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Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

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Source Category Survey: Starch Manufacturing Industry

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Emission Standards and Engineering Division

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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1. SUMMARY

The starch manufacturing industry (basically SIC 2046) was examined during this survey to develop the background information necessary to assess the need for the development of a new source performance standard (NSPS). Starch is manufactured in the United States by the corn wet milling, wet potato crushing, tapioca extraction, or dry wheat milling processes; the corn wet milling process dominates the industry owing to lower costs and greater product flexibility. Most of the 24 corn wet milling operations in the U.S. are located near the source of raw materials in Iowa (6), Illinois (5), and Indiana (4). In the corn wet milling process the corn kernels are soaked in water with sulfur dioxide added, then coarsely ground in a mill. The components are then divided using various density separation techniques, processed, and dried. Potato and tapioca (cassava) starches are produced by crushing the raw tuberous vegetables and extracting the starch in water. Four of the eight existing plants are located in Maine. The dry wheat milling procedure grinds the grain into flour, adds water to make a batter, and extracts starch in a combined beating/water spraying process. Three of the seven wheat plants are located in Kansas. Each type of starch has certain characteristics that make it useful for given applications; however, corn starch and its by-products dominate the industry. In 1977, more than 9.8×10^6 Mg (10.8×10^6 tons) of corn products valued at $1.9 billion were shipped, while only 7.1×10^4 Mg (7.8×10^4 tons) of starches from other vegetables with a value of $32 million were shipped.

The starch industry produces a variety of products with extremely diversified applications. The corn wet milling industry produces common and modified specialty starches; refined starch products: dextrins, dextrose, glucose (corn) syrup, high-fructose corn syrup (HFCS), and ethanol (grain alcohol); and by-products: corn oil and animal feeds. Quantities and values of shipments of these major corn wet milling products in 1977 are given in Table 1-1. The syrups are used as sweeteners in a variety of food products with an increasingly large market for HFCS in the soft drink industry. The dextrins and modified specialty starches are finding uses as filler in biodegradable plastics, rubber hardeners

TABLE 1-1. QUANTITY AND VALUE OF SHIPMENTS OF MAJOR CORN WET MILLING PRODUCTS IN 1977[a]

Product	Shipments (billion kg)	Value (Million $)
Common and modified specialty starches	2.5	408
Refined starch products:		
Dextrins	0.063	25
Dextrose	0.57	139
Glucose (corn) syrup	2.1	284
High-fructose corn syrup (HFCS)	1.5	251
Ethanol	Negligible	Negligible
By-products:		
Corn oil	Indeterminate	325
Animal feeds	3.1	462

[a]Extracted from Table 4-3; data from U.S. Department of Commerce Census of Manufacturers.

for tire manufacturing and super water absorbents for health care (disposable diapers and bedsheets, sponges, etc.) or horticultural needs. Corn, potato, and tapioca starches are also used in foods as thickeners, in textile weaving to protect the yarn, and in paper products as filler or to add texture and stiffness.

Total U.S. corn wet milling production capacity (generally expressed in standard bushels - 56 lb - of corn grind) has increased at about five percent per year over the last 10 years. Actual production has been more erratic, however, since the production of different co-products has varied from minus three percent to greater than nine percent depending on the different market situations in a given year. The production of the more traditional co-products (e.g., starch and corn syrup) is expected to continue to grow at about five percent and production of some other co-products (e.g., dextrins and dextrose) is expected to stabilize or decline. The production of HFCS is expected to increase sharply to meet a shortage as HFCS captures from sugar an increasing share of the soft drink sweetener market. Depending on government policy, corn wet milling production of alcohol for gasohol will either increase utilization of existing capacity or act as an incentive to add new capacity. As the production of these starch and refined products (especially HFCS and ethanol) increases, the production of the corn oil and animal feed by-products will increase correspondingly. The markets for both of these by-products are essentially unlimited, even though there may be stiff competition from substitutes.

The starch manufacturing processes emit particulate, sulfur dioxide and hydrocarbon pollutants to the atmosphere. Sulfur dioxide gas and hydrocarbon vapors are evolved from the corn wet milling steeping and steepwater evaporation procedures. In newer plants or processes, sulfur oxide emissions may be absorbed in a caustic scrubber for recycle use and emission control. The total annual SO_2 emissions are estimated at 700 Mg (800 tons). Hydrocarbon emissions have not been adequately assessed, but are sometimes evidenced as odorous emissions. Odors that are strong and offensive to neighbors of the plant are frequently incinerated. Particulate emissions emanate from grain handling operations, grinding mills, feed, germ, and starch dryers and product transfer to storage or bagging. The total annual particulate emissions are an estimated 2900 Mg (3200 tons). The dryers for starch, feed, and germ products are the largest emissions sources. Controlled emissions from a corn wet milling plant of average size (processing about 2500 m^3/day - 70,000 bu/day - of corn) are estimated to be about 55-200 Mg/yr (60-220 tons/yr), 50 Mg/yr (55 tons/yr), and 6.0 Mg/yr (6.6 tons/yr) from feed, starch, and germ dryers, respectively. They are typically controlled by a cyclone, cyclones in series, or a cyclone followed by a low-pressure drop wet scrubber. These systems have collection efficiencies of 90 to 95+ percent. All other plant operations and some starch dryers have been equipped with a fabric filter or have been retrofitted with a fabric filter after an existing cyclone. The estimated control efficiency of processes using this equipment is 99.9+ percent. There is limited stack testing data available for dryers or other emission sources.

The present control level for feed dryers may be improved by addition of a high-efficiency (90+ percent) wet scrubber after the cyclones. Some plants have significant particulate emissions using only the cyclone or cyclone/scrubber control methods. Emissions may be reduced with the addition of a high-efficiency scrubber or a fabric filter.

Most corn wet milling facilities are in compliance with the emission limitations under State regulations, which are generally in the form of process weight rate equations. Raw material and product handling emissions are generally controlled excellently by using fabric filters with adequate explosion prevention equipment. Germ dryers appear to be adequately controlled using cyclones due to the large particle size and relatively low throughputs of the material. Controlled particulate emissions in 1985 from new starch dryers are estimated, based on very limited data, to be no greater than 470 Mg/yr (520 tons/yr), or as small as 20 Mg/yr (20 tons/yr), depending on the prevalence of fabric filters for product recovery and prevention of explosions in the ambient air. Production of feed by-products will increase in conjunction with increases in production of common, modified, and refined starches. Thus, 1985 particulate emissions from new feed drying sources are estimated to be 1800 Mg/yr (2000 tons/yr) if the control techniques currently in use are still applied, or 910 Mg/yr (1000 tons/yr), if exhaust recirculation is applied for energy conservation and is effective in reducing particulate emissions. The potential emission reduction of a new source performance standard for animal feed dryers is estimated to be at least 700 Mg/yr (800 tons/yr) or as much as 1600 Mg/yr (1800 tons/yr), depending on the process and control technology in use in 1985.

2. INTRODUCTION

A study of the starch manufacturing industry was performed in this survey. The starch industry includes corn wet milling, potato starch, and wheat milling processes. These are generally classed under standard industrial classification (SIC) 2046, wet corn milling, by the U.S. Department of Commerce. The corn wet milling industry is the largest of these operations producing corn starch, specialty starches, corn syrup, high fructose corn syrup, animal feed by-products and corn oil. Wheat milling processes yield animal feed, starch, flour and wheat gluten for making breads. The potato starch industry manufactures the desirable cold water soluble potato starch and bulk animal feed.

The goal of this survey was to determine the need for a new source performance standard (NSPS) for the starch industry. Starch is source category number 53 out of 59 on the NSPS priority list. The Clean Air Act (CAA), as amended in 1977, provides authority for the U.S. Environmental Protection Agency (EPA) to control discharges of airborne pollutants. The CAA contains several regulatory and enforcement options for control of airborne emissions from stationary sources. Section 111 of the CAA calls for issuance of standards of performance for new, modified, or reconstructed sources which may contribute significantly to air pollution. The standards must be based on the best demonstrated control technology. Economic, energy, and non-air environmental impacts of control technology must be considered in the development of standards.

To determine which processes and pollutants, if any, should be regulated by national NSPS, the following information has been provided in this survey:

1. Description of facilities included in source category,
2. Number and location of facilities,
3. Past and current volumes of production and sales, products, and product uses,
4. Past and future growth trends in the industry,
5. Description of the processing operations and identification of emission sources,
6. Characterization of emissions from processing operations,
7. Estimation of national emissions from source category,

8. Identification and description of control techniques currently used in the industry,

9. Identification of candidate "best systems" of control,

10. Description of state regulations applicable to the source category, and

11. Preferred methods of sampling and analyzing the pollutants.

Several information sources were used in the development of this report. Initially, a literature search was conducted to gather background material on the starch manufacturing industry. This material provided a basis for futher information gathering in the form of telephone and letter contacts with manufacturers engaged in the production of starch and its co-products. Other individuals knowledgeable about the industry, regional offices of EPA, and state and local air pollution control agencies. The trade association for the corn wet millers, the Corn Refiners Association, was also contacted. Visits were made to five corn, two wheat, and two potato starch plants, using a variety of process and control technology.

3. CONCLUSIONS

The starch (wet corn milling) industry growth rate over the last 10 years has been approximately five percent per year. The soft drink industry has recently begun to shift from sugar (sucrose) to high-fructose corn syrup (HFCS) as a sweetener. The demand that could be generated by the decision to allow HFCS usage in Coca-Cola is alone greater than present industry HFCS capacity. Even higher capacity may be needed if a crystallized HFCS is developed as a sugar substitute. Government policy could favorably swing the economics toward production of ethanol for gasohol by corn wet millers. Industry experts feel that raw starch will first be diverted from the production of other co-products to meet HFCS and alcohol demand before actual increases are made in the total capacity (corn grind) of corn wet milling. The extent of diverting raw starch to increase capacity utilization and profits versus building new capacity will depend on the demand for the various co-products and the configuration of existing plants. The industry will most likely increase capacity to handle greater quantities of raw grain. In addition, starch research and development is pointing out many new uses for starches in tire manufacturing, biodegradable plastics, and water absorbents (for horticultural or health care uses, e.g., disposable diapers). These developments suggest that industry growth over the next five to 10 years will increase to 15 percent or more per year.

The manufacture of starch from grain (e.g., corn or wheat) or potatoes has several potentially significant emission sources. Grain receiving and handling operations can emit significant amounts of particulate pollutants if not properly controlled. The emissions from grain handling operations are presently regulated under a new source performance standard for grain elevators and appeared to be well controlled during survey plant visits. Most facilities were using fabric filters to prevent particulate emissions and achieve compliance with opacity regulations.

Starch drying procedures can also be a significant emissions source. The economics of the industry necessitate efficient product recovery and energy usage, forcing facilities to employ well designed dryers (especially the newer flash dryers) equipped with efficient control devices. The most common control system configurations are cyclones followed by another collector. The secondary collector is generally another cyclone or a wet scrubber; however, some plants utilize fabric filters that are protected against explosion hazards.

Feed drying processes at starch manufacturing plants are the other major source of particulate emissions. The high moisture content of the hot gases leaving these dryers has prevented control by fabric filter. In the past these dryers have been controlled by cyclones with some plants adding a scrubber for further emissions reduction. This operation probably is best suited to control by a high-efficiency wet scrubber. Recirculating dryer exhaust gases through dryers connected in series also reduces emissions.

Particulate emissions test data was found only for starch, feed, or germ dryers. These sources have been tested to meet state SIP requirements. The test data indicates that feed dryers are the most significant particulate emissions sources. The remaining sources of pollutant emissions have been characterized for state emission inventories by material balance. The tight control of process operations and product yields maintained throughout the industry makes this material balance technique reasonably reliable.

The control technology needed for reducing emissions from the starch manufacturing industry is readily available. Control techniques for the starch manufacturing industry are noted below in the order of the process steps. Grain handling and product storage (bins and silos) emissions are effectively controlled by small fabric filter modules. The wet processing operations do not emit particulate pollutants but do have SO_2 and hydrocarbon emissions. The limited data available indicate that these emissions are extremely small. However, potential increases in alcohol production could generate increased hydrocarbon emissions. Hydrocarbon vapors from separation are being controlled to some extent by energy and odor conscious operators who incinerate these vapors and thus provide heat for drying operations. If greater control is required, incineration can be augmented or replaced by absorption/adsorption control. At least one plant is using a caustic scrubber to absorb SO_2 emissions from steeping; however, other (older) plants consider capture and control of steeping emissions to be excessively expensive. Starch dryer emissions, which have traditionally been controlled by a cyclone or a series of cyclones, can be further reduced by the addition of a scrubber or fabric filter baghouse. Feed dryers usually have cyclone or cyclone/scrubber controls installed for abating particulate emissions. Energy conservation programs have led some facilities to recirculate exhaust gases through dryers or to operate dryers in series, thereby saving energy and reducing emissions. Those plants using only cyclone controls may consider the recirculation technique or high-efficiency scrubbers for emission reduction. Fabric filters are not used for feed dryers owing to the high moisture content of the effluent (presenting the likelihood of condensation in the filter) and possible fire risks.

4. DESCRIPTION OF INDUSTRY

4.1 SOURCE CATEGORY

The starch manufacturing industry is basically contained in Standard Industrial Classification 2046, Wet Corn Milling. This category not only includes plants manufacturing corn products, but also those manufacturing starch from other vegetable sources such as potatoes and wheat. Plants known to produce starch and by-products from corn, wheat, or potato are listed in Tables 4-1a, b, and c, respectively. Plants reported to be in the SIC, but which may not manufacture starch or which may manufacture presumably small quantities of starch products from undetermined raw materials, are listed in Table 4-1d. The majority of the 24 corn wet milling operations are located in the Midwest with six plants in Iowa, five in Illinois, and four in Indiana. Four of the eight potato starch plants are located in Maine or in the western states. Wheat starch production is concentrated in Kansas (three of six reported plants). A list of individuals who are knowledgeable about some aspect of the industry and were helpful during this survey is given in Table 4-2.

Of the 54 plants currently listed in the Economic Information System for SIC 2046, 24 of them employ 20 to 49 workers, nine plants employ 50 to 99 workers, 12 plants employ 100 to 249 workers, one plant employs 250 to 499 workers, five plants employ 500 to 999 workers, and the three largest plants, A.E. Staley (Decatur, Illinois), CPC International (Argo, Illinois), and Clinton Corn Processing (Clinton, Iowa), employ 1000 to 2499 workers with an average of 1,870 per plant. The total employment level for SIC 2046 is 12,000.

In 1958, the four largest corn wet milling plants accounted for approximately 75 percent of the total production and the eight largest plants accounted for about 92 percent of the total.[1] Currently, about 85 percent of the market is supplied by seven corporations with 19 plants with the largest market share of 24.7 percent being held by CPC International which has only three plants. A.E. Staley represents 21 percent of the industry with five plants: three corn wet milling operations and two small potato starch plants.[2]

TABLE 4-1a. STARCH MANUFACTURING OPERATIONS -- CORN

ADM Corn Sweeteners/Archer Daniels Midland
1350 Waconia Avenue S.W.
Cedar Rapids, Iowa 52406
(319) 398-0600

ADM Corn Sweeteners/Archer Daniels Midland
P.O. Box 1470
Decatur, Illinois 62525
(217) 424-5752

Amalgamaize Co., Inc./American Maize Products
Rt. 1 Alabama State Dock Road
Decatur, Alabama 35601
(205) 355-8815

American Maize Products Co.
113th & Indianapolis
Hammond, Indiana 46320
(219) 659-2000

Anheuser Busch, Inc.
2245 Sagamore Parkway
Lafayette, Indiana 47902
(317) 447-6911

Cargill, Inc.
1710 16th Street S.E.
Box 1467
Cedar Rapids, Iowa 52406
(319) 366-3591

Cargill, Inc.
411 N. Cherry
Mt. Pleasant, Iowa 52641
(319) 385-3103

Cargill, Inc.
Milling Division
3201 Needmore Road
Dayton, Ohio 45414
(513) 236-1971

Cargill Nutrena Feeds Division/Cargill, Inc.
4943 Stepherson Road
Memphis, Tennessee 38118
(901) 795-2660

Chemstar Products
McPherson, Kansas

TABLE 4-1a (Cont'd). STARCH MANUFACTURING OPERATIONS -- CORN

Clinton Corn Processing/Standard Brands, Inc.
1251 Beaver Channel Parkway
Clinton, Iowa 52732
(319) 242-1121

Clinton Corn Processing/Standard Brands, Inc.
Montezuma, New York 13117
(315) 776-4811

Colorcon
Indianapolis, Indiana

Corn Sweeteners, Inc./Archer Daniels Midland
900 19th Street
Granite City, Illinois 62040
(618) 452-2746

CPC International
64 & Archer Road
Argo, Illinois 60501
(312) 458-2000

CPC International
Corpus Christi, Texas
(reportedly sold to a petroleum refiner)

CPC International
1300 S. 2nd Street
Box 31
Peking, Illinois 61554
(309) 346-1121

CPC International
1001 Bedford
N. Kansas City, Missouri 64116
(816) 471-8000

CPC International
Stockton, California
(to be on line in 1981)

CPC International
Winston-Salem, North Carolina
(to be on line in 1982)

Dimmitt Corn/Amstar
E. Jones & 7th Streets
Box 169
Dimmitt, Texas 79027
(806) 647-4141

TABLE 4-1a (Cont'd). STARCH MANUFACTURING OPERATIONS -- CORN

Grain Processing Corp./Kent Feeds, Inc.
1600 Oregon
Muscatine, Iowa 52761
(319) 263-1321

Holly Sugar Corp.
100 Chase Stone Center
Colorado Springs, Colorado 80901

Hubinger Company/H.J. Heinz Co.
1005 S. 5th Street
Keokuk, Iowa 52632
(319) 524-4641

Lincoln Grain Co./General Life Co., Inc.
RR 3
Box 436
Atchison, Kansas 66002
(913) 367-1621

National Starch & Chemical
1515 Drover Street
Box 1084
Indianapolis, Indiana 46206
(317) 635-4455

A.E. Staley Mfg. Co., Inc.
2200 Eldorado
Decatur, Illinois 62525
(217) 423-4411

A.E. Staley Mfg. Co., Inc.
Lafayette, Indiana 47902
(317) 474-5474

A.E. Staley Mfg. Co., Inc.
Morrisville, Pennsylvania 19067
(215) 698-9402

TABLE 4-1b. STARCH MANUFACTURING OPERATIONS -- WHEAT

Centennial Mills
1464 N.W. Front Avenue
Portland, Oregon 97208

Centennial Mills
Spokane, Washington 99220

Henkel
410 Johnson Street
Keokuk, Iowa 52632
(319) 524-2323

Industrial Grain Products/Olgilvie Mills
Aiken, South Carolina

Midwest Solvents Co., Inc.
1300 Main Street
Atchison, Kansas 66002
(913) 367-1480

TABLE 4-1c. STARCH MANUFACTURING OPERATIONS -- POTATO

Boise Cascade
Stanfield, Oregon

Colby Cooperative Starch Co.
Water St.
Caribou, Maine 04736
(207) 492-5971

Frenchville Starch
Frenchville, Maine 04745

J.R. Simplot
Heyburn, Idaho 83336

A.E. Staley Mfg. Co., Inc.
Cary Mills
P.O. Box 786
Houlton, Maine 04730
(207) 532-9523

A.E. Staley Mfg. Co., Inc.
N. Washington
Box 911
Monte Vista, Colorado 81144
(303) 852-2412

Stein Hall & Co./National Starch and Chemical
Burleigh Street
Island Falls, Maine 04747
(207) 463-2288

Western Starch/Western Polymer
P.O. Box 488
Tulelake, California 96134
(916) 667-2269

TABLE 4-1d. STARCH MANUFACTURING OPERATIONS -- TYPE UNCERTAIN

Adolph Coors Co.
Golden, Colorado 80401

ADM Corn Sweeteners/Archer Daniels Midland
Peoria, Illinois

American Maize Products
1602 16th Street
Central City, Nebraska 68826
(308) 324-5036

Anheuser Busch, Inc.
700 Edwards Avenue
New Orleans, Louisiana 70123
(504) 733-6740

Ashland Roller Mills
Highway 1 N.
Ashland, Virginia 23005
(804) 798-8329

Blue Magic of N.C. Inc.
509 South Lodge
Wilson, North Carolina 27893
(919) 237-3107

Boone Valley Co-Op
N. Commercial Street
Eagle Grove, Iowa 50533

Burrus Mills/Cargill, Inc.
2525 N. Field
Dallas, Texas 75215
(214) 748-5947

California Milling Corp.
Los Angeles, California 90055

Cargill, Inc.
Rt. 3
Grinnell, Iowa 50112
(515) 236-3522

Coeval, Inc.
St. Joseph, Illinois 61873
(217) 469-2213

Conagra, Inc.
Omaha, Nebraska 68108

TABLE 4-1d (Cont'd). STARCH MANUFACTURING OPERATIONS -- TYPE UNCERTAIN

Cre Mel Co., Inc.
1504 Forestdale Boulevard
Birmingham, Alabama 35214
(205) 798-6056

De Kalb Ag. Research, Inc.
1101 Darlington Avenue
Box 683
Crawfordsvill, Indiana 47933
(317) 362-2104

Dekalb Agresearch, Inc.
P.O. Box 847
Sikeston, Missouri 63801
(314) 471-6995

Faultless Starch/Bon Ami Co.
1025 W. 8th Street
Kansas City, Missouri 64101

Gem, Inc.
Gem Boulevard
Byhalla, Mississippi 38611

Great Western Sugar Co./Hunt International Resources
9501 Southview Avenue
Brookfield, Illinois 60513
(312) HU5-2050

International Multifoods Corp.
Minneapolis, Minnesota 55440

Krause Milling Co.
Milwaukee, Wisconsin 53201

Johns Manville
Virginia

Marschall Division
Granite City, Illinois 62040

W.O. McCurdy & Sons
Fremont, Iowa 52561
(515) 933-4292

Menan Starch
P.O. Box Drawer N
Moses Lake, Washington 98837
(509) 765-1803

TABLE 4-1d (Cont'd). STARCH MANUFACTURING OPERATIONS -- TYPE UNCERTAIN

F.O. Mitchell & Brother, Inc.
Perryman, Maryland 21130

Moews Seed Co.
P.O. Box 214
Granville, Illinois 61326
(815) 339-2201

Monahan Co.
202 N. Oak Street
Arcola, Illinois 61910
(217) 268-4955

National Starch & Chemical
735 Battery
San Francisco, California 94111
(415) 981-1630

Olympic Corn Products, Inc.
No. 605 Fancher
Box 3627
Spokane, Washington 99220
(509) 535-0321

Pacific Resins & Chemicals, Inc.
1754 Thorne Road
Tacoma, Washington 98421

Philbrick Starch Co.
Limestone, Maine 04750
(207) 325-3071

Pioneer Hibred Corn
816 N. Main Street
Princeton, Illinois 61356
(815) 875-2845

J.R. Short Milling Co.
Chicago, Illinois 60658

Unilever United States, Inc.
10 E. 53rd Street
New York, New York 10007

Union Oil Mill, Inc.
West Monroe, Louisiana 71291

TABLE 4-1d (Cont'd). STARCH MANUFACTURING OPERATIONS -- TYPE UNKNOWN

Univar Corp.
1600 Norton Building
Seattle, Washington 98104

Valley Lea Dairies, Inc.
South Bend, Indiana 46624

X Way Milling Co.
Rt. 1
Box 89
Laurinburg, North Carolina 28352
(919) 276-3488

TABLE 4-2. LIST OF CONTACTS

Name	Affiliation	Phone Number
Allen, Jerry	A.E. Staley Mfg. Co., Inc.	(217) 423-4411
Anderson, Lori	Potato Promotion Board	(303) 758-7783
Brenner, Kyd	Corn Refiners Association	(203) 331-1634
Erickson, Keith	Linn County (Cedar Rapids), Iowa Health Dept.	(310) 741-3931
Fink, Bob	Proctor & Schwartz, Inc. (Dryers)	(312) 358-5262
Flowers, Eric	Tenn., Div. of Air Pollution Control	(615) 741-3931
Glenn, Brian	Barr-Murphy, Ltd. (Dryers)	(514) 337-9160
Gorman, Paul	Midwest Research Institute	(816) 753-7600
Gray, Fred	USDA (Sugars & Sweeteners)	(202) 447-7290
Hagman, Bob	Dedert Corp. (Dryers)	(312) 754-4690
Harris, Paul	American Maize Products Co.	(219) 659-2000
Hayward, Michael	Iowa Dept. of Environmental Quality	(515) 281-8853
Jobias, Dick	CE Raymond (Flash Dryers)	(312) 236-4044
Keim, Carroll	Carroll R. Keim Consultants, Inc.	(203) 324-4366
Larson, Richard	First Manhattan Co.	(212) 949-8070
Lewis, Dennis	CE Raymond (Dryers)	(312) 236-4044
Miller, Dwight	USDA, Northern Regional Branch Center	(309) 685-4011
Pavlovich, James	American Maize Products Co.	(219) 659-2000
Reape, Patty	U.S. EPA Region V	(312) 353-2259
Seitz, David	Hammond Air Pollution Control	(219) 853-6306
Selby, Roger	Flex Kleen (Baghouses)	(312) 648-5300
Snell, Russ	CPC International	(312) 458-2000
Tomevi, Gary	National Starch & Chemical Company	(201) 685-5208
Willard, Wayne	Carter Day, R&D (Baghouses)	(612) 571-1000
Wells, Ron	Hubinger Company	(319) 524-4151
Wilson, Diane	U.S. Dept. of Commerce (SIC 2046)	(202) 377-4793

Products manufactured by the corn wet milling process include starch, corn syrups, corn oil, and animal feeds. There are four kinds of commercial corn starch: unmodified, modified, oxidized, and dextrin. Unmodified or common starch is the most widely utilized and its uses include paper coating and sizing, adhesives, salad dressing, beers, canned fruit, dry food mixes, and laundry starch. Starch may be modified with acids or other chemicals in conjunction with heat treatments to alter the starch characteristics. After acid modification, which reduces viscosity, the starch is used mostly for sizing in the textile industry and in starch-based gums. Starch also can be oxidized to reduce viscosity. Oxidized starch is used by the paper industry and as an adhesives component. Dextrins can be produced by cooking unmodified starch. The three different kinds of dextrin vary in solubility and are used in pastes and adhesives.

Two-fifths of the corn starch produced is sold as corn starch, the remaining three-fifths is converted into other products such as sweeteners. There are five types of nutritive sweeteners made from starch which include: (1) four grades of corn syrup (including high-fructose corn syrup), (2) dried corn syrup, (3) maltodextrin, (4) dextrose monohydrate, and (5) dextrose anhydrous. The major application of corn syrups, besides HFCS, is confectionary. All of these sweeteners are used in a variety of food products such as bakery goods, beverages, jellies, breakfast food, liqueurs, fruit drinks, canned foods, salad dressings, sauces, and syrups. Dextrose also can be used in the pharmaceutical, fermentation, and chemical industries.

Two by-product groups of the corn wet milling process are animal feeds and corn oil. There are four main feed products: (1) corn gluten feed, which is composed of the bran and fibrous portions of the corn kernel in combination with the starch and protein fractions not recovered in the primary separation process; (2) corn gluten meal, which consists of insoluble protein (gluten) separated in the corn wet milling process in combination with minimal quantities of starch and fibrous fractions not recovered in the primary separation process; (3) corn germ meal, which is obtained from the corn germ fraction after the corn oil has been removed; and (4) condensed fermented corn extractives, commonly known as corn steepwater which consists of the soluble portions of the corn kernel, removed by the steeping process and concentrated to high solids.[3] The corn oil which is extracted from the germ is used, with or without refining, in foods for human consumption.

4.2 INDUSTRY PRODUCTION

Corn wet milling lends itself to large scale production because of the wide variety of food and industrial products obtained from one raw material. In 1970, the corn wet milling industry processed 125 million bushels of shelled corn while in 1977 they processed almost 375 million bushels. This amount represents about 10 percent of all corn sold on the cash market (which is about one-half to two-thirds of the corn grown).[4] The cost of purchasing this quantity of raw materials may be as high as 70 percent of the total cost of manufacturing starch and its related products. In order to keep corn demand in line with increasing production by farmers, industrial uses for corn must double in the near future.[5,6]

During the 1950's and 1960's, corn starch shipments averaged 6 kg (14 lb) for each bushel* of corn processed. With current milling practices which attain 98 percent recovery, the same 25 kg (56 lb) standard bushel of corn will yield approximately 15 kg (34 lb) of starch, 1.0 kg (2 lb) of oil, and 5.9 kg (13 lb) of feed.[7] Full use must be made of all corn wet milling by-products to make the process economically feasible and the co-products must be relatively inexpensive to be competitive for general industrial uses.

Shipments of the majority of the wet corn milling products increased between 1963 and 1977 (see Table 4-3). According to the 1977 Census of Manufacturers,[8] the value of all wet corn milling products shipped from 38 plants was $1.9 billion. These figures for SIC 2046 include starch products manufactured from vegetables other than corn. These other starches (primarily wheat, potato, and tapioca) are used similarly to corn starch in a variety of applications. The manufacture of all non-corn starches decreased between 1972 and 1977 when shipments totaled 71 million kg (156 million lb) with a value of $32 million.

*The corn wet milling industry defines a standard bushel as a quantity of corn weighing about 25.4 kg (exactly 56 lb).

TABLE 4-3. QUANTITY AND VALUE OF SHIPMENTS BY ALL PRODUCERS IN WET CORN MILLING INDUSTRY (SIC 2046), 1963-77*[8]

Product	1977 Quantity (000,000 lb)	1977 Value ($000,000)	1972 Quantity (000,000 lb)	1972 Value ($000,000)	1967 Quantity (000,000 lb)	1967 Value ($000,000)	1963 Quantity (000,000 lb)	1963 Value ($000,000)
ALL WET CORN MILLING TOTAL	(x)	1938.6	(x)	786.7	(x)	646.6	(x)	547.2
Glucose syrup (corn syrup), unmixed:								
Type I (20 dextrose equivalent up to 38)	207.7	12.7	385.2	14.4	210.5	10.5	89.4	4.5
Type II (38 dextrose equivalent up to 58)	2980.5	160.5	1592.6	60.2	1598.0	74.9	1328.9	66.5
Type III (58 dextrose equivalent up to 73)	1175.5	72.4	1630.4	68.1	871.4	43.2 }		
Type IV (73 dextrose equivalent and above:							} 843.0	42.5
High fructose corn syrup	3202.9	250.5 }						
All other Type IV	207.9	12.3 }	519.9	22.4	60.6	2.8 }		
Glucose syrup solids (dried glucose syrup)	154.5	25.6	84.2	7.8	127.1	10.4	110.4	3.8
Dextrose monohydrate and dextrose anhydrous	1266.7	138.6	1349.5	92.1	1227.9	81.6	1093.6	71.5
Manufactured starch:								
Corn starch, including milo	5486.4	408.2	3588.3	208.8	3119.0	199.5	2565.1	177.3
Other starch, including Irish potato, wheat, rice, etc.	156.4	32.2	185.5	20.9	121.3	11.0	235.4	17.9
Dextrin (corn, tapioca, and other)	138.0	25.2	83.3	11.5	168.7	16.0	118.9	9.9
Corn Oil:								
Crude }								
Once-refined }	a/	325.1	a/	84.9	a/	76.4	a/	60.9
Fully refined, including margarine oil }								
Wet process corn by-products:								
Steepwater concentrate (50 percent solids basis)	135.5	4.1	99.8	2.3	78.0	1.5	42.7	1.0
Corn gluten feed	4199.8	226.6	3050.8	76.4	2365.9	55.1	1316.8	27.4
Corn gluten meal	905.2	113.0	783.0	51.3	875.2	36.6	1078.2	33.3
Other wet process corn by-products	1564.0	117.9	1076.0	50.5	341.4	16.9	N/A	17.2
Other wet corn milling products, n.s.k., typically for establishments with 15 employees or more (see note)	(x)	7.3	(x)	13.4	(x)	9.9		
Other wet corn milling products, n.s.k., typically for establishments with less than 15 employees (see note)	(x)	6.4	(x)	1.7	(x)	0.3	(x)	8.6

a/Quantity data are withheld due to duplication arising from shipments between establishments in the same industry classification.

*Total shipments including interplant transfers.

Corn starch production in 1977 totaled 2.5 billion kg (5.5 billion lb) at a value of nearly $410 million. Corn starch production increased slightly from 1.4 billion kg (3.1 billion lbs) in 1967 to 1.6 billion kg (3.6 billion lb) in 1972 and then increased nearly 900 million kg (1.9 billion lb) to 2.5 billion kg (5.5 billion lb) between 1972 and 1977.[8]

Prior to 1969, from 450 to 680 million kg/yr (1 to 1.5 billion lb/yr) of starch were sold to the paper and related industries and approximately 160 to 180 million kg/yr (350 to 400 million lb/yr) to each of the food and textile industries.[9] While the amounts sold to the paper and food industries have increased, the amount sold to the textile industry decreased to approximately 125 million kg/yr (275 million lb/yr) between 1972 and 1976.[10] During 1969, 85 percent of the starch produced was used for industrial uses, with 10 percent for food processing industry uses and 5 percent for exportation. By 1977, over 80 percent of all corn starch-based products (starches and syrups) have gone to the food processing industry.[4]

Increases in production of corn syrup and corn sugar continued until 1972; thereafter production declined. In 1977, corn syrup production totaled 3.6 billion kg (7.9 billion lb) with a value of $534 million. Between 1972 and 1977, high-fructose corn syrup production increased substantially. In 1977, more high-fructose corn syrup (HFCS) (1.5 billion kg (3.2 billion lb)) was produced than the quantity of any of the other three major types of corn syrup. The amount of dextrose produced in 1977 was 570 million kg (1.2 billion lb) with a value of $139 million. Although the quantity of corn oil produced is undetermined, the value was $325 million in 1977. From 1972 to 1977, the value of corn oil increased from 11 to 17 percent of the total value of corn wet milling products.[8]

Other wet process corn by-products, such as gluten feed and gluten meal, totaled 3 billion kg (nearly 7 billion lb). The value of the shipments was $462 million. Shipments of animal feed by-products increased by more than 600 million kg (1.3 billion lb) between 1967 and 1972 and by about 800 million kg (1.8 billion lb) between 1972 and 1977. These increases amount to over 36 percent over each five-year period or an annual growth rate of over six percent. Gluten feed production alone increased from approximately 1.4 to 1.9 billion kg (3 to 4 billion lb) over the period from 1967 to 1977. This greatly increased (nearly 38 percent over the five-year period) gluten feed production was accompanied by a much smaller increase (about 16 percent) in gluten meal production.[8]

Currently, the U.S. is importing starch and starch derivatives. Eighty percent of all starch imports in 1960 to 1965 were tapioca starch, as approximately 136 million kg/yr (300 million lb/yr) was imported from Brazil and Thailand.[8] Dextrin, dextrose, dextrose syrup, and related products also are imported, primarily from the Netherlands.[11]

Exports of corn wet milling products have fluctuated over the past 20 years with a decrease in the early 1960's brought about by modernization and expansion of plants in foreign countries.[12] However, in 1977-78, exports of corn wet milled feed products rose from 1.3 billion kg (2.9 billion lb) in 1976-77 to 1.6 billion kg (3.5 billion lb). This rise was accompanied by a decrease in the export of substitutes such as prepared feed and alfalfa and grain by-products which fell 3.1 billion kg (6.8 billion lb) in 1976-77 and 2.8 billion kg (6.2 billion lb) in 1977-78. Currently, the European Economic Community is the recipient of 97 percent of all annual corn wet milling industry exports.[13] In 1950, the principal importer was Canada.

Employment and economic statistics for the wet corn milling industry (SIC 2046) from 1958 to 1977 are given in Table 4-4. These data were compiled from the Census of Manufacturers[8] and the Annual Survey of Manufacturers[14] and give general industry trends. Specific plant capacity and product information is currently unavailable.

The projected production figures for each major co-product are presented in Table 4-5. Historical production trends and projections of future production were estimated based on information from industry experts.[15-21] In general, total U.S. corn wet milling production capacity (usually expressed in standard bushels - 56 lb - of corn grind) has increased at about 5 percent per year over the last 10 years. Production levels have been erratic, as the production of the different co-products have varied from minus three percent to greater than nine percent over the same time period, with greater variations depending on the different

TABLE 4-4. GENERAL STATISTICS FOR CORN WET MILLING INDUSTRY (SIC 2046) 1958-77[8,14]

	All Employees Number (000)	All Employees Payroll ($000,000)	Production Workers Number (000)	Production Workers Wages ($000,000)	Cost of Materials ($000,000)	Value Added By Manufacture ($000,000)	Value of Shipments ($000,000)	Capital Expenditures New ($000,000)
1977 Census	10.8	189.2	7.7	131.0	1322.2	658.0	1990.7	228.8
1976 ASM[a/]	11.0	179.8	8.0	126.1	1352.4	650.2	2002.5	164.7
1975 ASM[a/]	10.9	162.9	7.9	112.7	1274.8	872.9	2141.7	157.8
1974 ASM[a/]	11.1	151.4	7.7	92.5	1197.5	673.4	1852.1	82.1
1973 ASM[a/]	11.7	143.7	8.2	94.1	768.9	359.7	1123.0	67.3
1972 Census	12.1	137.7	8.4	88.6	498.7	331.2	832.3	59.7
1971 ASM[a/]	13.0	134.0	9.0	86.7	475.7	328.4	807.3	35.8
1970 ASM[a/]	13.5	143.9	9.3	89.3	460.7	373.5	830.5	40.5
1969 ASM[a/]	13.5	129.8	9.4	82.2	436.4	395.9	828.5	35.2
1968 ASM[a/]	14.1	120.1	9.9	78.4	396.5	382.8	781.1	40.4
1967 Census	14.1	116.1	9.8	75.2	401.7	353.6	751.3	40.5
1966 ASM[a/]	13.9	106.6	9.9	73.6	417.7	346.6	755.3	43.7
1965 ASM[a/]	12.9	98.4	9.3	70.3	382.1	302.7	679.9	47.7
1964 ASM[a/]	12.5	95.3	9.2	66.0	345.1	291.8	629.5	47.9
1963 Census	13.2	89.7	9.8	65.3	335.8	290.9	622.4	26.1
1962 ASM[a/]	13.9	91.8	10.2	63.0	321.2	277.1	602.0	28.1
1961 ASM[a/]	13.9	87.4	10.3	60.2	307.7	282.3	584.7	33.9
1960 ASM[a/]	13.7	83.2	10.1	57.2	286.3	277.6	566.4	27.0
1959 ASM[a/]	13.3	79.5	7.9	55.6	293.6	262.2	557.8	25.0
1958 Census[b/]	13.8	78.8	10.4	56.3	282.0	249.4	528.5	18.1

[a/] Based on a representative sample of establishments canvassed in the annual survey of manufacturers (ASM). These estimates may differ from the results of a complete canvass of all manufacturing establishments. ASM publication shows percentage standard errors. The percentage standard errors of the 1966/1965 relatives for employment and value added were 1 and 1, respectively.

[b/] Data prior to 1958 appear in Volume II, 1963 Census of Manufacturers, in Table 1 of the chapter devoted to this industry.

TABLE 4-5. PROJECTED PRODUCTION OF CORN WET MILLING (10^9 lbs/yr)[a]

Product	1980	1981	1982	1983	1984	1985	Remarks
Starches	4.5	4.7	5.0	5.2	5.5	5.7	Estimated 5%/yr growth rate
Glucose (corn syrup)	5.0	5.2	5.5	5.8	6.1	6.4	Estimated 5%/yr growth rate
Dextrose	1.5	1.5	1.5	1.5	1.5	1.5	Estimated 5%/yr growth rate
High-Fructose Corn Syrup (HFCS):							Expected to approach market saturation of ~10×10^9 lbs by 1985
42% fructose	3.0	3.1	3.2	3.3	3.4	3.5	Estimated 4%/yr growth rate
55% fructose	1.6	2.0	2.6	3.4	4.5	5.8	Estimated 30%/yr growth rate
Ethanol (alcohol)	0.2	3.3	5.1	6.4	8.0	10.0	Estimated planned increases through 1982, followed by 25%/yr growth rate
Total Starch & Refined Products	15.8	19.8	22.9	25.6	29.0	32.9	
Animal Feeds (gluten feed, gluten meal, germ meal)	7.2	8.9	10.3	11.5	13.0	14.8	Estimated as equal to 0.45 times the Total Starch and Refined Products
Total of Major Products	23.0	28.7	33.2	37.1	42.0	47.7	
Total Grind -- Millions of Bushels of Corn Per Year	500	620	720	810	910	1000	Estimated from 56 lb standard bushel containing 15.5% H_2O & 98% (dry) product recovery (i.e., 46 lb total products/bu)

[a]Based on estimated current production and expected growth trends according to industry experts.[15-21]

market situations in any given year. While the production of the major co-products (e.g., starch and corn syrup) is expected to continue to grow at a rate of approximately five percent, production of other products (e.g., dextrins and dextrose) is expected to stabilize or decline.

During the past 20 years there has been a dramatic change in the whole corn wet milling industry brought about by new technologies and new products. The new product that has had the greatest impact on the industry is high-fructose corn syrup. The bulk of the 20th century sweetener consumption was primarily sucrose from sugarcane and sugar beets. In 1958, a shortage of sugar and other sweeteners as well as the development of new corn syrup manufacturing processes created a surge in corn syrup demand. The use of these high technology specialty syrups continued to rise, thereby broadening the base for corn syrups in the food industry. Around 1970, the introduction of HFCS created a new surge in corn syrup sales in response to a severe sugar shortage. Since 55 percent fructose HFCS is virtually identical to sugar syrups, its introduction has created substantial competition in the sweeteners market, which has helped to keep sweetener prices down. In 1974, the domestic consumption of sugar was 9.9 billion kg (22 billion lb), while in 1979 the consumption was 9.6 billion kg (21 billion lb) with 771 million kg (1.7 billion lb) of HFCS being consumed. Recently, the sales of HFCS have been temporarily slowed by unrealistically low sugar prices, but the use of HFCS will continue to rise steadily. In the long run, HFCS will bring vast changes in two major crop economies and two major food industries, sugar and corn wet milling.

Since the introduction of HFCS, corn processors have had a production capacity of about 450 million kg (1 billion lb) which is not enough to supply all of the soft drink bottlers demands during a sugar shortage. The capacity rate is expected to increase to 1.8 to 3.6 billion kg/yr (4 to 8 billion lbs/yr) in the 1980's and 4 to 4.5 billion kg/yr (9 to 10 billion lb/yr) in the 1990's.[22]

By 1985, HFCS is expected to comprise one-third of the food and beverage sweeteners. The industry experts contacted expect the market for 55 percent HFCS to increase sharply as additional soft drink manufacturers allow it to be used in their products. It is anticipated that HFCS will have replaced sugar in all available liquid applications by about 1985.

After 1985, growth is expected to approximate sugar's current growth trends and level off at approximately five percent per year. Corn syrup (glucose) production is expected to grow at slightly lower rates as HFCS usage increases. Expansion of plant capacity to meet the HFCS demand will continue at a slow rate because HFCS production is capital intensive. The economics of production are also influenced by operating rates, and the cost of energy, enzymes, and labor.

A second new production technology that will be undertaken by the corn wet milling industry is the production of alcohol for gasohol. As petroleum prices, energy demands for liquid fuels, pollution abatement costs, and needs for rural assistance increase, alcohol (ethanol), production will be developed. Production costs are highly dependent on grain prices, conversion costs, and product value; however, as the difference between gasohol and oil prices lessen, many plants will turn to gasohol production to utilize excess grind (capacity) during reduced demand for other products. Any new wet milling facilities constructed primarily for alcohol production would be dependent upon government policy; however, for the purposes of this study, a median growth scenario was used.

The projected product growth rates would lead to a doubling of total (grind) capacity by 1985 (see Table 4-5). The production of feed and oil by-products will increase proportionally with increases in total grind; however, the available markets for feed by-products are much greater than for the other co-products and are continuing to grow with an increased domestic demand for high-protein feed. In the past, the biggest supplier of feed has been soybean meal which is a by-product of the soybean oil industry. While soybean meal continues to hold the largest market share, gluten meal and gluten feed use in pet, poultry, and dairy food also has increased. Steepwater concentrates are also being used as a protein additive.

Corn oil has sold at a premium on the retail market for years with 40 to 50 percent of total production being used for salads and frying, and 30 to 35 percent being used for margarine. Currently, the soybean industry produces 80 percent of the oil sold in the vegetable oil market. Before a noticeable change in this market share would occur, there would have to be a significant increase in the price of soybeans. However, demand for corn oil will continue to be strong, even if soybean oil supply and prices remain the same. Thus, there will be no problem marketing the increased supply of corn oil due to production of HFCS and alcohol.[23]

The projected increase in total corn wet milling brought about by increased production of starch and refined starch products will probably result in 10 to 20 new plants or major modifications by 1985. Construction of several new plants and several major modifications has been announced or commenced. These new facilities generally include HFCS and/or alcohol capacity. Other similar facilities presently are being considered.

Several recent or potential applications may also increase demand for starch products in the longer-term future. Some of these products are currently on the market while others are possible improvements on current products or new products under development. During the 1960's, the starch manufacturing segment of the industry developed new starch derivatives to counteract the maturing of the traditionally large markets in paper, textiles, and corrugating. These new starch derivatives are low cost stabilizers and thickeners and are used extensively in the newly engineered food products industry.

There has been expanded use of new products in the traditional industries such as paper. For example, adding starch as a temporary wet-strength agent allows repulping of treated paper, thereby decreasing energy requirements. Also, starch is an excellent replacement for petroleum-based polyols in the manufacture of rigid urethane forms since modified starch has flame retardant properties. The manufacture of plastics may become more economical while producing biodegradable products by using starch as a filler. Using starch in plastics allows the plastics to decompose and can shorten the time needed for biodegradation to one year; such plastics also do not release toxic substances when burned as petroleum-based plastics do. It can replace 30 percent of the nonrenewable oil and gas currently used in plastics while cutting industry costs.[24] The rubber industry has used common starch as a reinforcement agent partially replacing carbon black. The addition of starch also allows the rubber to be handled in a powdered form. Thus, rubber slabs, which have high energy consumption and transportation costs, are not required.

A new development for the use of common starch is the manufacture of a graft polymer capable of absorbing up to 1400 times its weight in water. This property makes it an unusually versatile agent for prevention of soil erosion, as an absorbent in diapers and bed pads, or as a moisture-retention coating for agricultural purposes. It is also nontoxic, nonmutagenic, and biodegradable.[25,26]

A final new use for starch has been developed to remove metals from water. By mixing a starch compound which does not dissolve in water with water-containing metals, the charged metal ions are drawn to the starch to form a sludge. The metal and starch are then removed by nitric acid.[27]

4.3 PROCESS DESCRIPTION[28,29]

4.3.1 Corn Wet Milling[30-33]

The objective of the wet milling process (see Figure 4-1)[34] is to provide as complete a separation of the corn kernel components as possible and practical. A corn kernel contains a germ (oil-rich center) surrounded by starch (carbohydrate) and gluten (protein-rich) which are enclosed within a fibrous hull. The large differences in the density of the components provide for relatively easy separation.

The corn kernels are steeped (soaked) in water with sulfur dioxide (1)* prior to wet milling. The sulfur dioxide prevents putrefaction during steeping and aids in the swelling and dispersion of the protein. The mixture is steeped for 30 to 50 hours at about 10^oC (50^oF).[35] The softened kernels are then coarsely ground in a cracking mill (2) freeing the components from the hull. The first grind material is sent to hydroclone separators (4) where the lighter germ is removed. The germ is dried (5) and sold or processed into corn oil or corn germ meal (an animal feed). The heavier hull, gluten, and starch fractions are sent through a second, more thorough, milling procedure (6) to obtain free starch. The fiber is separated from the starch by screening (7). Water is removed

*Numbers in circles throughout corn wet milling process description refer to steps in Figure 4-1, the process flow diagram, marked with the same circled number.

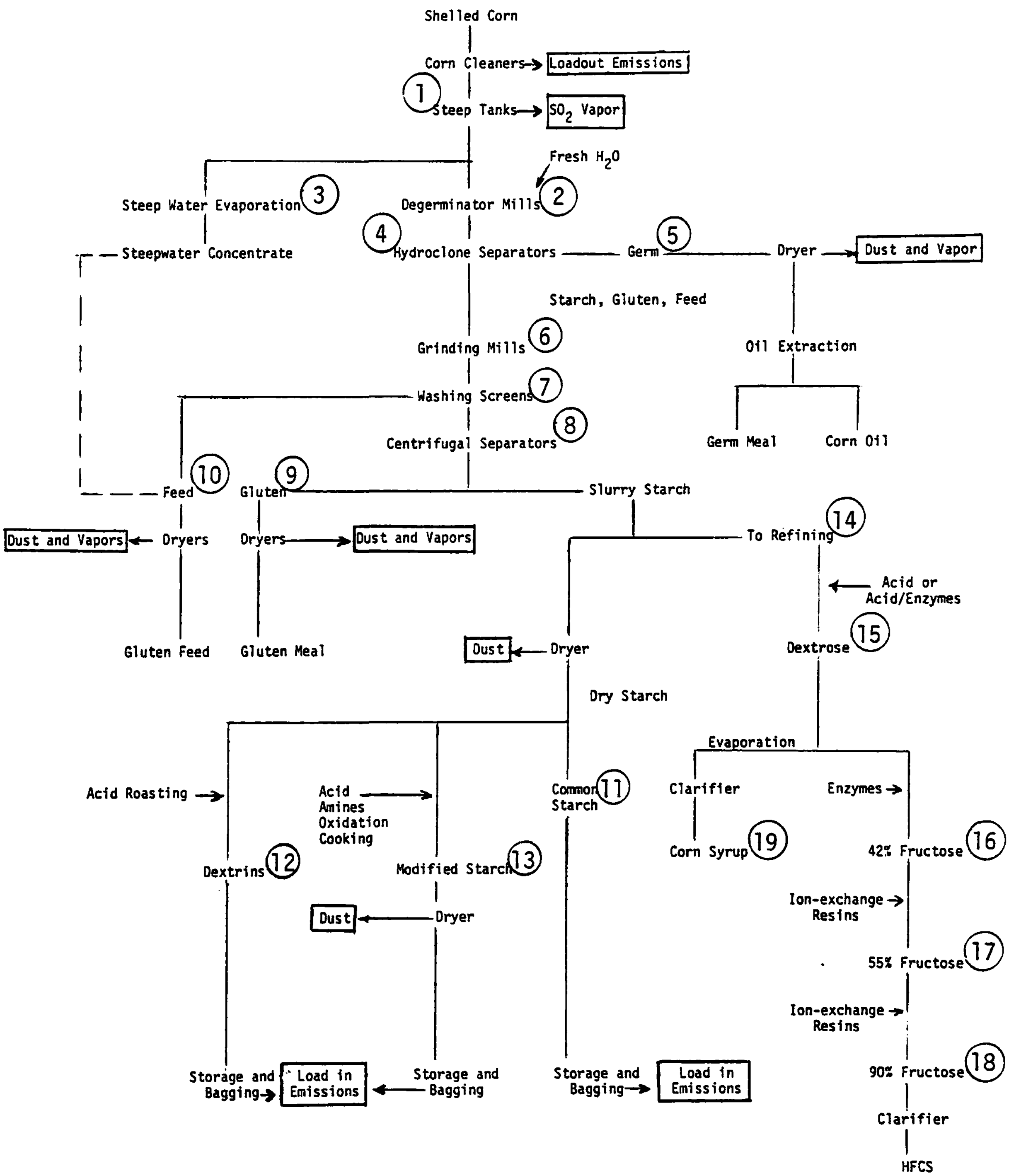

Figure 4-1. Corn wet milling process flow diagram.

from the fiber (10) which may be pressed into pellets or sold as bulk animal feed (corn gluten feed, 21 percent protein). Concentrated steepwater (3) may be added to the fiber or the germ meal to increase protein content.

The fiber-free mixture of protein-rich gluten and starch is known as mill starch (14). The low-density gluten (1.1 specific gravity) is separated from starch (1.5 specific gravity) in a centrifugal separation (8). The gluten is dewatered and dried. Starch is used to produce common starch or diverted into processing streams for the manufacture of dextrin, modified starches, refined corn products, or alcohol.

Common starch (11) is dried and prepared for use in foods or industry. Both food-grade and industrial starches may be cooked for various time, temperature, and agitation patterns in order to swell the starch granules by breaking hydrogen bonds. Several characteristics such as viscosity or gelatinization, can be modified by cooking; however, very good process control is required to obtain specific characteristics. The preparation and handling of food-grade starch must meet hygienic standards of the Food and Drug Administration. Common corn starch is dried, sized, and bagged, boxed, or shipped in bulk for use in foods or by industry, primarily in the production of textiles and paper.

Dextrins (12) are produced from dewatered common starch by dry-heating or roasting the unmodified starch with an acid or alkaline catalyst. The dry starch (five to seven percent moisture) is heated with the catalyst in an agitated vessel. This process disrupts the integrity of the starch granule allowing dextrins, which are later suspended in water and reheated, to "peel" into layers. This process changes the viscosity and cold water solubility of the dextrins.[36] The degree of "peeling" of the dextrin determines whether it will be used for adhesives, gums, or in gels.

Modified starches (13) are produced by acid or amine modification or by oxidation of the common starch. The prime starch slurry is reacted with the appropriate reagent to produce a modified starch with the desired properties. The acid or amine modified starches possess firm gelling properties which make them useful to confectioners for gum candies or to textile manufacturers as warp sizes, i.e., yarn adhesive binders protecting the fibers during weaving. Oxidized starches have high solids content with low viscosity. They are very useful in the paper industry in tub, size press, and calendar size operations. In addition, oxidized starches find uses in the food and textile industry.[37]

Refined corn products (14) - glucose (corn) syrup (which is actually high-dextrose syrup) and high-fructose corn syrup - are produced by the acid/enzyme conversion of prime starch.[32] A colloidal starch solution is reacted in a pressurized, heated converter vessel with acid or acid/enzyme reagents at pH 2. The acid or acid/enzyme reaction breaks down the starch molecule into the simple sugars, dextrose (15) and maltose. The reaction is terminated by releasing the vessel pressure and neutralizing the liquor. The corn syrup (19) is clarified to remove solids, decolorized, and concentrated. If high-fructose corn syrup (HFCS) is being made, the dextrose solution is further treated enzymatically, producing a first generation (42 percent fructose) fructose/dextrose syrup (16). This 42 percent fructose syrup can be passed over ion-exchange resins to concentrate (17) the solution to approximately 55 percent fructose (second generation HFCS). For specific market purposes, the fructose concentration may be brought to as high as 90 percent (18) for market purposes. The HFCS is clarified in the same manner as regular corn syrup. These syrups have numerous uses in the food and soft drink industries.[34]

The corn wet milling industry is presently producing a limited amount of ethyl alcohol by fermentation of the prime starch slurry. Ethanol is distilled from the solution after the enzymatic reaction on the slurry is completed. The economics of the procedure are difficult to calculate precisely, therefore, the industry is proceeding cautiously into this market. If the price of gasoline continues to rise, it is expected that alcohol production will increase with more favorable economics. Government policy regarding alcohol for gasohol production will probably be a major factor in the economics.

The process flow diagram for corn wet milling points out the sources of atmospheric emissions. There can be sulfur dioxide and odorous vapor emissions from the steeping tanks and the feed, gluten, and germ dryers. Particulate emissions emanate from the loading and storage sites and the numerous product dryers.

4.3.2 Wheat Starch[28,38]

Wheat starch can be used interchangeably with corn starch for most applications; however, it is not as economic to modify wheat starch for many uses as it is with corn or potato starch. Wheat starch may be manufactured by several different processes. The preparation of starch from wheat is one of the oldest starch manufacturing processes. The early starch operations were interested only in the starch without regard for the protein-rich gluten. The wheat was steeped to soften the grain which was crushed and then fermented to destroy the gluten. The starch was recovered and dried for sale. Today, the recovery of wheat gluten is extremely important. It is used as a high-protein supplement in baked goods and flour, adding protein without much flavor or odor. Approximately 56 to 68 million kg (125 to 150 million lbs) of wheat starch are manufactured every year. This comprises 60 to 70 percent of wheat manufacturing products, the other 12 to 16 percent is gluten, 6 to 9 percent process water solids, and 8 percent fiber.

The wheat gluten may be recovered through several procedures. The Martin process involves grinding the dry wheat grain into flour, then forming a stiff dough containing about 40 percent water. The hydrated dough is then rolled between fluted rollers or kneaded in a trough with water sprays to wash away the starch. Gluten and starch are dried separately, bagged, and sold. The alkali process extracts wheat protein from the flour using a 0.03 normal sodium hydroxide solution. Gluten can also be obtained through the slack dough or batter process, either a traditional process or a modified one such as the Raisio process. A batter or slack dough is mixed by adding water to wheat flour. The batter is then mechanically broken up while water is added to wash away the starch. Gluten is recovered as fine curds.[28] Starch liquor also is recovered, evaporated, and dried. A generalized process flow diagram is presented in Figure 4-2. Although handling and dry milling of wheat and product handling can generate particulate emissions, the major emissions from wheat starch operations are also expected to be from the dryers.

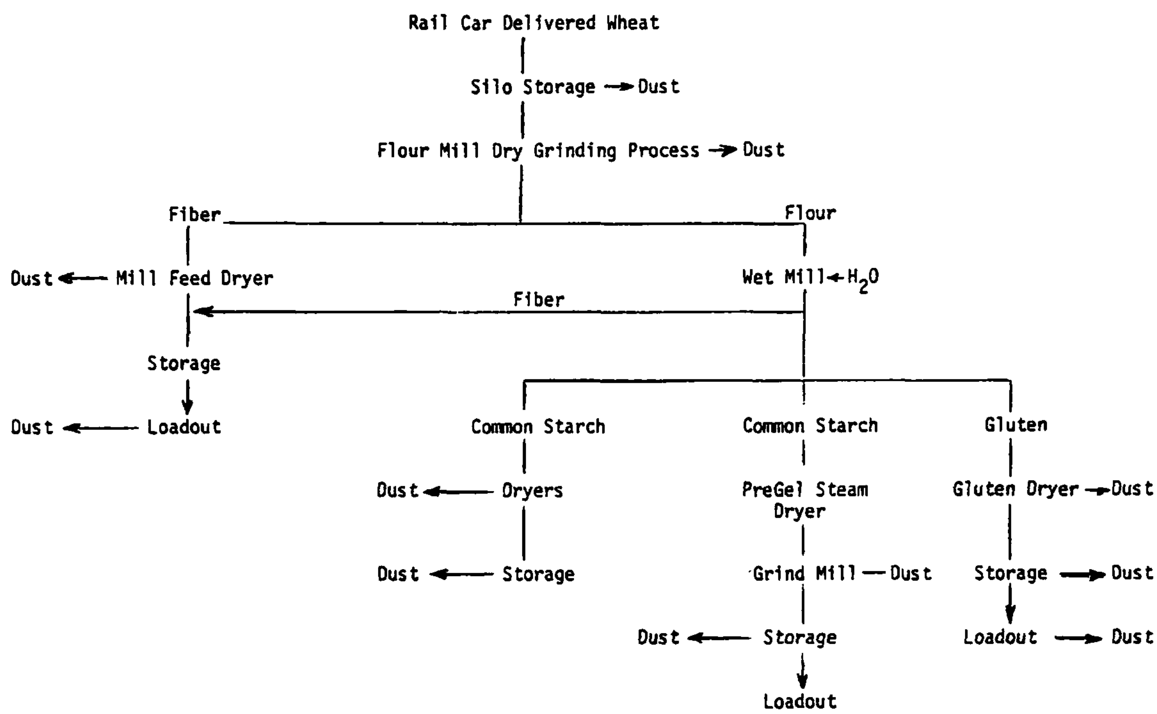

Figure 4-2. Wheat starch process flow diagram.

4.3.3 Potato Starch[28,39]

Potato starch has become a specialty starch with unique gel properties and excellent cold water solubility. These properties make it highly desirable for sizing and coating quality paper products, warp sizing, cotton yarns, instant food thickeners in baking items and puddings, and producing flexible adhesive films.[40] Potato starch uses in the traditional industries are 60 percent in paper, 30 percent in textiles, and 10 percent in food and adhesives. The biggest increase in the use of potato starch has been in the paper industry where its properties are preferable to those of other starches. Its cohesive strength and stringiness are beneficial in paper coating. The higher degree of toughness and flexibility of potato starch is important in the textile industry and is considered superior in warp sizing.[41]

Currently, the starch output per bushel of potatoes ranges between 2.7 to 3.6 kg (6 to 8 lb), or 10 to 12 percent of the weight of potatoes.[42] In the U.S., the manufacture of potato starch has lost its once strong position to corn starch which can be made from abundant raw materials at a lower price. The availability of potatoes as a raw material for starch has declined as its use in food processing, especially frozen potato products, has increased. Thus, potato starch raw materials have become difficult to obtain at a reasonable price.[41]

There are a great variety of procedures and equipment used in manufacturing potato starch but all processes follow the same basic steps. Fresh potatoes produce the best grade starches; therefore, potatoes are quickly processed near production areas. Potatoes are held in storage bins from which they are dropped into a running water flume. The flume run removes stones and much of the dirt while delivering the potatoes to a conveyor belt. The conveyor carries the potatoes to a washer for a thorough cleaning. Clean potatoes are sent to a grinder/crusher which disintegrates the cell structure liberating the water soluble starch. Fiber and potato skin are separated by screening, or through a rotary sieve. The starch solution is dewatered and the starch is then dried and bagged. The fiber and skins are dried and sold as bulk animal feed.[39] The potato starch operation illustrated in Figure 4-3 has only two significant points of emissions - the fiber dryer exhaust and the starch dryer exhaust.

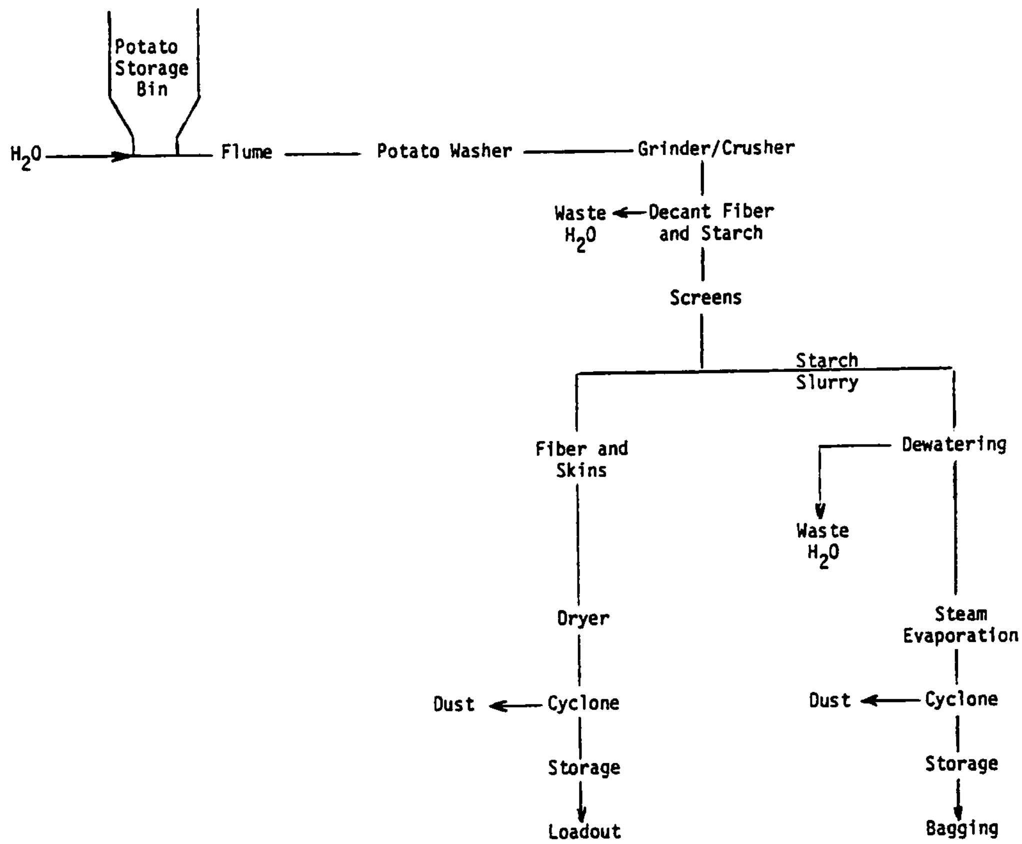

Figure 4-3. Potato starch process flow diagram.

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5. AIR EMISSIONS DEVELOPED IN SOURCE CATEGORY

5.1 PLANT AND PROCESS EMISSIONS

The corn wet milling industry can emit sulfur dioxide, hydrocarbon and particulate emissions to the atmosphere. Particulate emissions have been indicated by data in the state files as the major pollutant emitted by the process. The state files contained a limited amount of data on emissions from controlled process pollutant sources (Table 5-1); no data was available for uncontrolled emission rates. A 1973 study by the EPA[1] was used to augment the state emissions information (Table 5-2) and allow study objectives to be met. Uncontrolled emission factors presented in this report were calculated from controlled emission rates and assumed control device efficiencies based on those given in the state files. Some effort has been made to measure SO_2 and hydrocarbon emissions, but little reliable information exists. A summary of the process volumetric flowrates, temperatures, stream compositions, and typical emission rates is presented in Table 5-3.

The animal feed (gluten feed and gluten meal) dryers are the major sources of particulate emissions. Gluten feed has a size distribution of about 50 percent larger than 240 μm and only one percent smaller than 60 μm while gluten meal is somewhat smaller than gluten feed.[2] The test and production data presented in Tables 5-1 and 5-2 were used to calculate a controlled emission factor for the animal feed dryers. The controlled emission factor indicated for these dryer types is 0.36-1.3 kg/Mg (0.71-2.6 lb/ton) of product throughput (Table 5-4). This factor shows some agreement with findings of the 1973 EPA report which listed an emission factor of 0.2-0.6 kg/Mg (0.39-1.2 lb/ton) of throughput.[3] The uncontrolled emission factor was calculated from the controlled emission factor assuming a cyclone control device with 95 percent efficiency. Such a high efficiency is possible since particles are large and the device is carefully operated for product recovery (see Section 6). The uncontrolled emission factor, thus calculated, is 7.1-26 kg/Mg (14.2-52 lb/ton) of product throughput. Due to the great variety of process, equipment, and product mixes used in differing sizes and configurations at the different wet milling operations, no one typical plant size or configuration

TABLE 5-1. SUMMARY OF PARTICULATE EMISSION STACK TEST RESULTS FROM STATE EMISSION INVENTORIES

Plant Designation	Throughput (ton/yr)	Emission Point	Emission Rate (lb/hr)	Flowrate	Operation (hr/yr)	Emissions (ton/yr)	Control
Plant A	~2,030	Pulp feed, Dryer	7.08	31,000 scfm	2,900	10.3	None
Plant B		#1 Gouda Dryer Pregel	0.2	4,387 acfm	~8,200	0.82	None
		#2 Gouda Dryer Pregel	0.1	3,797 acfm	~8,200	0.4	None
Plant C	800,000	Stearns-Rogers Dryer	16.9	20,387 acfm	~8,600	72.5	Cyclone
	300,000	P&M Starch Flash Dryers	27.6	36,934 acfm	~8,600	118.6	Cyclone
Plant D		Gluten Feed Dryer	0.068	45,000	8,400 Est.	0.3	Cyclone/ Scrubber
		Gluten Meal Dryer	0.034	22,500 acfm	8,400 Est.	0.14	Cyclone/ Scrubber
		Starch Dryer	0.062	30,000	8,400 Est.	0.26	Cyclone/ Scrubber
Plant E		Gluten Feed Flash Dryer	30.8	36,000 acfm	8,400 Est.	129.4	Cyclone
		Finish Feed Dryer	0.288	15,000 scfm	8,400 Est.	1.2	Cyclone
		Starch Dryer	0.033	5,399	8,400 Est.	0.14	Cyclone
		Barr-Murphy Dryer	0.049	44,635 scfm	8,400 Est.	0.21	None
Plant F		By-product Flash Dryer	7.3	52,000	8,400 Est.	30.66	Cyclone/ Scrubber
		Starch Dryer	7.4			31.1	Scrubber
Plant G		Feed Dryer	22.2	38,380 acfm		68	Cyclone
		Feed Dryer	10.7	10,020 acfm		33	Cyclone
		Starch Flash Dryer	7.5	34,000 acfm		23	Cyclone
		Starch Flash Dryer	0.09	32,270		2	Scrubber
		Starch Belt		3,290	8,400 Est.	1	FF
Plant H		Fiber Dryer	4.4	40,000 acfm	8,400 Est.	18.5	Cyclone/ Scrubber
		Feed Flash Dryer	14	81,000	8,400 Est.	58.8	Cyclone
		P&S Dryer	6.3	15,000 acfm	8,400 Est.	26.5	None
Plant I		Raymond Flash Dryer #1	25.2	50,000 acfm	8,400 Est.	105.8	Cyclone/ Scrubber
		RFD #2	39.6	77,000 acfm	8,400 Est.	166.3	
		Gluten Feed #1	15.4	16,000 acfm	8,400 Est.	64.7	
		Heil Dryer	30.8	32,000 acfm	8,400 Est.	129.4	
		Germ Dryer	7.0	20,500 acfm	8,400 Est.	29.4	Cyclone/ Rotoclone
		Gluten Meal Dryer	6.0	3,500	8,400 Est.	25.2	Cyclone/ Rotoclone
		Gluten Meal Dryer	12.6	25,000	8,400 Est.	52.9	Cyclone/ Rotoclone
		Feed Dryer	22.6	25,000	8,400 Est.	94.9	Cyclone/ Rotoclone

TABLE 5-2. SUMMARY OF PARTICULATE EMISSION STACK TEST RESULTS FROM EPA 450/3-73-003a[1]

Plant Designation	Source	Product Recovery Device	Gas Volume (cfm)	Emission Rate from Product Recovery Device (gr/scf)	Emission Rate from Product Recovery Device (lb/hr)	Secondary Dust Control Device On Product Recovery Device or Process Equipment	Emission Rates from Secondary Dust Control Device: Inlet Dust Load (lb/hr)	Emission Rates from Secondary Dust Control Device: Outlet Dust Load (lb/hr)
Plant A[a]	Gluten meal dryer	Cyclone	37,500	0.076	24.4			
	2 Gluten feed dryers	8 cyclones per dryer	46,000 per dryer	0.05	20.4			
	Proctor and Schwartz starch dryer	--	27,700	0.012	2.8[b]			
	Proctor and Schwartz starch dryer	--	9,600	0.024	1.96[b]			
	Flash starch dryer	2 cyclones	43,000	0.019	7.0			
	Flash starch dryer	2 cyclones	43,000	0.019	7.1			
	Syrup spray dryer	Cyclone	23,700		--	Wet scrubber	216	66
	Syrup spray dryer	Cyclone	32,600		--	2 cyclones		92
	Germ dryer	N/A	20,500		--	Dry rotoclone		23.3
	Feed conveying	1 cyclone (Aerodyne Type B)	25,100	0.02	4.2			
Plant B[a]	Feed dryer (Raymond flash, regular feed	Cyclone	44,400	0.12	44.0			
	Feed dryer (Raymond flash, regular feed)	Cyclone	45,400	0.06	23.0			
	Feed dryer (Raymond flash, hominy feed)	Cyclone	40,100	0.11	37.0			
	Feed dryer (Heil rotary dryer, regular feed, finish drying)	Cyclone	45,000	0.038	14.6			
	Gluten dryer (Barr-Murphy dryer, gluten, single pass)	Cyclone	72,600	0.061	38.0			
	Starch dryer (belt dryer)	N/A	32,800	0.26	73.5[b]			
	Dextrose dryer (rotary dryer)	Cyclone	9,300			Rotoclone		0.6
Plant C[c]	Feed dryer	Cyclones	29,500	0.04	11.25			
	Gluten dryer	Cyclones	16,300	0.07	9.65			

TABLE 5-2 (Cont'd). SUMMARY OF PARTICULATE EMISSION STACK TEST RESULTS FROM EPA 450/3-73-003a

Plant Designation	Source	Product Recovery Device	Gas Volume (cfm)	Emission Rate from Product Recovery Device (gr/scf)	(lb/hr)	Secondary Dust Control Device On Product Recovery Device or Process Equipment	Emission Rates from Secondary Dust Control Device: Inlet Dust Load (lb/hr)	Outlet Dust Load (lb/hr)
Plant D[c/]	Gluten dryer (Barr-Murphy dryer)	6 cyclones in parallel	17,600	0.026-0.077	8.0[d/]			
	Distillers, dark grains dryer (rotary dryer)	Cyclone	31,000	0.03	8.7[d/]			
Plant E[c/]	Feed dryer (Raymond flash)	Cyclone	27,000	0.024	5.55			
	Feed dryer (Raymond flash)	Cyclone	27,000	0.028	6.58			
	Feed dryer (Heil, rotary finish drying)	Cyclone	13,000	0.045	5.01			
	Gluten dryer (Barr-Murphy dryer)	8 cyclones	55,000	0.034	16.3			
Plant F[c/]	Starch dryer (Intensa flash dryer)	Cyclones	45,000			Wet scrubber		17.3

[a/]Western Precipitation sampling equipment used for source testing.

[b/]No product recovery device or dust control device installed on belt dryer.

[c/]RAC sampling equipment used for source testing.

[d/]Average of several individual tests.

TABLE 5-3. PROCESS EMISSIONS SUMMARY FOR CORN WET MILLING[a,b]

Emission Point		Range of Volumetric Flowrate (acfm)	Stream Composition	Exit Temperature °F	Mean Controlled Emission Rate	Measurement Method
Corn Loadout Emissions		5,000-20,000	Particulate	Ambient	5 tons/yr	Material Balance
Steep Tanks		8,000-12,000	SO_2	Ambient	40 tons/yr	Estimate
Germ Meal Dryer		5,000-20,000	Particulate	220[c]	26 tons/yr	Material Balance
Gluten Feed Dryer		30,000-80,000	Particulate	250[c]	80 tons/yr	EPA - RM 5
Gluten Meal Dryer		10,000-50,000	Particulate	240[c]	30 tons/yr	EPA - RM 5
Starch Dryer -	Belt	10,000-35,000				
	Flash	30,000-60,000	Particulate	250-275[c]	20 tons/yr	EPA - RM 5
	Spray	30,500-90,000				
Loadout Emission Points		1,000-3,000	Particulate	Ambient	5 tons/yr	Material Balance

[a]Summary represents the limited data accessible within the Phase I survey time period. Data is extremely limited in availability and applicability across the industry as a whole.

[b]The data presented was obtained from emission test data in state files, plant information, and EPA-450/3-73-003a, Emissions Control in the Grain and Feed Industry, Volume I -- Engineering and Cost Study.[1]

[c]Temperature is carefully controlled to prevent cooking the product which can reduce saleable yield or to prevent driving off organics which can produce a visible haze or odors.

TABLE 5-4. FEED DRYER EMISSION FACTORS[a]

Plant Designation	Emission Point	Throughput (tons/yr)	Controlled Emission Rate (lb/hr)	Controlled Emission Factor (lb/ton throughput)	Control
Plant A	Raymond Flash Dryer	35.6	25.2	0.71	Cyclone
	Heil Dryer	11.9	30.8	2.6	Cylone
	Intensa (flash) Gluten Feed Dryer	15.4	15.4	1.0	Cyclone
Plant B	Gluten Feed Dryer	14.4	0.068	0.005	Cyclone
Plant C	Stearns-Rogers Gluten Feed Dryer	17.4	16.9	0.97	Cyclone
Plant D	Gluten Feed Flash Dryer	2.95	30.8	10.4	Cyclone

[a]Data from state files.

exists that adequately represents the industry as a whole. However, an average-sized plant (based on the literature and site visits[4,5]) would process approximately 2500 m^3/day (70,000 bu/day) of corn kernels, producing about 180 kg of animal feeds/m^3 (14 lb/bu). It usually would operate 340 days/yr making 1.5 x 10^5 Mg of gluten feed/yr (1.7 x 10^5 tons/yr). Based on these parameters, the average plant has controlled dryer emissions of 55-200 Mg/yr (60-220 tons/yr); or a potential uncontrolled emission rate - assuming a 95 percent efficient cyclone control device - of 1100-4000 Mg/yr (1200-4400 tons/yr).

The other emission points in the corn wet milling process emit much lower amounts of particulate pollutants. The emissions from grain loadout and from product handling and bagging operations have not been tested. State data files contain emission estimates based on material balance calculations. The EPA study on emissions control in the grain and feed industry contains a controlled emission factor for grain handling operations of 0.01 kg/Mg (0.02 lb/ton) throughput or about 4.5 Mg/yr (5 tons/yr)[6] emitted from each operation at the average plant. In the past, cyclones with efficiencies of 95 percent or better were used as control measures. The uncontrolled emission factor was back calculated from this information as 0.2 Kg/Mg (0.41 lb/ton) of product throughput - about 98 Mg/yr (110 tons/yr) for the average plant. The coverage of corn wet milling grain handling operations under the NSPS for grain elevators has caused the widespread use of fabric filters on these operations. In addition, the need for prevention of ambient air explosions in the work environment and the incentives for product recovery have led many plants to adopt fabric filter controls (99.9 percent efficiency) for product handling operations. Emissions are thus being reduced to less than 0.18 Mg/yr (0.2 ton/yr).

It is standard practice throughout the starch industry to install double cyclones, cyclone/scrubber or cyclone/fabric filter control at starch dryers.[4,5] Corn starch granules vary in diameter from 5 to 25 μm.[7] The state data files indicate that most plants expect 95-99.5 percent control efficiency with these methods. A controlled emission factor was estimated from the emission rates available in state files by using approximated throughputs for the plants with data. The calculated factor is 0.5 kg/Mg (1 lb/ton) throughput - about 50 Mg/yr (55 tons/yr) for the average plant. The uncontrolled emission factor (calculated assuming a 95 percent control efficiency) is 9 kg/Mg (20 lb/ton) starch throughput. The average plant would be expected to have uncontrolled emissions of 970 Mg/yr (1100 tons/yr).

The germ meal dryer controlled emission factor has been estimated from the only operation listed in the collected state data which identifies the dryer, product, and tested emission rate. The controlled emission factor for germ dryers is estimated as 0.5 kg/Mg (1 lb/ton) throughput, using an approximated throughput. The average plant has controlled emissions estimated at about 10 Mg/yr (10 tons/yr). An uncontrolled emission factor was calculated from the controlled emissions data assuming a cyclone control device with 95 percent efficiency. The uncontrolled emission factor is estimated at 9 kg/Mg (20 lb/ton) product throughput or about 240 Mg/yr (260 tons/yr) for an average plant.

The emissions from wheat and potato starch operations can be assessed in a similar manner. Wheat and potato starch manufacturing emits particulate matter from dryers and loading operations. Wheat starch granules vary from about 3 to 75 μm in diameter, while potato starch granules vary from 15 to 100 μm.[7] The collected data indicate that feed dryers, when used, are the only major sources of particulate emissions.[8,9] Two potato starch and two wheat starch plants were visited during the survey. There is almost no data available on wheat or potato starch, or tapioca operations owing to the dominance of the corn wet milling industry for starch production. It is, therefore, not feasible to estimate typical emission factors or total emissions for these plants. Their specialty applications gives them small, but secure, niches in the industry. The plants are generally small and use some air pollution control, so emissions are expected to be low. Sample emissions data for single plants are given in Table 5-5 for wheat starch and Table 5-6 for potato starch manufacturing.

Most State implementation plans (SIP's) reviewed during this survey, allow particulate emissions for sources that have production capacities of up to 30 tons/hr, at a rate equal to:

TABLE 5-5. PROCESS EMISSIONS SUMMARY FOR WHEAT STARCH MANUFACTURING[a,b]

Emission Point	Range of Volumetric Flowrate (scfm)	Stream Composition	Exit Temperature °F	Mean Controlled Emission Rate	Measurement Method
Receiving, Storage, and Clearance	11,000-15,000	Particulate	Ambient	1.1 tons/yr	Material Balance
Grinding Process	40,000	Particulate	Ambient	0.32 ton/yr	Material Balance
Mill Feed Dryer	5,000	Particulate	212	0.32 ton/yr	Material Balance
Mill Feed Storage	1,500	Particulate	Ambient	0.1 ton/yr	Material Balance
Mill Feed Loadout	520	Particulate	Ambient	Negligible	Material Balance
Starch Dryer	30,000	Particulate	500	4.9 tons/yr	Material Balance
Starch Storage	2,500	Particulate	Ambient	0.3 ton/yr	Material Balance
Starch Loadout	2,000	Particulate	Ambient	Negligible	Material Balance
Pre-gel Dryer	30,000	Particulate	500	5.92 tons/yr	Material Balance
Pre-gel Grinding	2,500	Particulate	Ambient	0.17 ton/yr	Material Balance
Pre-gel Loadout	1,000	Particulate	Ambient	Negligible	Material Balance
Gluten Dryer	20,000	Particulate	500	5 tons/yr	Material Balance
Gluten Storage	1,000	Particulate	Ambient	0.1 ton/yr	Material Balance
Gluten Loadout	1,000	Particulate	Ambient	Negligible	Material Balance

[a]Obtained through direct communication with Wheat Starch Manufacturer. [8]

[b]All baghouse controlled except for mill feed dryer which has wet scrubber. The summary presents the emissions calculated by material balance for the wheat starch operation visited during the Phase I survey. This is very limited data and does not have actual stack testing to support its validity.

TABLE 5-6. PROCESS EMISSIONS SUMMARY FOR POTATO STARCH MANUFACTURING[a]

Emission Point	Range of Volumetric Flowrate (acfm)	Stream Composition	Exit Temperature °F	Mean Controlled Emission Rate	Measurement Method
Fiber and Skins	53,750	Particulate	450	10 tons/yr	Stack Test
Starch Steam Dryer		Particulate		Negligible	N/A

[a]Obtained through communication with Potato Starch Manufacturer.[9]

$$E = 4.1 \left(\frac{\text{production rate}}{\text{ton/hr}}\right)^{0.67}$$

$$E = \text{lb emissions/ton throughput}$$

The average plant described would have a production rate of approximately 19 Mg (20 tons) of feed per hour and 12 Mg (13 tons) of starch per hour (nearly 45 Mg, or 50 tons of starch and refined products). The SIP would allow emissions from the feed dryer of 15 kg/Mg (31 lb/ton) and from the starch dryer of 11 kg/Mg (23 lb/ton). (Assuming there is only one dryer; most plants have several parallel dryers, both for feed and for starch with the production flow divided between the parallel units.) The plant would be allowed controlled emissions of 2300 Mg/yr (2600 tons/yr) and 1100 Mg/yr (1250 tons/yr), respectively. The plants surveyed were usually within the allowable emissions and often were emitting far less than the allowable amount.

5.2 TOTAL NATIONAL EMISSIONS FROM SOURCE CATEGORY

The starch manufacturing industry emits sulfur dioxide, hydrocarbons and particulate pollutants. No data was found on hydrocarbon emissions. They are assumed to be very small. Sulfur dioxide (SO_2) is emitted from grain steeping and steepwater evaporation operations. Total national SO_2 emissions were estimated by theoretical calculations and were confirmed by industry information. The estimated national total particulate emissions for the drying and material handling operations are calculated using information on the industry capacity, proportion of product produced from raw material and emission factors developed in the survey.

The estimated total national SO_2 emissions from the starch industry are 700 Mg/yr (800 tons/yr). This estimate is based on the worst case assumption that each bushel of corn is steeped in an equivalent volume of three percent sulfurous acid in water ($H_2SO_3 = SO_2 + H_2O$) and that about half the SO_2 is emitted during steeping and evaporation of the steepwater. Contact with industry suggested uncontrolled emissions of over 100 ppm SO_2 (10 lb/hr)[10,11] which corresponds with emissions calculated from the worst case assumptions. One company has estimated SO_2 emissions based on equilibrium concentration reactions so that the calculated emissions are independent of production rates and only dependent on the volume of aspirated air.[11] This company, which uses about 800 g of

SO_2/Mg corn (0.1 lb SO_2/bu), also has measured SO_2 emissions from an existing mill house scrubber of 160 ppm and 5389 scfm (8.7 lb/hr) and has two vendor quotes that will guarantee 10 ppm SO_2 emissions from scrubbers operated at the optimum pH.[11]

The anticipated SO_2 emissions in 1985 from new sources only assuming current (no) control is approximately 800 Mg/yr (900 tons/yr). In order to comply with state and local regulations, especially in nonattainment areas, new facilities would be expected to control SO_2 emissions to 10 ppm using scrubbers operated at optimum pH. Thus, estimated 1985 emissions would be reduced to about 80 Mg/yr (90 tons/yr). These estimates are based upon a probable 1.8×10^7 m^3/yr (500×10^6 bu/yr) increase in corn grind (production capacity) and a 3.2×10^6 m^3/yr (90×10^6 bu/yr) replacement of grind in existing facilities by 1985. A replacement rate of 3.3 percent per year (18 percent from 1980-1985) of the total industry grind capacity was used. This replacement rate assumes a 30 year equipment life. Nevertheless, the current (500×10^6 bu/yr), rather than 1950-1955 (130-170 $\times 10^6$ bu/yr) grind was conservatively assumed as the baseline for replacement of steeping equipment since limited information on equipment life and historical production was readily available. (The replacement baseline is the basis for calculating production capacity needing replacement as it is the capacity installed one equipment life in the past.)

The estimated total current national particulate emissions from starch dryers is 1000 Mg/yr (1100 tons/yr). The present 1.8×10^7 m^3/yr (500×10^6 bu/yr) raw material grind produces about 2.0×10^6 Mg/yr (2.3×10^6 tons/yr) of starch (nearly 30 percent by weight of the total starch and refined starch products). The emission factor for current control developed during this study is 0.5 kg/Mg (1 lb/ton) product throughput. These data allow the calculation of the 1000 Mg/yr current national emission estimate. The estimated emissions in 1985 from new facilities (about 10-20 dryers due to both replacement and added capacity) alone are 470 Mg/yr (520 ton/yr), assuming present control measures, a 5 percent per year production growth rate, a 5 percent per year dryer replacement rate (i.e., a 20 year life), and the 1967 starch production of 1.4×10^6 Mg/yr (1.6×10^6 tons/yr) as the replacement baseline. At this time, cyclones in series (95 percent efficient) are the typical control measure for starch dryers. Although expensive explosion prevention equipment is required in the system, fabric filter controls are being installed after a product recovery cyclone in many new facilities in order to increase product recovery and decrease emissions, thus reducing the explosion hazard from uncollected starch in the ambient air of the workplace. These filters will most likely have a control efficiency of 99.9 percent thus reducing estimated 1985 emissions from new facilities alone to 19 Mg/yr (21 tons/yr).

The starch industry presently produces 3.3×10^6 Mg/yr (3.6×10^6 tons/yr) of animal feed. The emission factor developed for feed drying is 0.5 kg/Mg (1 lb/ton) of product through the dryer. Thus, total national particulate emissions from feed drying are estimated at 1600 Mg/yr (1800 tons/yr). The anticipated growth in animal feed production by 1985, coupled with a replacement rate of five percent per year (i.e., an assumption of 20 year dryer life or a compounded replacement rate of 28 percent in five years - 1980 to 1985) and a baseline for replacement of the 1967 feed production, indicated new sources alone producing 3.7×10^6 Mg/yr (4.1×10^6 tons/yr) of feed products. The present particulate control is generally by product recovery cyclones which have design control efficiencies of at least 95 percent. Particulate emissions from new feed dryers (probably 10 to 20 units) are estimated at 1800 Mg/yr (2000 tons/yr) in 1985 if current controls are used. If the exhaust from half of the new dryers is recirculated into the combustor of another dryer, net emissions projected in 1985 would be effectively halved. Other available process or control modifications could further reduce 1985 particulate emissions from new feed dryers.

The 1980 total national particulate emissions from germ dryers are estimated at 130 Mg/yr (140 tons/yr). Data on shipments in 1977 and 1978 by members of the Corn Refiner Association[12] support a production ratio of 0.035:1 corn germ to corn starch (total starch and refined starch products). The amount of germ processed in 1980 is, therefore, approximately 2.5×10^5 Mg/yr (2.8×10^5 tons/year). The emission factor for these dryers using current control methods is about 0.5 kg/Mg (1 lb/ton) product throughput. In 1985, the new germ dryers alone (assuming the current control methods; dryer life of 20 years or a compounded replacement rate over the five years of 28 percent of 1967 estimated germ production; and new plant capacity of 2.7 x 10^5 Mg/yr - 3 x 10^5 tons/yr) are expected to have total particulate emissions of 150 Mg/yr (170 ton/yr) from about 15 units.

Grain receiving and product bagging operations at starch facilities have an emission factor of 0.01 kg/Mg (0.02 lb/ton). The estimated emissions from each operation at the average plant using cyclone controls (95 percent efficiency) is 4.5 Mg/yr (5 tons/yr) or 9 Mg/yr (10 tons/yr) total for both operations at the plant. The total estimated national emissions from grain and product handling together are 180 Mg/yr (200 tons/yr). New plants using fabric filter controls (99.9 percent efficiency) will reduce total national emissions to 7 Mg/yr (8 tons/yr) in 1985.

The corn wet milling industry has total national 1980 particulate emissions estimated at 2900 Mg/yr (3200 ton/yr). The total national particulate emissions from new facilities in 1985 are estimated at 2600 Mg/yr (2900 tons/yr) with current control or 1100 Mg/yr (1200 tons/yr) with expected control. A summary of the national emission estimates developed in this study are presented in Table 6-1.

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6. EMISSION CONTROL SYSTEMS

6.1 CONTROL APPROACHES

The corn wet milling operations reviewed in this study employed several types of particulate control devices. The dryers were predominantly controlled by a cyclone or two cyclones in series. The estimated efficiency of these cyclones is greater than 90 percent due to the large particle size of the material throughput. Some plants used various types of wet scrubbers, again with 90+ percent efficiency, for particulate control on the feed dryer. The rest of the operations throughout the industry used small fabric filters (unit modules) to control emissions and product losses. These units were estimated (very little actual test data exists) to attain 99+ percent efficiency.

The industry is presently using efficient control techniques on most process operations to assure economic product recovery. There are several possible process and equipment changes, however, that may decrease particulate emissions from the dryers or odorous emissions from the steepwater operations. Several new feed dryer designs (flash-, ring-, or rotary-type) are being manufactured which exhibit much better energy efficiency and lower emission rates. Some installations are also using the exhaust gases from one dryer to assist drying in downstream devices, e.g., operating dryers in series, or recycling part of the exhaust of a dryer, to maximize energy use and emissions control. These dryer configurations reduce gas flows and emissions to some extent; however, emissions control equipment could still be required to meet state regulations. Other installations are using rotary steam tube dryers in conjunction with coal-fired boilers to reduce both energy costs and generation of particulate emissions. (A lower gas throughput is used in rotary steam tube dryers than other dryer types, while effecting the same drying.) The control efficiency for starch dryers has been improved at newer facilities with the addition of a fabric filter after the cyclone. Use of a fabric filter to control moist dryer exhaust can become feasible through increased mechanical dewatering of the product and improved explosion venting systems which allow location of fabric filters within heated buildings. Along with these innovations, steepwater evaporative vapors can be recirculated through the dryers or burned in a waste heat recovery boiler to incinerate odorous compounds and provide heat recovery.

Steeping and steepwater emissions, consisting of both corn particulate matter and sulfur dioxide (SO_2), are generally controlled with wet scrubbers in the newer corn wet milling facilities. The removal of SO_2 in a scrubber is an equilibrium reaction so that the outlet SO_2 concentration is inversely proportioned to the pH. At one plant, SO_2 emission concentration is 10 ppm when the pH in the caustic soda solution was about eight. A pH higher than for this emission level will cause the formation of insoluble calcium carbonates that will plug the scrubber spray nozzles. New facilities are expected to use scrubbers with controls capable of maintaining the optimum pH.

The flow diagram (Figure 4-2) for wheat starch manufacture points out the sources of emissions from this process. The major emission points again are the product dryers. In the traditional batter process plant, the feed was not dried by forced air; the starch spray dryer was controlled with a baghouse. The Raisio modified batter process plant visited during this survey controlled the mill feed dryer emissions with a wet collector; all other emission points (including loading fugitive emissions) were controlled with small fabric filter modules. The efficiency of all control equipment (for this relatively new plant) was estimated by the equipment manufacturer/installer at 99+ percent. No emission test data on this equipment is available at this time, although typical efficiencies for these control methods is well established.

The potato starch process diagram (Figure 4-3) shows emission points from this type operation. The fiber/skins dryer is the only major emission point for the process visited during the survey. The dryer was tested in 1974 and exhibited an emission rate of 3.2 kg/hr (7 lb/hr; 9 lb/ton throughout). Control at the plant was by a single cyclone. A new facility has been planned, reportedly with modern processing and control methods. Construction of the facility has not begun and no specific information is available at this time.

6.2 ALTERNATIVE CONTROL TECHNIQUES

The starch industry strives for efficient particulate control on most operations to assure economic product recovery. The use of fabric filter controls wherever possible and the process changes such as recirculation of vapors or hot exhaust gases illustrate the industry's approach to product recovery, energy conservation, and emissions control. These procedures should receive more examination by the industry in the near future especially if production capacity expands for alcohol manufacture.

The other possibility for increased emissions control is the addition of a high-efficiency (90+ percent for 2 to 10 μm particles) cleaning device (a moderate or high pressure drop scrubber or fabric filter) after the cyclone(s) on the dryer exhaust. The present use of cyclones on the dryers has given good product recovery and emissions control, but a high-efficiency scrubber could reduce emissions further. A fabric filter offers even better control than most high-efficiency scrubbers and has the added advantage of dry product recovery; however, it could be blinded (i.e., partially or totally blocked due to water) by the high moisture effluent from animal feed dryers.

6.3 "BEST SYSTEMS" OF EMISSION REDUCTION

The starch manufacturing industry is extremely competitive. It is a capital intensive process with a relatively low profit margin. The entire process is carefully monitored for product yield per unit raw material input. The necessity of good product yield in conjunction with protection from explosion hazard has led to the industry's adoption of effective dust control measures by the industry. The plants visited during the survey employed fabric filter particulate control devices at all storage bin emission points, loading operations, dry product grinding processes, and most starch dryers. A typical feed dryer is controlled with a cyclone (sometimes two cyclones in series) or cyclone/scrubber thus providing reasonable control efficiency. Feed dryer control may be improved with the addition of a high-efficiency wet collector; however, process and control modifications for improved heat and product recovery, which are currently available and will also reduce emissions are likely to be installed at most new facilities. These process changes probably will result in reducing emissions by at least half, but at a net cost savings. The following plants, which have been recently built or are currently being planned, generally incorporate some of these features:

A.E. Staley Manufacturing Co.	Lafayette, Indiana
CPC International	Stockton, California
CPC International	Winston-Salem, North Carolina
Amalgamaize	Decatur, Alabama
Clinton Corn Processing	Montezuma, New York
Cargill, Inc.	Dayton, Ohio
ADM Corn Sweeteners	Decatur, Illinois

Also, some plants in Canada have employed state-of-the-art drying process and control technology.

A preliminary selection of the "best" control systems which are currently available, based on recently constructed or currently planned facilities, would include the following systems. Fabric filter baghouses or cyclones followed by baghouses are feasible and very effective for controlling grain and product handling, starch dryers, and germ dryers. Cyclone/scrubber combinations are feasible and effective for animal feed dryers, while baghouses could be used if potential moisture problems can be overcome. Scrubbers with an absorbent slurry such as caustic have been effectively used to control sulfur dioxide emissions from steeping.

The estimated national emissions from the various corn wet milling process sources are given in Table 6-1 for the present and for 1985. Emissions estimates for 1985 are presented for the continued use of current control techniques, the control techniques expected to be in use, and the use of the best control techniques currently available.

TABLE 6-1. ESTIMATED NATIONAL EMISSIONS FROM CORN WET MILLING

Source	Pollutant Type	Current Emissions Mg/yr (tons/yr)	1985 Emissions from New Sources Mg/yr (tons/yr)		
			Current Control	Expected Control	Best Control
Grain Handling	Particulate	90 (100)	90 (100)	4 (4)	4 (4)
Steeping and Steepwater	Sulfur Dioxide	730 (800)	820 (900)	80 (90)	80 (90)
Starch Dryers	Particulate	1,000 (1,100)	470 (520)	20 (20)	20 (20)
Germ Dryers	Particulate	130 (140)	150 (170)	150 (170)	15 (17)
Animal Feed Dryers	Particulate	1,600 (1,800)	1,800 (2,000)	910 (1,000)	180 (200)
Product Handling	Particulate	90 (100)	90 (100)	4 (4)	4 (4)
Total Sulfur Dioxide		730 (800)	820 (900)	80 (90)	80 (90)
Total Particulate		2,900 (3,200)	2,600 (2,900)	1,100 (1,200)	230 (250)

7. EMISSIONS DATA

7.1 AVAILABILITY OF DATA

Emission test data for the starch manufacturing industry is available for some of the product dryers. An examination of state emissions data files collected during this survey revealed that starch manufacturing operations were usually required to test particulate emissions from the gluten feed and gluten meal dryers. The limited test data indicated that some dryers using the typical cyclone product recovery/particulate control method had particulate emissions of 45 Mg/yr (50 tons/yr) or greater. No uncontrolled emission test data was found. The testing required was typically performed using EPA Reference Method 5 (Federal Register, August 18, 1977) test procedures. Many plants did not have actual emissions test data for the dryers or any other process emissions. The only sulfur dioxide emissions data found was that acquired during plant visits. No hydrocarbon emissions data was located.

Particulate emissions from process sources other than the gluten feed/meal dryers were calculated by material balance. The material balance emissions calculations were made in conjunction with the control equipment efficiency stated by the manufacturer. The starch industry conducts relatively precise material balance calculations for process control and marketing reasons which lends credibility to the estimated emissions. The material balance computations did not show other emissions points in the process as significant particulate emitters. Additional test data, including some data for sulfur dioxide emissions, should become available after the compliance testing of new plants and expansions currently under construction.

7.2 SAMPLE COLLECTION AND ANALYSIS

The typical method used for sampling particulate emissions for the sources tested was EPA Reference Method 5. This method is described in the August 18, 1977, Federal Register and has been the required test method by state agencies. The procedure requires the extraction of a representative gas/particulate sample from the effluent emitted to the atmosphere. A pitot tube is used in conjunction with a sampling nozzle and probe to assure that a representative sample is taken. The gas sample is extracted from equal sampling areas as prescribed in the EPA reference method. The sample is filtered to catch particulate matter on a glass mat filter substrate then sent through a condenser to dry the gas. The dry gas volume is measured with a calibrated dry gas meter. The actual volume is later corrected to standard conditions (20^{o}C and 760 mm Hg). The standard volume of gas sampled is used with the measured particulate catch from the test to calculate the particulate mass concentration per standard cubic volume in the effluent. The standard flowrate of the effluent (calculated from the gas velocity data and effluent cross-sectional area) can then be employed to calculate the pollutant mass emission rate. This method is recommended for all particulate sampling when properly conducted within the required 90-110 percent isokinetic rate.

8. STATE AND LOCAL REGULATIONS

Relatively minor hydrocarbon, nitrogen oxide, and carbon monoxide can be emitted from corn wet milling operations; however, these emissions generally are not regulated except when nuisance odors are present.

Particulate emissions occur at various stages throughout the corn wet milling process. These stages include grain handling and storage, and separation and subsequent processing (e.g., drying) of starch and fiber, and gluten feeds.

Grain elevators, including those at wet corn mills, are already federally regulated under a new source performance standard. Emissions cannot be greater than 0.025 g/sm^3 (0.01 gr/scf) or greater than zero percent opacity. Certain grain drying operations must meet the zero percent opacity requirement. Fugitive emissions from truck or railcar unloading, grain handling, truck loading, and barge or ship loading are not to exceed 5, 0, 10, and 20 percent opacity, respectively. Work practice requirements are specified for barge or ship unloading. There are state regulations for grain elevators, specifically Indiana, which are similar to the federal regulations.

Emissions from most starch manufacturing operations are covered by process weight regulations. There are a variety of process weight formulas with the most common being $E=4.10P^{0.67}$ for process weights up to 27 Mg/hr (30 tons/hr), and $E = 55.0P^{0.11}$ for weights of 27 Mg/hr (30 tons/hr) or greater, where E equals the allowable emissions in pounds per ton of throughput and P equals the process weight rate in tons per hour. Illinois has one of the strictest sets of formulas for new sources; $E = 2.54P^{0.53}$ for process weights up to 410 Mg/hr (450 tons/hr) and $E = 24.68P^{0.16}$ for weights over 410 Mg/hr (450 tons/hr). Starch and related products manufactured from potatoes and wheat are usually also regulated by the same process weight rate formulas that would be used for corn wet milling in the particular state. For those states with potato and wheat starch operations, the most common formula is $E = 3.59P^{0.62}$ for under 27 Mg/hr (30 tons/hr) and $E = 17.31P^{0.16}$ for 27 Mg/hr (30 tons/hr) or greater.

Iowa has specific processing and handling regulations which are the most restrictive state regulations applicable to starch manufacturing. Section 4.4(7) states that equipment operated for the processing or handling of grain, grain products, and grain by-products cannot discharge particulate matter into the atmosphere at a concentration exceeding 0.25 g/sm^3 (0.1 gr/scf) of exhaust gas. Illinois also specifically regulates wet corn milling by limiting emissions from feed and gluten dryers to 0.74 g/sm^3 (0.3 gr/scf) rather than using the general process weight regulation. All other processes in new plants are regulated by process weight. Existing sources are regulated by the less restrictive process weight formula.

The majority of the states have a visible emission regulation with the upper limit being 20 percent opacity. This opacity level corresponds to number one on the Ringelmann scale.

Fugitive emissions, when mentioned in the state regulations, are usually controlled by requiring the installation and use of hoods, fans, fabric filters, and other devices to enclose and vent areas used in the handling of dusty materials. Also, fugitive emissions should not be visible beyond the property line.

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16. ABSTRACT

This report documents a study assessing the need for new source performance standards (NSPS) for the starch manufacturing industry. This industry is basically contained in SIC 2046, Wet Corn Milling, and includes the manufacture of corn starch, corn oil, corn syrups, wheat starch, wheat gluten (protein), potato starch, and by-product animal feeds. Starches can also be refined to produce ethanol alcohol for gasohol. Information and assessments concerning the products, processes, product uses, plants, historical statistics, and growth potential of the industry are presented. Air pollution emissions are identified and quantified as feasible with the limited data. Animal feed and starch dryers are the major sources of particulate emissions. Present methods of air pollution control and their effectiveness are examined. State regulations applying to the industry are summarized. Based on the estimated industry growth in new sources and the emission reduction attainable using the best available control, an estimate of the total emission reduction achievable through a NSPS is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Starch Manufacturing, Wet Corn Milling, Wheat Starch, Potato Starch, Animal Feeds, Gluten, Dryers, Air Pollution, Particulate Matter, Pollution Control, Control Equipment, Standards of Performance	Air Pollution Control	13 B

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