9.9.7 Corn Wet Milling

9.9.7.1 General[1]

Establishments in corn wet milling are engaged primarily in producing starch, syrup, oil, sugar, and byproducts such as gluten feed and meal, from wet milling of corn and sorghum. These facilities may also produce starch from other vegetables and grains, such as potatoes and wheat. In 1994, 27 corn wet milling facilities were reported to be operating in the United States.

9.9.7.2 Process Description[1-4]

The corn wet milling industry has grown in its 150 years of existence into the most diversified and integrated of the grain processing industries. The corn refining industry produces hundreds of products and byproducts, such as high fructose corn syrup (HFCS), corn syrup, starches, animal feed, oil, and alcohol.

In the corn wet milling process, the corn kernel (see Figure 9.9.7-1) is separated into 3 principal parts: (1) the outer skin, called the bran or hull; (2) the germ, containing most of the oil; and (3) the endosperm (gluten and starch). From an average bushel of corn weighing 25 kilograms (kg) (56 pounds [lb]), approximately 14 kg (32 lb) of starch is produced, about 6.6 kg (14.5 lb) of feed and feed products, about 0.9 kg (2 lb) of oil, and the remainder is water. The overall corn wet milling process consists of numerous steps or stages, as shown schematically in Figure 9.9.7-2.

Shelled corn is delivered to the wet milling plant primarily by rail and truck and is unloaded into a receiving pit. The corn is then elevated to temporary storage bins and scale hoppers for weighing and sampling. The corn then passes through mechanical cleaners designed to remove unwanted material, such as pieces of cobs, sticks, and husks, as well as meal and stones. The cleaners agitate the kernels over a series of perforated metal sheets through which the smaller foreign materials drop. A blast of air blows away chaff and dust, and electromagnets remove bits of metal. Coming out of storage bins, the corn is given a second cleaning before going into "steep" tanks.

Steeping, the first step in the process, conditions the grain for subsequent milling and recovery of corn constituents. Steeping softens the kernel for milling, helps break down the protein holding the starch particles, and removes certain soluble constituents. Steeping takes place in a series of tanks, usually referred to as steeps, which are operated in continuous-batch process. Steep tanks may hold from 70.5 to 458 cubic meters (m^3) (2,000 to 13,000 bushels [bu]) of corn, which is then submerged in a current of dilute sulfurous acid solution at a temperature of about 52°C (125°F). Total steeping time ranges from 28 to 48 hours. Each tank in the series holds corn that has been steeping for a different length of time.

Corn that has steeped for the desired length of time is discharged from its tank for further processing, and the tank is filled with fresh corn. New steeping liquid is added, along with recycled water from other mill operations, to the tank with the "oldest" corn (in steep time). The liquid is then passed through a series of tanks, moving each time to the tank holding the next "oldest" batch of corn until the liquid reaches the newest batch of corn.

Water drained from the newest corn steep is discharged to evaporators as so-called "light steepwater" containing about 6 percent of the original dry weight of grain. By dry-weight, the solids

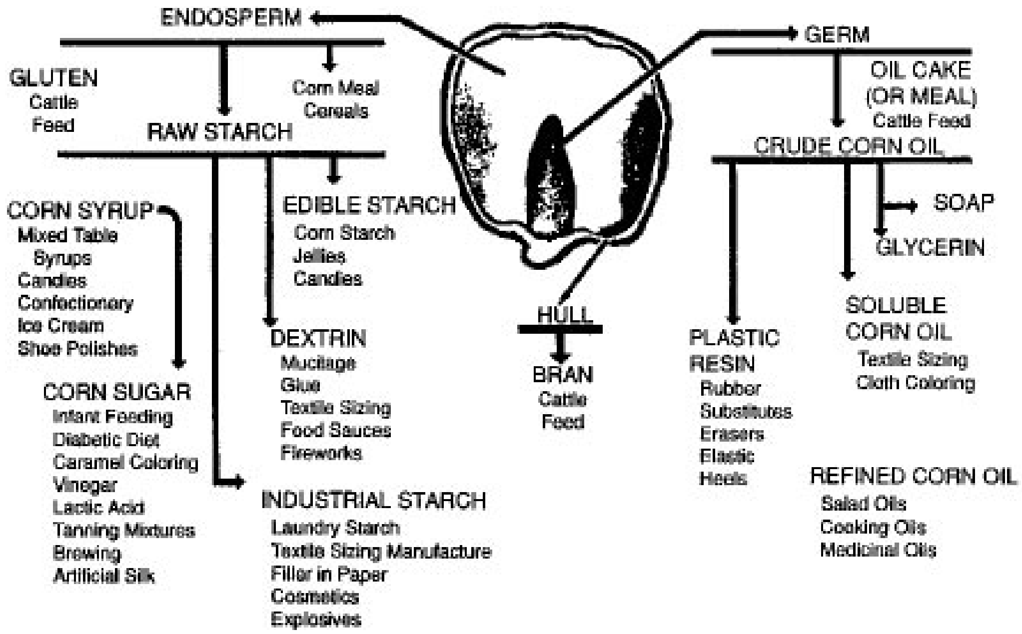

Figure 9.9.7-1. Various uses of corn.

in the steepwater contain 35 to 45 percent protein and are worth recovering as feed supplements. The steepwater is concentrated to 30 to 55 percent solids in multiple-effect evaporators. The resulting steeping liquor, or heavy steepwater, is usually added to the fibrous milling residue, which is sold as animal feed. Some steepwater may also be sold for use as a nutrient in fermentation processes.

The steeped corn passes through degerminating mills, which tear the kernel apart to free both the germ and about half of the starch and gluten. The resultant pulpy material is pumped through liquid cyclones to extract the germ from the mixture of fiber, starch, and gluten. The germ is subsequently washed, dewatered, and dried; the oil extracted; and the spent germ sold as corn oil meal or as part of corn gluten feed. More details on corn oil production are contained in Section 9.11.1, "Vegetable Oil Processing".

The product slurry passes through a series of washing, grinding, and screening operations to separate the starch and gluten from the fibrous material. The hulls are discharged to the feed house, where they are dried for use in animal feeds.

At this point, the main product stream contains starch, gluten, and soluble organic materials. The lower density gluten is separated from the starch by centrifugation, generally in 2 stages. A high-quality gluten, of 60 to 70 percent protein and 1.0 to 1.5 percent solids, is then centrifuged, dewatered, and dried for adding to animal feed. The centrifuge underflow containing the starch is passed to starch washing filters to remove any residual gluten and solubles.

The pure starch slurry is now directed into 1 of 3 basic finishing operations, namely, ordinary dry starch, modified starches, and corn syrup and sugar. In the production of ordinary dry starch, the starch slurry is dewatered with vacuum filters or basket centrifuges. The discharged starch cake has a moisture content of 35 to 42 percent and is further dewatered thermally in 1 of several types of dryers. The dry starch is then packaged or shipped in bulk, or a portion may be kept for use in making dextrin.

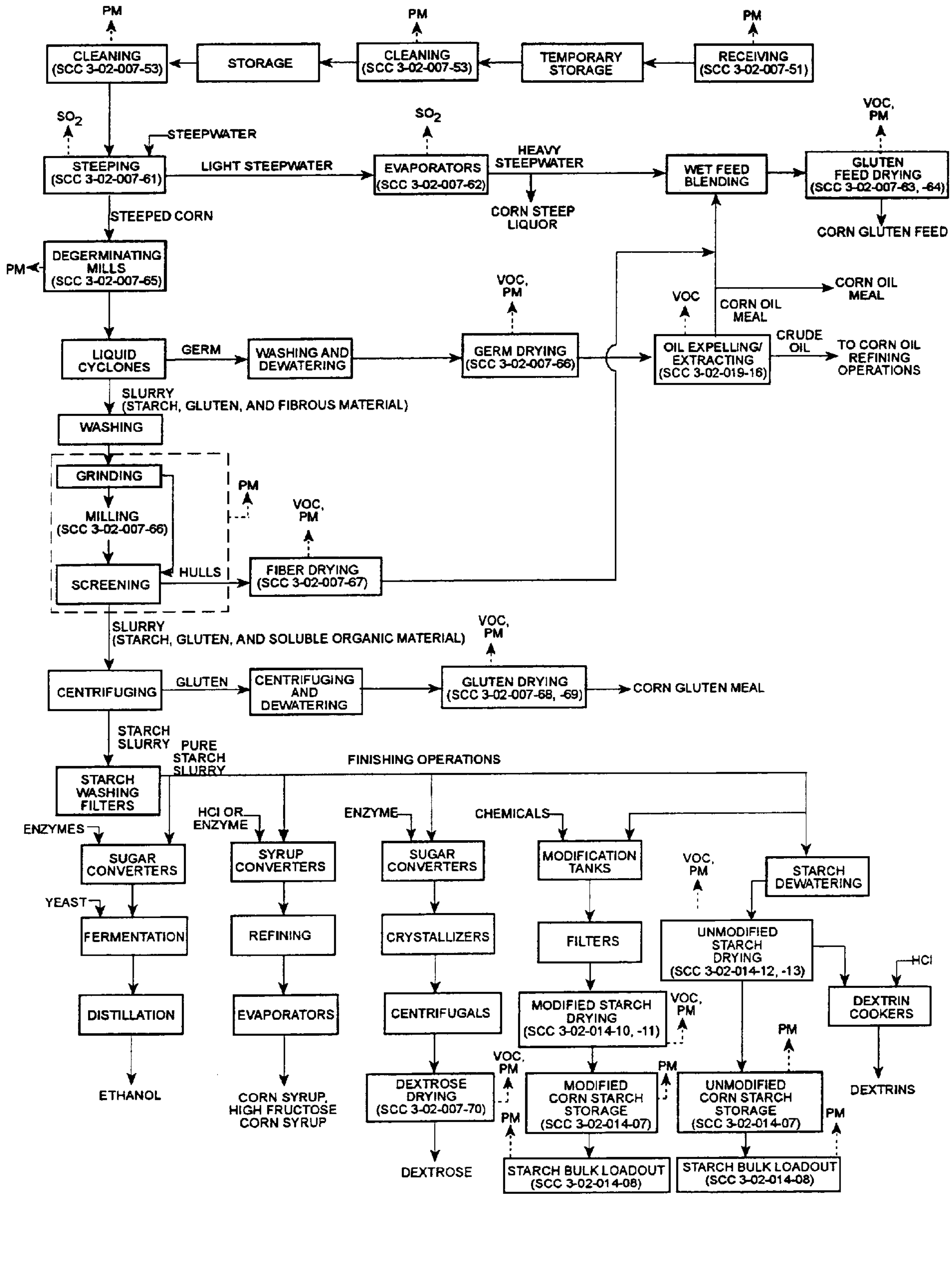

Figure 9.9.7-2. Corn wet milling process flow diagram.[1-4]
(Source Classification Codes in parentheses.)

Modified starches are manufactured for various food and trade industries for which unmodified starches are not suitable. For example, large quantities of modified starches go into the manufacture of paper products as binding for the fiber. Modifying is accomplished in tanks that treat the starch slurry with selected chemicals, such as hydrochloric acid, to produce acid-modified starch; sodium hypochlorite, to produce oxidized starch; and ethylene oxide, to produce hydroxyethyl starches. The treated starch is then washed, dried, and packaged for distribution.

Across the corn wet milling industry, about 80 percent of starch slurry goes to corn syrup, sugar, and alcohol production. The relative amounts of starch slurry used for corn syrup, sugar, and alcohol production vary widely among plants. Syrups and sugars are formed by hydrolyzing the starch — partial hydrolysis resulting in corn syrup, and complete hydrolysis producing corn sugar. The hydrolysis step can be accomplished using mineral acids, enzymes, or a combination of both. The hydrolyzed product is then refined, which is the decolorization with activated carbon and the removal of inorganic salt impurities with ion exchange resins. The refined syrup is concentrated to the desired level in evaporators and is cooled for storage and shipping.

Dextrose production is quite similar to corn syrup production, the major difference being that the hydrolysis process is allowed to go to completion. The hydrolyzed liquor is refined with activated carbon and ion exchange resins, to remove color and inorganic salts, and the product stream is concentrated by evaporation to the 70 to 75 percent solids range. After cooling, the liquor is transferred to crystallizing vessels, where it is seeded with sugar crystals from previous batches. The solution is held for several days while the contents are further cooled and the dextrose crystallizes. After about 60 percent of the dextrose solids crystallize, they are removed from the liquid by centrifuges, are dried, and are packed for shipment.

A smaller portion of the syrup refinery is devoted to the production of corn syrup solids. In this operation, refined corn syrup is further concentrated by evaporation to a high dry substance level. The syrup is then solidified by rapid cooling and subsequently milled to form an amorphous crystalline product.

Ethanol is produced by the addition of enzymes to the pure starch slurry to hydrolyze the starch to fermentable sugars. Following hydrolysis, yeast is added to initiate the fermentation process. After about 2 days, approximately 90 percent of the starch is converted to ethanol. The fermentation broth is transferred to a still where the ethanol (about 50 vol%) is distilled. Subsequent distillation and treatment steps produce 95 percent, absolute, or denatured ethanol. More details on this ethanol production process, emissions, and emission factors is contained in Section 6.21, "Ethanol".

9.9.7.3 Emissions And Controls[1-2,4-8]

The diversity of operations in corn wet milling results in numerous and varied potential sources of air pollution. It has been reported that the number of process emission points at a typical plant is well over 100. The main pollutant of concern in grain storage and handling operations in corn wet milling facilities is particulate matter (PM). Organic emissions (e. g., hexane) from certain operations at corn oil extraction facilities may also be significant. These organic emissions (and related emissions from soybean processing) are discussed in Section 9.11.1, "Vegetable Oil Processing". Other possible pollutants of concern are volatile organic compounds (VOC) and combustion products from grain drying, sulfur dioxide (SO_2) from corn wet milling operations, and organic materials from starch production. The focus here is primarily on PM sources for grain handling operations. Sources of VOC and SO_2 are identified, although no data are available to quantify emissions.

Emission sources associated with grain receiving, cleaning, and storage are similar in character to those involved in all other grain elevator operations, and other PM sources are comparable to those found in other grain processing plants as described in Section 9.9.1, "Grain Elevators And Processes". However, corn wet milling operations differ from other processes in that they are also sources of SO_2 and VOC emissions, as described below.

The corn wet milling process uses about 1.1 to 2.0 kg of SO_2 per megagram (Mg) of corn (0.06 to 0.11 lb/bu). The SO_2 is dissolved in process waters, but its pungent odor is present in the slurries, necessitating the enclosing and venting of the process equipment. Vents can be wet-scrubbed with an alkaline solution to recover the SO_2 before the exhaust gas is discharged to the atmosphere. The most significant source of VOC emissions, and also a source of PM emissions, from corn wet milling is the exhaust from the different drying processes. The starch modification procedures also may be sources of acid mists and VOC emissions, but data are insufficient to characterize or to quantify these emissions.

Dryer exhausts exhibit problems with odor and blue haze (opacity). Germ dryers emit a toasted smell that is not considered objectionable in most areas. Gluten dryer exhausts do not create odor or visible emission problems if the drying temperature does not exceed 427°C (800°F). Higher temperatures promote hot smoldering areas in the drying equipment, creating a burnt odor and a blue-brown haze. Feed drying, where steepwater is present, results in environmentally unacceptable odor if the drying temperature exceeds 427°C (800°F). Blue haze formation is a concern when drying temperatures are elevated. These exhausts contain VOC with acrid odors, such as acetic acid and acetaldehyde. Rancid odors can come from butyric and valeric acids, and fruity smells emanate from many of the aldehydes present.

The objectionable odors indicative of VOC emissions from process dryers have been reduced to commercially acceptable levels with ionizing wet-collectors, in which particles are charged electrostatically with up to 30,000 volts. An alkaline wash is necessary before and after the ionizing sections. Another approach to odor/VOC control is thermal oxidation at approximately 750°C (1382°F) for 0.5 seconds, followed by some form of heat recovery. This hot exhaust can be used as the heat source for other dryers or for generating steam in a boiler specifically designed for this type of operation. Incineration can be accomplished in conventional boilers by routing the dryer exhaust gases to the primary air intake. The limitations of incineration are potential fouling of the boiler air intake system with PM and derated boiler capacity because of low oxygen content. These limitations severely restrict this practice. At least 1 facility has attempted to use a regenerative system, in which dampers divert the gases across ceramic fill where exhaust heats the fumes to be incinerated. Incinerator size can be reduced 20 to 40 percent when some of the dryer exhaust is fed back into the dryer furnace. From 60 to 80 percent of the dryer exhaust may be recycled by chilling it to condense the water before recycling.

The PM emissions generated from grain receiving, handling, and processing operations at corn wet milling facilities can be controlled either by process modifications designed to prevent or inhibit emissions or by application of capture collection systems.

The fugitive emissions from grain handling operations generated by mechanical energy imparted to the dust, both by the operations themselves and by local air currents in the vicinity of the operations, can be controlled by modifying the process or facility to limit the generation of fugitive dust. The primary preventive measures used by facilities are construction and sealing practices that limit the effect of air currents, and minimizing grain free fall distances and grain velocities during handling and transfer. Some recommended construction and sealing practices that minimize emissions are: (1) enclosing the receiving area to the extent practicable; (2) specifying dust-tight cleaning and processing equipment; (3) using lip-type shaft seals at bearings on conveyor and other equipment housings; (4) using flanged inlets and outlets on all spouting, transitions, and miscellaneous hoppers; and (5) fully enclosing and sealing all areas in contact with products handled.

While preventive measures can reduce emissions, most facilities also require ventilation or capture/collection systems to reduce emissions to acceptable levels. Milling operations generally are ventilated, and some facilities use hood systems on all handling and transfer operations. The control devices typically used in conjunction with capture systems for grain handling and processing operations are cyclones (or mechanical collectors) and fabric filters. Both of these systems can achieve acceptable levels of control for many grain handling and processing sources. However, even though cyclone collectors can achieve acceptable performance in some scenarios, and fabric filters are highly efficient, both devices are subject to failure if not properly operated and maintained. Ventilation system malfunction, of course, can lead to increased emissions at the source.

Table 9.9.7-1 shows the filterable PM emission factors developed from the available data on several source/control combinations. Table 9.9.7-2 shows potential sources of VOC and SO_2, although no data are available to characterize these emissions.

Table 9.9.7-1 (Metric And English Units). PARTICULATE MATTER EMISSION FACTORS FOR CORN WET MILLING OPERATIONS[a]

EMISSION FACTOR RATING: E

Emission Source	Type Of Control	Filterable PM[b]	
		kg/Mg	lb/ton
Grain receiving[c] (trucks) (SCC 3-02-007-51)	Fabric filter	0.016	0.033
Grain handling[c] (legs, belts, etc.) (SCC 3-02-007-52)	None	0.43	0.87
Grain cleaning[d] (SCC 3-02-007-53)	None	0.82	1.6
Grain cleaning[d] (SCC 3-02-007-53)	Cyclone	0.086	0.17
Starch storage bin[e] (SCC 3-02-014-07)	Fabric filter	0.0007	0.0014
Starch bulk loadout[f] (SCC 3-02-014-08)	Fabric filter	0.00025	0.00049
Gluten feed drying			
Direct-fired rotary dryers[g] (SCC 3-02-007-63)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers[g] (SCC 3-02-007-64)	Product recovery cyclone[h]	0.25	0.49
Starch drying			
Flash dryers[j] (SCC 3-02-014-10, -12)	Wet scrubber	0.29	0.59
Spray dryers[k] (SCC 3-02-014-11, -13)	Fabric filter	0.080	0.16
Gluten drying			
Direct-fired rotary dryers[g] (SCC 3-02-007-68)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers[g] (SCC 3-02-007-69)	Product recovery cyclone	0.25	0.49
Fiber drying (SCC 3-02-007-67)	ND	ND	ND
Germ drying (SCC 3-02-007-66)	ND	ND	ND
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND
Degerminating mills (SCC 3-02-007-65)	ND	ND	ND
Milling (SCC 3-02-007-56)	ND	ND	ND

Table 9.9.7-1 (cont.).

[a] For grain transfer and handling operations, factors are for an aspirated collection system of 1 or more capture hoods ducted to a particulate collection device. Because of natural removal processes, uncontrolled emissions may be overestimated. ND = no data. SCC = Source Classification Code.
[b] Emission factors based on weight of PM, regardless of size, per unit weight of corn throughput unless noted.
[c] Assumed to be similar to country grain elevators (see Section 9.9.1).
[d] Assumed to be similar to country grain elevators (see Section 9.9.1). If 2 cleaning stages are used, emission factor should be doubled.
[e] Reference 9.
[f] Reference 9. Emission factor based on weight of PM per unit weight of starch loaded.
[g] Reference 10. Type of material dried not specified, but expected to be gluten meal or gluten feed. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
[h] Includes data for 4 (out of 9) dryers known to be vented through product recovery cyclones, and other systems are expected to have such cyclones. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
[j] References 11-13. EMISSION FACTOR RATING: D. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.
[k] Reference 14. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.

Table 9.9.7-2 (Metric And English Units). EMISSION FACTORS FOR CORN WET MILLING OPERATIONS

Emission Source	Type Of Control	VOC		SO_2	
		kg/Mg	lb/ton	kg/Mg	lb/ton
Steeping (SCC 3-02-007-61)	ND	ND	ND	ND	ND
Evaporators (SCC 3-02-007-62)	ND	ND	ND	ND	ND
Gluten feed drying (SCC 3-02-007-63, -64)	ND	ND	ND	ND	ND
Germ drying (SCC 3-02-007-66)	ND	ND	ND	ND	ND
Fiber drying (SCC 3-02-007-67)	ND	ND	ND	ND	ND
Gluten drying (SCC 3-02-007-68, -69)	ND	ND	ND	ND	ND
Starch drying (SCC 3-02-014-10, -11, -12, -13)	ND	ND	ND	ND	ND
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND	ND	ND
Oil expelling/extraction (SCC 3-02-019-16)	ND	ND	ND	ND	ND

ND = no data. SCC = Source Classification Code.

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