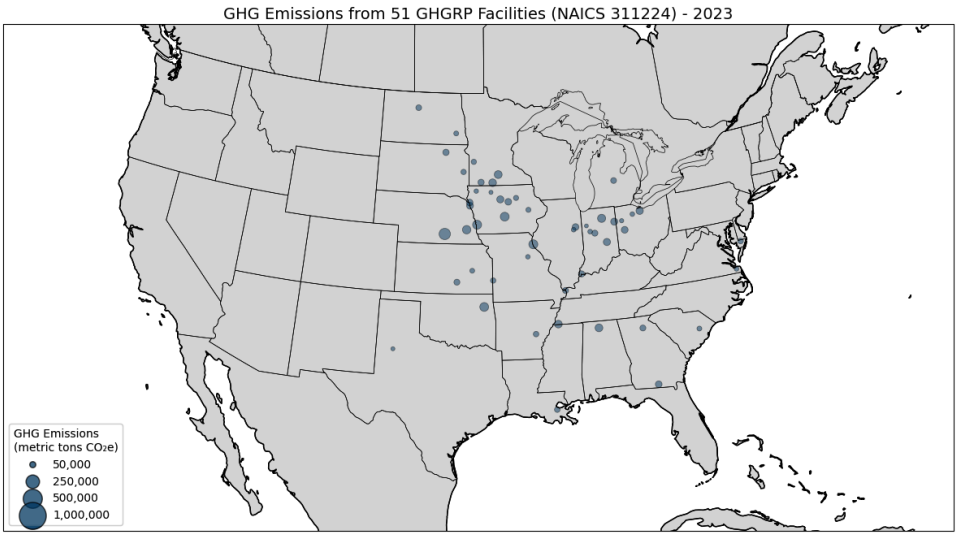
NAICS Code: Soybean and Other Oilseed Processing (311224)
DATE UPDATED: 3/12/2026
Authors: Aidan O'Neil*, Sanjana Ganti, Antoine Merlo, Madeline Ranalli, and Eric Masanet
ARCHETYPE CODE:
https://github.com/ISALGroup/archetypes/blob/main/archetypes_list/archetype_soybean_manufacturing.py
ARCHETYPE NAME: Soybean Oil Manufacturing via Hexane Extraction

SUMMARY INFO: The U.S. is the second-largest producer of soybean oil, generating 13.26 million metric tons in 2024 and accounting for 19% of global production.[1] Produced oil–commonly known as vegetable oil–is used in cooking and food production and as a feedstock for diesel fuel. As the largest agriculatural exporter in the United States, the soybean industry generates tens of billions of dollars in revenue each year, including $9.8 billion from soybean processing.[2] Soybean oil production employs 18,000 Americans in crushing facilities, and 280,000 Americans across its value chain.[3] Domestic soybean processing like oil production provides a stable market for American crops, stabilizing prices and minimizing dependence on export markets.[4]

Emissions and facility overview: According to the United States Census Bureau, there are 190 establishments associated with NAICS 311224 in the United States, 51 of which report annual GHG emissions in the GHGRP.[5] Reported emissions from GHGRP amounted to 2.9 Mt CO2e in 2023. The majority of these plants are concentrated in the Great Plains, as summarized in the map below.



[1] U.S. Department of Agriculture Foreign Agricultural Service. Production - Soybean Oil. 2025.
[2] United Soybean Board and National Oilseed Processors Association. The Economic Impact of the U.S. Soybeans & End Products on the U.S. Economy. August 2023.
[3] National Oilseed Processors Association. NOPA Brochure. 2023.
[4] United Soybean Board. The New American Engine: U.S. Soy Fuels Clean Energy, Biobased Products and Farm Resilience. July 2025.
[5] U.S. Census Bureau. NAICS Code 311224: Soybean and Other Oilseed Production. North American Industry Classification System (NAICS). 2022; U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). 2025.

Sector outputs: According to the US Census Bureau, NAICS code 311224 is responsible for producing seed oils, seed meals and other seed products.[6] We focused on soybean oil because it was the most-consumed seed oil in the United States in 2023 and 2024.[7] Refining and blending of purchased oils is captured within other NAICS codes. Soybean oil manufacturing plants can also produce soybean meal and soybean hull, two byproducts of lesser economic value.

Process pathways: There are multiple ways to make soybean oil. Processes to produce soybean oil include hexane extraction, mechanical pressing, aqueous extraction and supercritical carbon dioxide extraction. Hexane extraction and mechanical pressing represent the overwhelming majority of soybean oil production.[8] Mechanical pressing processes are often used in organic processing due to the lack of hexane usage.[9] However, this method has lower oil recovery rates, making it less prevalent at large industrial facilities. Mechanical processing also produces larger amounts of soybean meal, a byproduct of soybean oil manufacturing. We focused on hexane extraction methods because of its dominance in U.S. soybean processing. This method achieves very high oil recovery (optimized routes process oil at 98% recovery), has lower per-unit cost, and therefore best reflects typical industry practice compared to expeller/cold-press routes.[10]

In addition to oil extraction from oilseeds, NAICS code 311224 processing can include refinement of crude seed oils. Crude oil can be refined to remove phospholipids, fatty acids, pigments and trace contaminants. These processes are known as degumming, neutralization and bleaching. These refining steps occur at lower temperatures than extraction, but are still collectively significant in heat demand.[11] We do not include these unit processes within this archetype, instead focusing on production from raw oil seed to crude seed oil.

In GHGRP, some facilities within soybean oil manufacturing have secondary NAICS codes: Fats and Oil Blending (311225) and All Other Basic Inorganic Chemicals (235199).[12] Facilities with secondary NAICS 311225 are more likely to refine crude oil at their facilities. Soybean oil manufacturing is also a secondary NAICS code for Other Animal Food Manufacturing (311119) and Fluid Milk Manufacturing (311511). These processes are not included within the archetype.

Process Overview: The process flow diagram shown below in Figure 1 summarizes the dominant soybean crushing configuration. The process begins with bean receiving and preparation, followed by oil extraction and solvent recovery, then refining to produce edible-grade oil. Across the full pathway,

[6] Executive Office of the President Office of Management and Budget. North American Industry Classification System Manual. 2022.
[7] The American Soybean Association. U.S. Soybean Oil: U.S. Vegetable Oils Consumption. 2025.
[8] Qi'e Grain and Oil Machinery Co. Solvent Extraction vs Mechanical Pressing for Soybean Oil: Efficiency, Energy Use, and Plant-Scale Comparison. March 2026.
[9] Ibid.
[10] Ming-Hsung Chen and Kurt. A. Rosenstrater. Economic feasibility analysis of soybean oil production by hexane extraction. December 2017.
[11] R. Subramanian and M. Nakajima. Membrane degumming of crude soybean and rapeseed oils. August 1997; PBL Netherlands Environmental Assessment Agency. Decarbonisation options for the Dutch vegetable oil and fat industry. 2021; Harry L. Brown et al. Energy analysis of 108 industrial processes. 1996.
[12] U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP) data for food manufacturing. 2023.

most electricity demand is associated with mechanical handling and milling, while most thermal demand is tied to drying, conditioning, solvent evaporation and deodorization.[13] The process can be further broken down into the primary line, the soybean meal production line and the soybean oil line.

After soybeans arrive at the facility, they are sampled for moisture and impurities and cleaned to remove foreign material. Cleaning can occur using either water or compressed air. Cleaned soybeans are composed of three parts: germ, hull, and the soybean cotyledons. The soybean cotyledons make up the majority of the bean's weight and are the main source of soybean oil.

Soybeans have a typical moisture content of 13 wt%. In order to begin soybean oil extraction, the soybeans must be dried to 10 wt% within a dryer, either via steam- or direct-combustion drying units.[14] Drying occurs at a range of temperatures from 50 to 65 ℃.[15] Drying is often the single-largest heat consumer in the front-end crushing stage.[16] Following drying, cleaned beans are cracked into several particles to loosen hulls, the outermost casing not included in soybean oil or soybean meal production. It is therefore removed from the main process pathway, used as an additive to animal feed or for further processing as a fiber additive.

Following dehulling, the soybean oil-rich mass flow is sent to a conditioner, a thermal unit to soften the soybean cotyledons before flaking. Conditioning occurs at 60℃. Following conditioning, the soybean oil mass flow gets flattened into flakes to produce consistent surface area for oil extraction.[17]

Soybean oil is nonpolar, therefore hexane can be used as a solvent to dissolve the oil out of the soybean flakes to produce a mixture of hexane and soybean oil known as miscella. The spent flakes, or soybean meal, are then separated from the miscella, creating two production lines: a soybean meal line and a soybean oil line. Around 1.5% of the total mass of soybean oil is lost during extraction, as soybean meal still contains small amounts of oil.[18]

[13] Yong Li et al. Life cycle assessment of soybean oil production. 2006; PBL Netherlands Environmental Assessment Agency. Decarbonisation options for the Dutch vegetable oil and fat industry. 2021; Harry L. Brown et al. Energy analysis of 108 industrial processes. 1996.
[14] U.S. Environmental Protection Agency. AP-42 Emission Factor Documentation for AP-42 Section 9.11.1. November 1995; Harry L. Brown et al. Energy analysis of 108 industrial processes. 1996.
[15] Timothy G. Kemper. Meal Desolventizing, Toasting, Drying and Cooling. AOCS. July 2019.
[16] Yong Li et al. Life cycle assessment of soybean oil production. 2006.
[17] U.S. Environmental Protection Agency. AP-42 Emission Factor Documentation for AP-42 Section 9.11.1. November 1995; Harry L. Brown et al. Energy analysis of 108 industrial processes. 1996.
[18] Ming-Hsung Chen and Kurt. A. Rosenstrater. Economic feasibility analysis of soybean oil production by hexane extraction. December 2017.

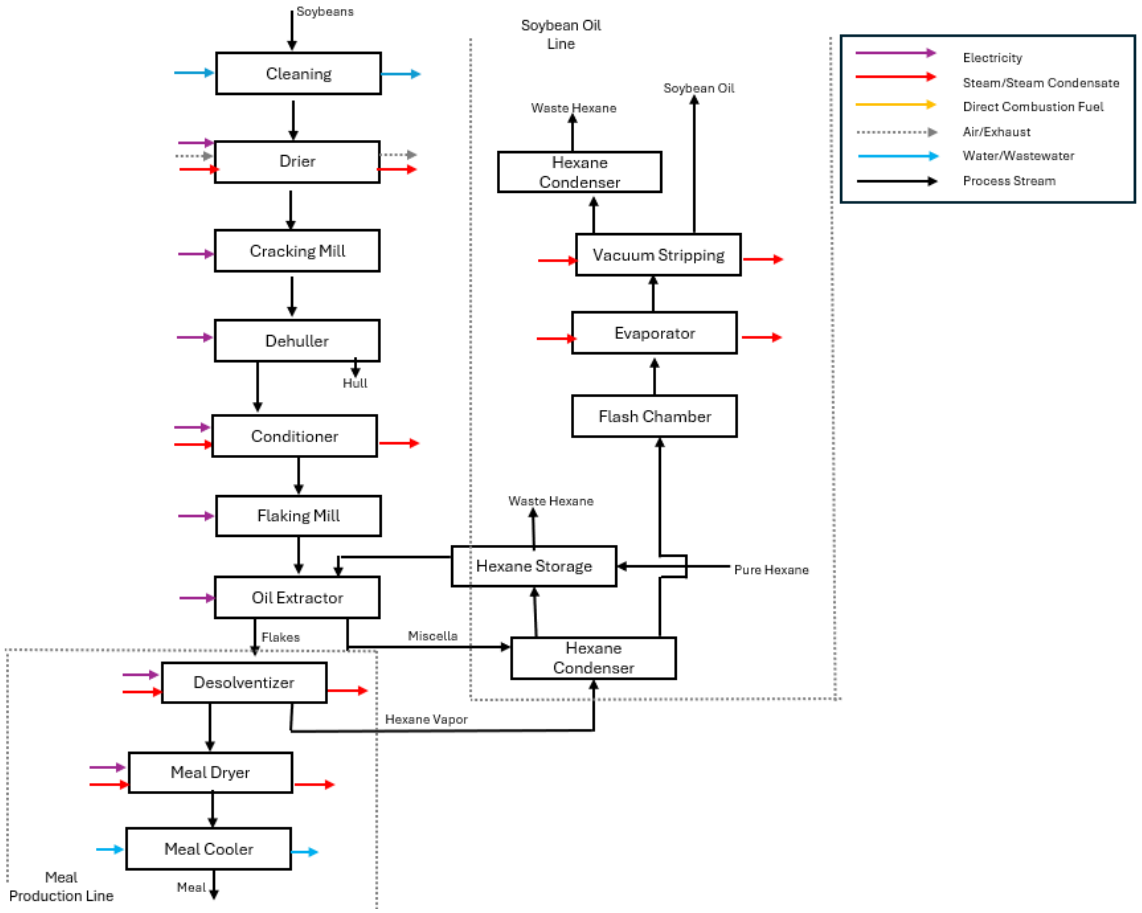


Figure 1: Process Flow Diagram for Hexane Extraction of Soybean Oil

Soybean Meal Production Line: Following oil extraction, solvent-laden spent flakes are sent to a desolventizer, where temperatures are increased to recover residual hexane. Hexane concentrations can range from 35-45% solvent by mass.[19] Hexane evaporation occurs at approximately 68 ℃, and the residual hexane is recycled to minimize how much raw hexane is needed for the process.[20] Following the desolventizer, the spent flakes are dried and chilled into animal feed, a coproduct of soybean oil manufacturing.

Soybean Oil Line: First, the miscella, a mixture of hexane solvent and oil, is routed to a hexane condenser and flash chamber. These two steps separate the majority of the hexane contained within the miscella, to produce a 0.35 wt% stream of hexane and soybean oil. Steam stripping is the final step to pure soybean oil. Hexane recovery systems typically include condensers, mineral oil scrubbers and hexane-water separators before the recycled solvent is stored.[21] This process models hexane recovery through condensation and flash evaporation to minimize fresh solvent demand. Despite high solvent recovery efficiencies, the extraction step requires a substantial circulating solvent flow: approximately

[19] U.S. Environmental Protection Agency. AP-42 Emission Factor Documentation for AP-42 Section 9.11.1. November 1995; Harry L. Brown et al. Energy analysis of 108 industrial processes. 1996.
[20] National Center for Biotechnology Information. PubChem Compound Summary for CID 8058, Hexane. 2026.
[21] Ibid.

0.93 kg of hexane per kg of soybeans entering the extractor.[22] This value reflects total solvent circulation rather than net consumption, as the majority of hexane is recovered and recycled via distillation, condensation, and stripping systems, with only small additional quantities required to offset system losses. Together, miscella evaporation and desolventizing account for the bulk oil steam requirement commonly reported for crushing and extraction.[23] The final product of this process is crude soybean oil.

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. This archetype assumes a constant heat capacity for soybean oil, soybean solids and hexane. Soybean has a heat capacity ranging from 0.7 to 1.0 $\frac{kJ}{kg℃}$.[24] We assume soybean solids has a heat capacity of 0.8 $\frac{kJ}{kg℃}$. Seed oils have heat capacities ranging from 1.88 to 2.00 $\frac{kJ}{kg℃}$.[25] We assume soybean oil has a heat capacity of 2.00 $\frac{kJ}{kg℃}$.

Model Comparison: In order to measure our archetype against prior studies, we compared two sources of thermal energy demand to the results of our archetype.[26] Modeled unit heat duties were normalized by mass flow into each unit and by total soybean oil output, then compared to published aggregate energy intensities for soybean preparation, drying, solvent extraction, desolventizing–toasting, evaporation, and deodorization. We compare it to Brown et al., which represents the broadest compilation of manufacturing models and has been widely used as the industrial standard.[27] As a secondary source, we consulted with AP-42 for understanding the process flow for soybean oil.[28] Ultimately, we find a 18% difference in overall thermal energy intensity when comparing a first principles approach to the output of Brown et al. These discrepancies can largely be explained by the increase in thermal demand within the dryer and conditioner. However, our models, based on first principles, represent a more thermodynamically efficient soybean oil production process, and therefore are likely closer to industrial standards than results produced in 1996 or 2003.

Limitations and future work: This archetype represents a generalized soybean oil manufacturing facility using conventional hexane solvent extraction and therefore does not capture the full diversity of plant designs, operating conditions and product slates observed across NAICS 311224. Furthermore, the archetype does not include crude seed oil refinement processes like degumming or bleaching, two unit processes which likely occur in NAICS 311224 following vacuum stripping. This model also does

[22] Fereidoon Shahidi. Bailey's Industrial Oil and Fat Products. April 2005.
[23] Yong Li et al. Life cycle assessment of soybean oil production. 2006; PBL Netherlands Environmental Assessment Agency. Decarbonisation options for the Dutch vegetable oil and fat industry. 2021; Jannick Schmidt. Life cycle assessment of rapeseed oil and palm oil. 2007.
[24] R. Paul Singh et al. Introduction to Food Engineering. December 2023.
[25] Muhammad Imran Sadiq et al. An Experimental Investigation of Static Properties of Bio-Oils and SAE40 Oil in Journal Bearing Applications. March 2022.
[26] Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996; U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Emission Factor and Inventory Group. Emission Factor Documentation for AP-42 Section 9.11.1. November 1995.
[27] Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.
[28] U.S. Environmental Protection Agency. Emission Factor Documentation for AP-42 Section 9.11.1 Vegetable Oil Processing Final Report. November 1995.

not focus on coproduct processing such as hull fiber extraction, soybean meal processing or soy milk manufacturing. We expect that adding co-product and refinement steps to this archetype would increase overall thermal energy demand of soybean processing; however, the percentage of in-scope heat would likely not change due to the low temperature requirements of coproduct manufacturing. For more information on seed oil refinement and milk processing, visit the archetype descriptions for Fluid Milk manufacturing (311511) and Fats and Oil Blending manufacturing (311225).

This archetype also only focuses on soybean oil extraction. Other seed oils are manufactured in the United States, and data does exist on the geographic distribution of these plants.[29] Future work should explore variations in seed oil manufacturing and how that affects industrial electrification.

Table 1: Soybean Oil via Hexane Extraction Archetype Unit Process Assumptions

Unit Process Name	Assumptions	Parameter Basis	Reference
Cleaner	Water to Soybean Ratio: 1.67	Engineering judgement	
Dryer	Water Evaporation Rate: .222/2.722	Literature derived	Agricultural Communities Focus. When Are Soybeans Harvested. 2024. Urs Keller. Seed Preparation.
	Air Temperature: Ambient	Literature derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Unit Temperature: 37.8 ℃	Engineering judgement	
	Exhaust Gas Temperature: 60 ℃	Literature derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025. Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.
	Air Ratio: 2	Engineering judgement	
	Electricity Demand: 0.000 kWh/kg		
	Heat Loses: 10%	Engineering judgement	
	Steam Temp: 100 ℃	Engineering judgement	

[29] U.S. Environmental Protection Agency. AP-42 Emission Factor Documentation for AP-42 Section 9.11.1. November 1995.

Cracking Mill	Electricity Demand: 0.000 kWh/kg		
Dehuller	Hull Ratio: 0.018	Literature-derived	Ravin Gnanasambandam and A. Proctor. Preparation of soy hull pectin. 1999.
	Electricity Demand: 0.0000 kWh/kg		
Conditioner	Unit Temp: 60 ℃	Literature-derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Steam Temp: 100 ℃	Engineering judgement	
	Heat Loses: 30%	Literature derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Electricity Demand: 0.0000 kW/kg		
Flaking Mill	Electricity Demand: 0.0000 kW/kg		
Oil Extractor	Hexane Ratio: 1.04	Literature-derived	Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.
	Oil out Ratio: .185	Sector-average	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Electricity Demand: 0.000 kW/kg		
Desolventizer	Hexane inlet wt%: .52/1.996	Literature-derived	Anibal Demarco and Véronique Gibon. Overview of the soybean process in the crushing industry. November 2020. DVC Process Technologists. Flash Desolventization.
	Outlet Flakes Temperature: 93.3℃	Literature-derived	P.R. Paraíso et al. Modeling and simulation of the soybean oil meal desolventizing–toasting process. June 2008.
	Outlet Hexane Temperature: 68.9℃	Literature-derived	P.R. Paraíso et al. Modeling and simulation of the soybean oil meal desolventizing–toasting process. June 2008.

			PubChem. Hexane.
	Electricity Demand: 0.000 kW/kg		
	Heat Loses: 30%	Literature-derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Steam Temp: 100 ℃	Engineering judgment	
Meal Dryer	Evaporated water wt % : .310/2.310	Literature-derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025. P.R. Paraíso et al. Modeling and simulation of the soybean oil meal desolventizing–toasting process. June 2008.
	Heat Loses: 85.5%	Engineering judgement	
	Electricity Demand: 0.000 kWh/kg		
	Steam Temp: 100 ℃	Engineering judgement	
Meal Cooler	Unit Temperature: ambient	Engineering judgement	
	Meal Heat Capacity: 1.47 kj/kg ℃	Sector-average	Dandan Kong et al. Thermal properties and conditioning temperature control of formula feeds containing high content of whey powder for weanling pigs. August 2017.
	Electricity demand: 0.000 kWh/kg		
Preheater/Condenser			
Hexane Storage	Hexane to Beans Ratio: 2.540/2.722	Literature-derived	Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.
Flash Chamber			
Evaporator	Vaporization Rate: .15/.364	Literature-derived	Toktam Mohammadi-Moghaddam et al. The Effect of Optimizing the Stripping and Drying Parameters During Industrial Extraction on the Physicochemical Properties of Soybean Oil. 2025.
	Unit Temperature: 51.7℃	Literature-derived	Papa M. Ndiaye et al. Vapor

			Pressure Data of Soybean Oil, Castor Oil, and Their Fatty Acid Ethyl Ester Derivatives. February 2005.
	Steam Temperature: 100℃	Engineering judgement	
	Heat Loses: 70%	Engineering judgement	
	Hexane wt%: 0.00350	Engineering judgement	
Vacuum Stripper	Unit Temperature: 65.6 ℃	literature-derived	P.R. Paraíso et al. Modeling and simulation of the soybean oil meal desolventizing–toasting process. June 2008. PubChem. Hexane.
	Steam Temperature: 100 ℃	Engineering judgement	
	Heat Loses: 10%	Engineering judgement	
Hexane Condensor			