A REVIEW OF ENERGY USE IN THE FOOD INDUSTRY

Sara Drescher, Nishant Rao, Jeannie Kozak, Martin Okos
Agricultural and Biological Engineering Department
Purdue University, West Lafayette, IN 47906

The United States food and kindred products industry or Standard Industry Code (SIC) 20 plays a vital role in the US economy and in foreign trade due to its large size, growth, and diverse products. The objective of this study was to conduct a review of the energy use and trends in the food industry, the fifth largest user of energy within the SIC 20 sector. Energy use in the food industry is examined by cost of fuels and electricity in all SIC 20 industries, energy use by fuel type in the top SIC 20 energy consuming industries, and energy end-use by fuel type in the top SIC 20 energy consuming industries. Examination of energy use in the food industries reveals energy intensive industries that may have the most incentive to reduce energy costs by implementing energy efficient processing methods. Wet corn milling is the most energy intensive industry in the SIC 20 sector with a 15% share of the total energy used. The beet sugar industry is second in energy use (7%), while soybean oil mills, malt beverage, and meat packing plants take about 5% each of the total energy use in this sector.

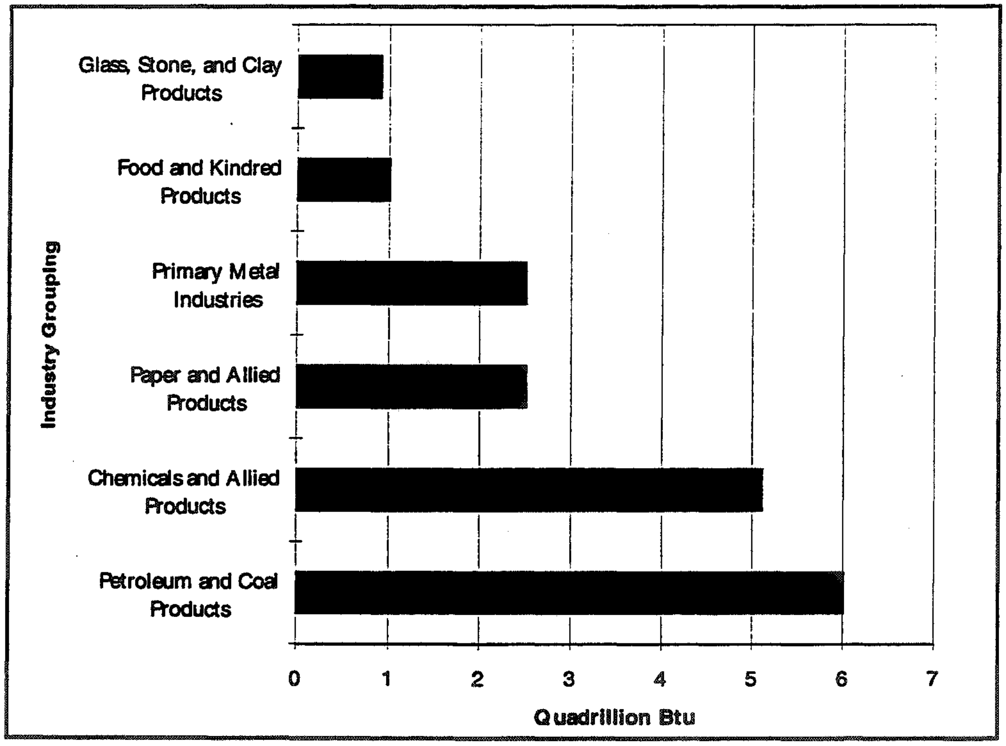
In order to determine which processes in an individual plant are energy intensive or inefficient, energy analyses must be performed. Processes and unit operations in the food industry vary in complexity and energy consumption. In this report, processes are defined as procedures using one or more unit operations. The most energy consuming processes and unit operations in each SIC sector are presented. Process heating and cooling was the most energy consuming process in the food industry taking up 44.6% of the total energy inputs. Boiler losses accounted for an average of about 22% of energy inputs. Wet corn milling, soybean oil milling, and the dairy industry are industries that have many opportunities for energy conservation and waste minimization. These industries are illustrated and opportunities for improvements discussed.

INTRODUCTION

The food and kindred products industry sector (SIC 20) is a grouping of all food related manufacturing industries in the United States. This sector is large, growing, and competitive, with value of shipments increasing from $309 billion in 1986 to $431 billion in 1994. The food industry had the second highest value of shipments when compared to all other industry sectors[4]. The food industry is crucial to foreign trade because it is one of the few industries in which exports exceed imports[21]. The food industry is also a major consumer of energy in the form of electricity and other fuels. The food industry was the fifth largest energy consumer in the manufacturing sector[9]. Figure 1 shows the top six energy consuming industry sectors in 1991. The food industry produces a wide variety of products that include meat products, dairy products, preserved fruits and vegetables, grain mill products, bakery products, sugar and confectionery products, fats and oils, beverages, miscellaneous food and kindred products. The industry groups and individual industries under SIC 20 are listed in columns 1 and 2 in Table 1.

Americans spend about 15 percent of their after-tax income on food products[22]. The food industry spent $2 billion in 1988 on research and development to create new products and further increase revenues[17]. The food industry is dependent on energy for processing, which adds to the value of food products. In addition to adding value, processing insures a fresh, safe, aesthetic product. Preservation techniques typically rely on heating and cooling and ensure quality products. In 1991, process heating accounted for approximately 29.1 percent of total energy input in the food industry[9].

Figure 1. Top Energy Consumers by Industry Grouping in 1991.



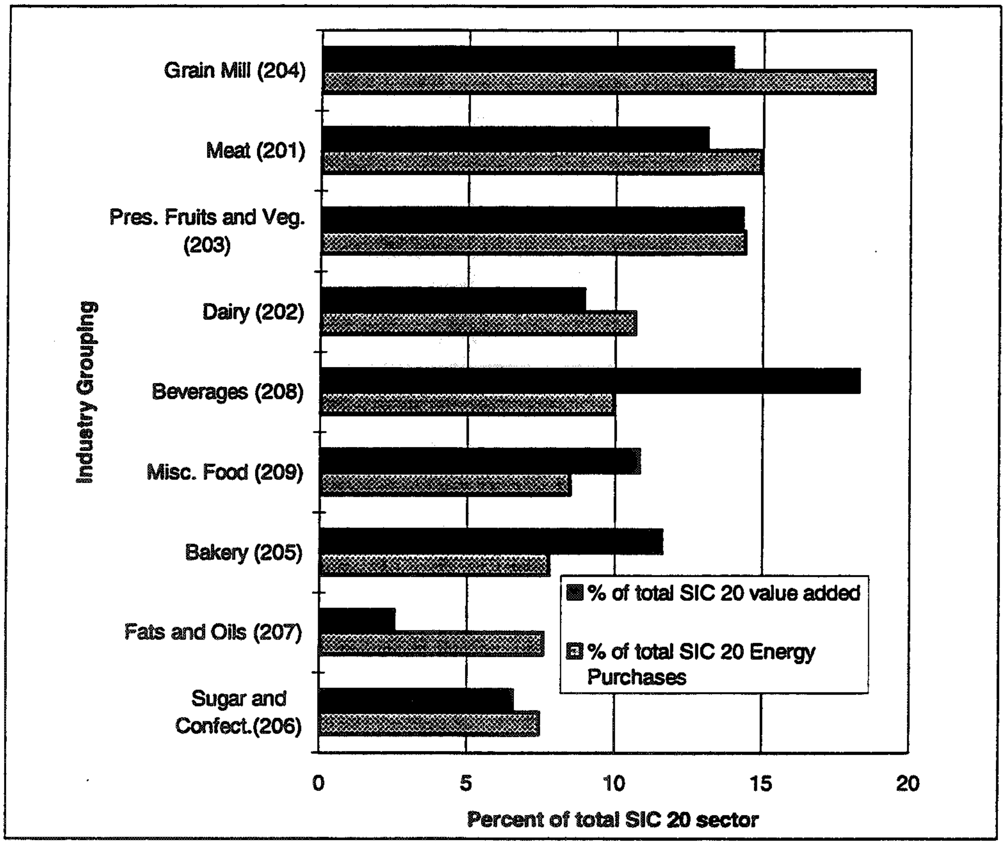
Source: Energy Information Administration, 1994

Process cooling and refrigeration consumed about 15.5 percent of total energy inputs. Foods that have undergone extensive processing have increased in popularity in the United States markets and in foreign markets. According to the US Industrial Outlook[22], food and beverage purchase patterns have changed since 1987. Consumers spend less of their food budget on meat, eggs and dairy. Recent trends indicate that consumers dedicate a greater percentage of their food budget to higher value-added foods and to cereal and bakery products. Higher value-added foods include prepared foods, nonalcoholic beverages, table spreads, and confectionery products. These foods are retail ready, packaged and brand name products. At least 40 percent of the industry shipment value is added through energy intensive manufacturing. The Bureau of the Census calculates value-added by value of industry shipments less the cost of materials, supplies, containers, fuel, electricity, and contract work[22]. Figure 2 demonstrates the relationship between energy use and value-added. Each industry grouping's energy purchases were expressed as a percentage of total SIC 20 energy purchases. Value-added of each industry was expressed as a percent of total SIC 20 value-added per industry grouping. This figure shows that industries that have added greater value to products by manufacturing usually consume more energy. Beverages, or SIC 208, are an exception by having the greatest percent value-added but only being the fifth largest energy user.

ENERGY USE IN THE FOOD INDUSTRY

The food industry was the fifth largest energy consumer in the manufacturing sector in 1994[9]. Food manufacturers are important utility customers because they have large utility loads. Electricity usually meets about 15% of the food industry's energy needs. Most of the processes that use electricity cannot substitute other forms of energy. The food industry was responsible for consuming 7% of the total electricity used by the manufacturing sectors. 94% of this electricity was purchased, and 6% was produced through co-generation by the individual food industries themselves. In addition to electricity, fossil fuels are also used, with natural gas being the most widely used. Meat, grain mill products and preserved fruits and vegetables spent the most money on electricity and purchased fuels in 1994 as seen in Table 1. Eight food industries represent approximately 50% of all SIC 20 energy inputs as shown in Figure 3 which shows the percentage of all SIC energy consumed by these industries.

Figure 2. Percent of Total SIC 20 Energy Purchases and Value Added per Industry Grouping in 1991.



Source: Bureau of Census, 1994

Table 1. Cost of purchased fuels and electricity in 1994 in the SIC 20 industry sector

SIC Code	Industry Group and Industry	Cost of Purchased Electric Energy (million $)	Cost of Purchased Fuels (million $)	Total Cost (million $)
20	**Food and Kindred Products**	**3206.2**	**2384.3**	**5590.5**
201	**Meat Products**	**578.7**	**857.0**	**835.7**
2011	Meat packing plants	170.0	94.7	264.7
2013	Sausages and other prepared meats	157.0	69.1	266.1
2015	Poultry slaughtering and processing	251.7	93.2	334.9
202	**Dairy Products**	**394.2**	**202.2**	**596.4**
2021	Creamery Butter	4.1	3.8	7.9
2022	Cheese	96.5	71.4	167.9
2023	Dry, condensed & evaporated dairy	46.8	44.0	90.8
2024	Ice cream and frozen desserts	71.0	12.3	83.3
2026	Fluid Milk	175.7	70.8	246.5

203	**Preserved Fruits and Vegetables**	**448.9**	**355.3**	**804.2**
2032	Canned specialties	39.7	38.0	77.7
2033	Canned fruits and vegetables	108.0	138.1	246.1
2034	Dehydrated fruits, vegetables & soups	33.4	44.6	78.0
2035	Pickles, sauces & salad dressings	38.9	21.7	60.6
2037	Frozen fruits and vegetables	140.4	79.8	220.2
2038	Frozen specialties	88.5	33.1	121.6
204	**Grain Mill Products**	**603.0**	**444.9**	**1047.9**
2041	Flour and other grain mill products	116.1	19.9	136.0
2043	Cereal breakfast foods	52.0	35.1	87.1
2044	Rice milling	26.8	9.2	36.0
2045	Prepared doughs and flour mixes	33.6	9.7	43.3
2046	Wet corn milling	197.8	268.3	446.1
2047	Dog and cat food	45.3	33.4	78.7
2048	Prepared feeds	131.4	69.3	200.7
205	**Bakery Products**	**242.3**	**192.8**	**435.1**
2051	Bread & cakes	156.9	132.3	289.2
2052	Cookies & crackers	55.2	43.2	98.4
2053	Frozen bakery products	30.1	17.3	47.4
206	**Sugar and Confectionery Products**	**163.4**	**252.8**	**416.2**
2061	Raw cane sugar	8.8	21.4	30.2
2062	Cane sugar refining	7.9	39.4	47.3
2063	Beet sugar	18.8	136.2	155.0
2064	Candy & chewing gum (SIC 2067)	83.4	35.4	118.8
2066	Chocolate and cocoa products	26.6	12.2	38.8
2068	Roasted nuts and seeds	18.0	8.2	26.2
207	**Fats and Oils**	**180.1**	**243.9**	**424.0**
2074	Cottonseed oil mills	27.8	15.6	43.4
2075	Soybean oil mills	77.6	115.7	193.3
2076	Vegetable oil mills	5.9	4.6	10.5
2077	Animal and marine oils	42.0	78.7	120.7
2079	Edible fats and oils	26.8	29.3	56.1
208	**Beverages**	**340.3**	**216.5**	**556.8**
2082	Malt beverages	124.1	104.9	229.0
2083	Malt	16.7	23.0	39.7
2084	Wines and Brandy	34.8	11.2	46.0
2085	Distilled and blended liquors	12.4	12.5	24.9
2086	Bottled and canned soft drinks	133.5	51.7	185.2
2087	Flavoring extracts and syrups	18.9	13.3	32.2
209	**Misc. Food and Kindred Products**	**255.4**	**218.9**	**474.3**
2091	Canned and cured fish seafoods	7.0	9.9	16.9
2092	Fresh or frozen prepared fish	49.3	69.8	119.1
2095	Roasted Coffee	29.3	22.9	52.2
2096	Potato chips & snacks	40.4	51.7	92.1
2097	Manufactured ice	8.5	3.8	12.3
2098	Macaroni and spaghetti	15.9	5.3	21.2
2099	Food preparations	105.1	55.5	160.6

Source: Bureau of the Census, 1994.

The Energy Information Association[9] defines industrial end-use categories as direct uses (process uses, non-process uses), indirect uses (boiler fuel), and unallocated end-use. Process uses include process heating, process cooling and refrigeration, machine drive (mechanical energy), electro-chemical processes, and other process uses. The food industry represents about 6% of total energy inputs in the manufacturing sector. 7.6% of electricity was used for processing, with 47.6% used for machine drive and 25% for process cooling and refrigeration in 1991. Less than eight percent of the energy consumed by manufacturing industry is end-use by non-process uses which include facility heating, ventilation, refrigeration, lighting; facility support; onsite transportation; and conventional electricity generation. Non-process uses accounted for 16.0% of electricity use. Lighting, heating, ventilation and air-conditioning accounted for about 12% of the 16%. 89.8% of residual fuel oil was used as boiler fuel. 6% was used for process heating. Distillate fuel oil was used mainly for boiler fuel (41.9%) and non-process uses (41.9%). Onsite transportation consumed the most distillate fuel oil in the non-process category. Processing consumed 9.1% of total distillate fuel oil, mostly by process heating. The third category used by the EIA is unallocated end-use. This category accounts for energy uses that do not fall into an assigned category. Unallocated end-use usually consists of byproduct energy sources. In the manufacturing industry, approximately one-half of all end-use consumption is used to change raw materials into products. Energy by end use for the entire SIC 20 industry can be seen in Table 2 and total energy consumption by fuel type of selected SIC 20 industries is shown in Table 3.

The effects of fuel and its byproducts on the food and economics of the fuel choice should be the two main considerations when selecting a fuel type. Design considerations should be evaluated to achieve the best compromise for fuel choice. These include lowest fuel cost per unit of useful heat generated, lowest capital and maintenance costs for combustion and transfer equipment, lowest direct labor costs per unit of useful heat generated, lowest fire and explosion hazard, lowest risk of product contamination by the fuel and its byproducts, maximum flexibility in operations and control, maximum reliability in continuity of supply, and compliance with environmental standards.

There are several approaches to performing energy analyses for industries[3,5,11,19]. The methodologies all include performing mass and energy balances for the industry to be analyzed. Several computer programs can be used to estimate water and energy use including WEP, FOODS, and BATCHES[2]. The Waste, Water, and Energy Estimating Program, or WEEP, estimates the water and energy use for products produced within a plant based on minimal input information to illustrate how the energy and waste production is distributed between individual operations taking place in a plant[2]. One industry where WEEP can be utilized is the dairy industry. The program requires information on the monthly production, monthly utility bills, and monthly municipal bills for waste disposal to model the distribution of energy and waste. WEEP targets specific areas with inefficiencies in water and energy usage or areas that produce excess waste. In the simulation, FOODS and BATCHES are used in addition to WEEP. FOODS is a food process flowsheeting and design program which individualizes each system and its unit operations. BATCHES is a dynamic simulation software which models the system in the time domain. In the dairy study, it was found that in the fluid milk plant, packaging consumes 41% of electricity and 35% water and uses 69% of refrigeration. Within the cottage cheese process, rinsing is the most intense operation using 22% of the electricity, 63% of the water, and 67% of the refrigeration load. In the ice cream plant, freezing processes take up 79% of electricity and 81% of refrigeration load.

In addition to estimating energy use with computer programs another method of realizing greater energy efficiency would be by the introduction of new technology. According to Kent et al. (1995), energy use in the food processing industry could be significantly decreased by 2010 with the development and use of advanced technology. Four processes that can be improved are:

1. Pasteurization and sterilization by cold pasteurization and electron beam sterilization.
2. Evaporation and concentration by supercritical extraction and protein separation.
3. Drying by vapor recompression, supercritical extraction, and extractive drying.
4. Chilling, cooling and refrigeration by controlled atmosphere packaging.

Table 2. End use by fuel type for entire SIC 20 in 1991

SIC Code	End-Use Categories		Total (Trillion Btu)	Net Electricity (million kWh)	Residual Fuel Oil (1000 bbls)	Distillate Fuel Oil (1000 bbls)	Natural Gas (billion cu ft)	LPG (1000 bbls)	Coal not Coke and Breeze (1000 short tons)	Other (Trillion Btu)
20	*Food and Kindred Products*									
Total Inputs			953	49536	4317	2966	497	1429	6913	69
Boiler Fuel			-	1073	3875	1242	306	441	6414	-
Total Process Uses			-	38445	a	270	140	292	a	-
	Process Heating		-	2030	260	212	133	224	a	-
	Process Cooling and Refrig.		-	12711	0	15	a	1	0	-
	Machine Drive		-	23597	b	35	a	56	0	-
	Electro-Chem. Processes		-	b	-	-	-	-	-	-
	Other		-	83	0	8	2	11	0	-
Total Non-Process Uses			-	7926	a	1242	34	598	a	-
	Heat, Ventilation, Air-Cond.		-	3430	26	128	20	50	a	-
	Lighting		-	3460	-	-	-	-	-	-
	Support		-	779	b	23	2	14	0	-
	Onsite Transportation		-	163	-	812	c	533	-	-
	Conventional Elect. Gen.		-	-	0	246	12	c	a	-
	Other		-	94	c	33	c	b	0	-
End-Use Not Reported			95	3166	82	212	17	b	0	69

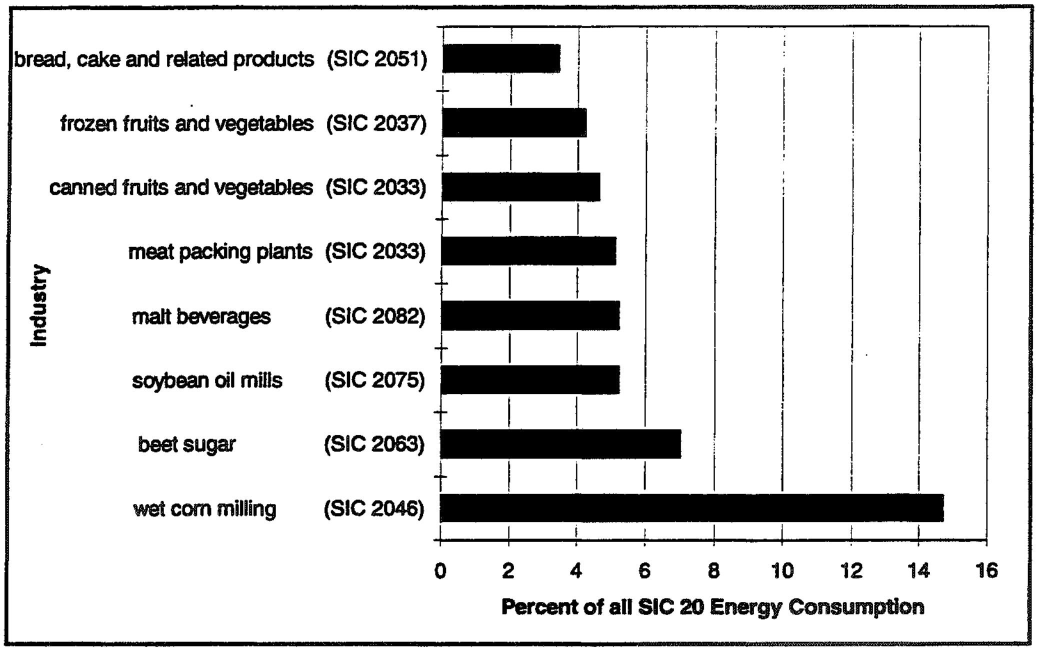
a = Withheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Withheld because standard error is greater than 50%. Data are included in totals.
c = Estimate is less than 0.5. Data are included in totals.
- = Not Applicable.
Source: Energy Information Administration (1994)

Table 3. Total energy consumption by fuel type of selected SIC 20 industries

SIC Code	Industry Groups	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
20	**Food & Kindred Prod.**	**922**	**172**	**27**	**17**	**512**	**5**	**154**	**W**	**W**
2011	Meat Packing Plants	48	12	1	1	32	1	1	0	1
2033	Canned Fruits & Veg.	44	5	2	1	36	8	Q	0	*
2037	Frozen Fruits & Veg.	40	11	2	*	26	*	0	0	1
2046	Wet Corn Milling	141	14	*	*	52	*	68	W	W
2051	Bread, cake, & related .	32	8	*	1	23	*	0	0	*
2063	Beet Sugar	67	1	W	*	19	*	43	W	*
2075	Soybean Oil Mills	50	6	*	*	24	*	13	0	6
2082	Malt Beverages	50	8	3	*	23	*	16	0	*

Estimates in trillion BTU
* - Estimate less than 0.5. Data are included in higher level totals.
W- Withheld to avoid disclosing data for individual establishments. Data are included in higher level totals.
Q- Withheld because relative standard error is greater than 50%. Data are included in higher level totals.
Source: Energy Information Administration (1994)

Figure 3. Top Eight Energy Consuming Food Industries and Percentage of total SIC 20 Energy Use.



Source: Energy Information Administration (1994)

Steinmeyer (1993) claims that changes made to improve quality or safety often result in energy savings. This is because labor and capital represent large costs and are more likely to be improved by firms. The measures taken to improve capital or labor can benefit the environment.

Manufacturing in the United States alone uses 10 billion gallons of water a day for various processes[8]. Several food industries that are not energy intensive use and waste large amounts of water. Methods of water purification include clarification, filtering, ion exchange, ultrafiltration, and reverse osmosis. In addition to wastewater recovery, there are many opportunities for waste conversion in the food industry[1,12,23]. The food products industry currently supplies fuels produced from its byproducts to other industries. Although the production and use of these biomass fuels have been shown to be technologically feasible, there are varying opinions concerning the economic stability of producing and using fuels from renewable resources. Food processors can fulfill a large portion of their energy requirements by converting their own wastes[6]. Natural gas can be produced from waste streams from a wide variety of organically rich sources such as nearly all food processing waste streams, municipal wastes, and agricultural wastes. There is also economic feasibility of producing other alternative fuels such as ethanol and methanol from food processing wastes. Each step in food processing has the potential to introduce energy losses and waste generation, and cause environmental damage. Research is needed in energy reclamation from by-products, by-product reduction, rapid analytical methods, sanitizing and cleaning agents and procedures, wastewater treatment technologies, refrigerants, and packaging technologies, to reduce environmental damage.

PROFILES OF FOOD INDUSTRY SECTORS AND MAJOR UNIT OPERATIONS IN THEM

The food industry is dependent on energy for key processes food preservation, safe and convenient packaging, and storage[17]. Fuels and electricity are used in heating processes that include roasting, baking, cooking, frying, and boiling. Roasting and baking require a direct application of heat, while cooking, frying, and boiling use a transfer medium. Cooling processes such as freezing, cooling, and refrigeration are almost completely dependent on electricity. Safe and convenient packaging is extremely important in food manufacturing and is also energy intensive. Freezing and drying are the most crucial methods of food storage. Freezing operations require a large portion of electricity used by industries while drying procedures usually depend on fossil fuels. Older dehydration systems were designed to operate with maximum throughput, disregarding energy efficiency[13]. Newer systems are designed with recirculating dampers and thermal energy recovery equipment to cut energy use 40%.

Energy efficiency improvements are currently being made by food industries to be more competitive with each other. However, these improvements are often lower priorities than energy saving strategies in industries such as dairy products manufacturers, since higher capital investments are usually required for more complex processing systems. Energy saving opportunities are generally more flexible than waste minimization plans in the degree of capital, level of training, and amount of management they require. Therefore industries tend to choose energy savings plans over complex waste minimization strategies. Each process varies in the flexibility and constraints of its energy and water requirements and waste generation. Major energy consuming processes/unit operations in the food industries are presented in Table 4.

Table 4. Main energy using operations in the SIC20 industries

SIC Code	Industry Group and Industry	Main energy using operations/processes[a]
20	**Food and Kindred Products**	
201	**Meat Products**	
2011	Meat packing plants	Boiler losses (20), Rendering (19), Hot water cleanup (11)
2013	Sausages and other prepared meats	Process steam/hot water (26), Boiler losses (18), Smoke house/cook ovens (8)
2016	Poultry dressing plants	Hot water production/cleanup (42), Boiler losses (19), Refrigeration (13)
2017	Poultry and egg processing industry	Process steam/hot water (23), Boiler losses (17), Hot water cleanup (12), Refrigeration (9)
202	**Dairy Products**	
2021	Creamery Butter	Boiler losses (29), Condensing (26), Drying (23)
2022	Cheese	Whey drying (29), Condensing/Heating (22), Boiler losses (27)
2023	Dry, condensed & evaporated dairy	Condensing (40), Spray drying (24), Boiler losses (22)
2024	Ice cream and frozen desserts	Boiler losses (28), Refrigeration (23), Hot water cleaning (12)
2026	Fluid Milk	Boiler losses (32), Hot water cleaning (16), Condensing Milk/Whey (9)
203	**Preserved Fruits and Vegetables**	
2032	Canned specialties	Processing (47), Preparation (41)
2033	Canned fruits and vegetables	Processing (79), Warehousing/Receiving (8)
2034	Dehydrated fruits, vegetables & soups	Processing (64), Preparation (23), Receiving/Warehousing (11)
2035	Pickles, sauces & salad dressings	Processing (70), Receiving/Warehousing (21)
2037	Frozen fruits and vegetables	Processing (79), Warehousing (7)
2038	Frozen specialties	Processing (45), Preparation (34), Warehousing (8)
204	**Grain Mill Products**	
2041	Flour and other grain mill products	Mechanical power (61), Drying (26)
2043	Cereal breakfast foods	Ovens (30), Drying/dehydrating (18), Mechanical power (16), Conditioning/cooking (14)
2044	Rice milling	Mechanical power (61), Drying (17), Parboil operations (10)
2045	Prepared doughs & flour	Mechanical power (75), Space heating (11)
2046	Wet corn milling	Process steam (31), Evaporation (21), Boiler losses (17), Mechanical power (14)

2047	Dog and cat food	Dry pet food – Drying (56), Conditioning/cooking (17), mechanical power (16).
		Canned pet food – Preparation/processing (57), Boiler losses (25), Mechanical power (14)
2048	Prepared feeds	Conditioning/Pelleting/Flaking (37), Mechanical power (35), Boiler losses (19)
205	**Bakery Products**	
2051	Bread & cakes	Ovens (34), Boiler losses (13), Space heating (8)
2052	Cookies & crackers	Ovens (60), Space heating (22)
206	**Sugar and Confectionery Products**	
2061	Raw cane sugar	Boiler losses (41), Evaporation (15), Vacuum pans (14)
2062	Cane sugar refining	Vacuum pans (48), Boiler losses (26), Evaporation (15)
2063	Beet sugar	Pulp dryer (26), Evaporators (38), Boiler losses (16.5)
2065	Confectionery products	Cooking (35), Roasting (19), Mechanical power (18)
2066	Chocolate and cocoa products	Roaster (34), Mixer/concher (22), Mechanical power (15), space heating (11)
2067	Candy & chewing gum	Process steam (41), Boiler losses (17), Mechanical power (11), Space heating (10)
207	**Fats and Oils**	
2074	Cottonseed oil mills	Mechanical power (30), Extraction/oil recovery (28), Seed conditioning (21), Boiler losses (20)
2075	Soybean oil mills	Dryer (21), Desolventizer/Toaster (21), Steam (20), Boiler losses (21)
2077	Animal and marine oils	Cooking/Press (31), Boiler losses (18), Space heating (12)
2079	Edible fats and oils	Hydrogen production (41), Boiler losses (28), Deodorization (23)
208	**Beverages**	
2082	Malt beverages	Steam/Hot water (43), Losses (28)
2083	Malt	Kiln (86), Mechanical power (10)
2084	Wines and Brandy	Distillation (51), Boiler losses (19), Refrigeration (7)
2085	Distilled and blended liquors	Process steam (40), Boiler losses (30), Mechanical power (11)
2086	Bottled and canned soft drinks	Steam heating (25), Bottle washer/filler (21), Boiler losses (17)
2087	Flavoring extracts & syrups	Evaporation/dehydration (83), Mechanical power (7)
209	**Misc. Food and Kindred Products**	
2091	Canned and cured fish seafoods	Processing (40), Preparation (38), Plant vehicles (14)
2092	Fresh or frozen prepared fish	Preparation (71), Processing (4), Warehousing (7)
2095	Roasted Coffee	Roasting (21), Boiler losses (16), Coffee extraction (12)
2097	Manufactured ice	Freezing operation (56), Refrigeration (20), Space heating (14)
2098	Macaroni and spaghetti	Drying operations (48), Boiler losses (24), Extrusion (6)

[a]Numbers in parentheses refer to percentage of total energy input in the category used by the operation
From: Casper (1977)

PROFILES OF IMPORTANT INDIVIDUAL FOOD INDUSTRIES

There are opportunities for reducing energy consumption and waste production in nearly every sector of the food and kindred products sector. Wet corn milling, soybean oil mills, and the dairy industries are energy intensive industries and will be covered in the following section.

Wet Corn Milling Industry (SIC 2046)

The size of the wet corn milling industry was estimated to be approximately 500 million bushels annually and is one of the most energy-intensive food industries[18]. Energy is expended in the wet corn milling industry for power and heat. Power is used for mechanical processes such as pumping, grinding, and separating the fractions from the corn. Heat is used for maintaining process temperature (38-54°C), evaporation, extraction, and drying. In 1974, about 112 x 10^{12} Btu were required by the wet corn milling industry to process the 308 million bushels of corn that were used in this year. The actual energy use for the different wet corn millers ranged from 176,000 to 336,000 Btu/bushel[5]. The following opportunities for energy efficiency improvements have been found to be technologically feasible and economically practicable[5]:

1. *Direct use:* The feed drying processes were found to have the greatest opportunity for energy efficiency improvements in the direct use category. Installation of feed dryers, which recycle exhaust gases, can save 10% of the fuel to fire the furnaces. Capital investments required would amount to approximately $3.00 per 10^6 Btu saved. The internal rate of return would be about 23%. Other opportunities in the end use category include new installation of and improved operation of the starch dryers and heat recovery and insulation in carbon regeneration.
2. *Boiler use*: A 13% savings of fuel energy was estimated to be feasible if the following measures to save energy are implemented: installation of economizers to reduce boiler losses, additional effects on evaporators, improvements in maintenance, and insulation involving process steam, heat recovery for plant heating
3. *Purchased electricity*: Savings can be achieved in both plant-generated and purchased electricity. Proper sizing and improvement on the power factor of motors could reduce electricity usage by 8%. Conversion to florescent lighting and improvements in overall management practices can also result in about 16% savings.

Recently discovered opportunities in energy conservation for the wet corn milling industry include decreasing steep times for soft-endosperm, high-lysine corn[10] and reduction of lactic acid bacteria in feedstock for ethanol fermentation (corn steep liquor or stillages)[15].

Soybean Oil Mills (SIC 2075)

In the United States, 3,373.1 million pounds of soybean oil is consumed per year[7]. Soybean oil is the leading source of oils in the US. In soybean processing three main stages exist: pre-extraction, extraction and post-extraction. The pre-extraction is the preparation stage for extraction, which includes cleaning, drying, tempering, classification, cracking, separation, conditioning and flaking. Extraction is the stage where the oil is removed from the soymeats. In the post extraction stage the solvent is removed from the oil and flakes. In 1972, about 43 trillion BTU were required for production of 21.7 million tons of soybean oil. Sixty-seven percent of the energy was provided by natural gas, 6.4% by fuel oil, and 18% by coal. The following opportunities for energy efficiency improvements have been found to be technologically feasible and economically practicable[5]:

1. *Direct use:* Recycling part of the grain drying air or using heat exchangers to increase the temperature of the incoming drying air would result in a 25% savings in energy used in the dryers. Capital investments required would amount to approximately $1.50 per million Btu saved. The after-tax internal rate of return would be about 70%. Economically practicable savings in the industry would be 23%.
2. *Boiler use*: Economically practicable savings in the industry of 30% would be possible with the installation of economizers to reduce boiler losses. Heating of boiler feedwater by heat recovery in boiler stacks would result in reduction in boiler losses from 30 to 19%.
3. *Purchased electricity*: Proper sizing and improvement on the power factor of motors have a potential savings in electricity of 14% while conversion to florescent lighting and improvements in overall management practices can save about 15%.

Dairy Industry (SIC 202)

The number of dairy plants has decreased, and the value added has increased in recent years[4]. Processing of dairy products requires large amounts of energy as seen in Table 4 with concomitant production of large amounts of high BOD and TSS waste. To reduce energy and costs associated with water and waste, measures such as optimizing CIP and reusing concentrated waste streams as ingredients should be taken. In addition, dairy processes require large amounts of energy for refrigeration and pasteurization processes. Efficient equipment, using "waste energy" from one stream as usable energy for another, and on-site energy generation are some methods of reducing energy costs. The dairy industry also creates a significant amount of waste per year. The most energy consuming process in this industry is the production of dried milk using drum rollers[19] as seen in Table 5. The dairy industry is the ideal focus for a minimum energy, zero discharge plant case study in the food industry.

A detailed energy audit performed on a fluid milk plant showed that approximately 52% of the fuel energy was lost to inefficient boiler operation[16]. The audit found that process steam requirements could be economically decreased to about 32% of the original usage through the use of modifications such as increase in regeneration of the HTST (high temperature short time) process, building and steam line insulation, and through conservation practices during sanitation. A 23% electricity saving could be achieved by implementing equipment such as efficient motors, lighting, and insulation. A reduction in boiler fuel requirement from 57 billion BTU/year to about 1 billion BTU/year was also found to be feasible using various heat recovery options.

Table 5. Fuel and electricity consumption during the production of various dairy products

Product	Fuel consumption (BTU/gal)	Electricity consumption (BTU/gal)
Pasteurized bottled milk	3157	717.6
Butter	15320	1614.5
Cheese	15930	2870.3
Spray dried milk	64940	4951.2
Roller dried milk powder	110757	5704.7
Casein	91311	5740.6
Anhydrous milk fat	15176	1901.6

Source: Okos *et al.*, 1981

CONCLUSIONS

The food industry sector is the fifth largest energy consumer in the manufacturing industry sector. Process heating, cooling/refrigeration, and boiler losses were the most energy consuming processes in the industry accounting for 29.1%, 15.5%, and 22% of total energy inputs respectively. Application of energy reducing techniques such as recovery and reuse of hot and cold streams, heat recovery from compressors, and more efficient boiler operations can lead to increases in efficiency. For example, recycling dryer air would result in a 25% savings in energy used in dryers in the soybean oil mills industry, while heating of boiler feedwater with stack gasses would decrease boiler losses by 37%. In the case of a fluid milk plant, the boiler fuel requirement could be reduced from 57 billion BTU/year to 1 billion BTU/year using various heat recovery options. Implementing efficient motors and lighting could potentially lead to about 23% savings in electricity.

There are many opportunities for improving energy efficiency in the food industry through evaluation and addition of effective governmental energy policies and voluntary process analysis and improvement. Future directions for energy efficiency studies should focus on improving existing plants, developing energy-efficient process technology, improving and expanding demand side management programs, creating informed and reasonable energy policies, and further research in the possibilities of zero-discharge plants.

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