ENERGY USAGE IN THE FOOD INDUSTRY

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A REVIEW OF ENERGY USE IN THE FOOD INDUSTRY

The United States food and kindred products industry plays a vital role in the US economy and in foreign trade due to its large size, stability, growth, diverse products, and competitive nature. This study reviews energy use and trends in the food industry, revealing energy intensive industries and processes that have the most incentive to reduce energy costs by implementing energy efficient processing methods.

The food and kindred products industry sector includes all food-related manufacturing industries in the US. The sector is identified by Standard Industrial Classification (SIC) code 20, which can be broken down into nine three-digit SIC industry groups:

201: Meat Products
202: Dairy Products
203: Preserved Fruits and Vegetables
204: Grain Mill Products
205: Bakery Products
206: Sugar and Confectionery Products
207: Fats and Oils
208: Beverages
209: Miscellaneous Food and Kindred Products.

The food industry sector is one of the largest manufacturers in the United States, with the second highest value of shipments in 1994, compared to all industry sectors. The food industry is also growing, with value of shipments increasing from $309 billion in 1986 to $431 billion in 1994. In 1991, the typical US household devoted 15 percent of after-tax income to the purchase of food and beverage products. The food industry is significant to US Foreign Trade because exports outnumber imports. Few trading categories display this phenomenon. Exports of foods, feeds, and beverages not only outnumber imports, but, since 1991, have increased at a greater rate than imports.

PROCESSING AND MARKETING TRENDS IN THE FOOD INDUSTRY

Industry is dependent on energy for the processes required for food freshness and safety. Thermal processing and dehydration are the most commonly used techniques for food preservation, and require significant amounts of energy. Process heating uses approximately 29% of total energy in the food industry, while process cooling and refrigeration demands about 16% of total energy inputs.

Foods that have undergone energy intensive processing have become increasingly popular in both domestic and foreign markets. Consumers spend less of their food budget on meat, eggs and dairy, and more of their food budget on higher value-added foods and cereal and bakery products. Higher value-added foods include prepared foods, nonalcoholic beverages, table spreads, and confectionery products. At least 40% 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.

ENERGY USE IN THE FOOD INDUSTRY

In 1991, the food industry consumed 7% of the total electricity used by the manufacturing sector -- 94% of which was purchased, and 6% of which was produced through co-generation by the individual food industries themselves. Electricity meets about 15% of the food industry's energy needs. Fossil fuels are also used, with natural gas being the most widely used.

The following eight industries consume approximately half of the total energy used by the food industry:

Industry	Percent of SIC 20 energy inputs
Wet corn milling	15%
Beet sugar	7%
Soybean oil mills	5%
Malt beverages	5%
Meat packing plants	5%
Canned fruits and vegetables	5%
Frozen fruits and vegetables	4%
Bread, cake and related products	3%

The food industry uses energy for food preservation, safe and convenient packaging, and storage. Food preservation is dependent on strict temperature controls. Safe and convenient packaging is extremely important in food manufacturing and is also energy intensive. The newest packaging techniques require aseptic techniques and electro-chemical changes. Proper storage is also energy dependent. Freezing and drying are the most crucial methods of food storage. Freezing operations require a large portion of electricity used by industries. Drying procedures usually depend on fossil fuels. Older dehydration systems were designed to operate with maximum throughput, disregarding energy efficiency. Newer systems are designed with recirculating dampers and thermal energy recovery equipment to cut energy use 40%.

Approximately half of all energy end-use consumption is used to change raw materials into products (process use). Process uses include process heating and cooling, refrigeration, machine drive (mechanical energy), and electro-chemical processes. Less than 8% of the energy consumed by manufacturing is for non-process uses, including facility heating, ventilation, refrigeration, lighting, facility support, onsite transportation, and conventional electricity generation. Boiler fuel represents nearly one-third of end-use consumption. This energy was transformed into another energy source. For example, boiler fuel can be used to produce steam, which can have end uses.

Processing uses 78% of electricity, with 48% used for machine drive and 25% for process cooling and refrigeration. Non-process uses account for 16% of electricity use. Lighting, heating, ventilation and air-conditioning accounted for about 12 of the 16%. Distillate fuel oil is used mainly for boiler fuel (42%) and non-process uses (42%). Onsite transportation consumes the most distillate fuel oil in the non-process category. Processing consumed 9% of total distillate fuel oil, mostly by process heating. Like residual fuel oil, natural gas was mostly consumed as boiler fuel (62%). Process heating accounted for 27 of the 28% used for processing.

OPPORTUNITIES TO SAVE ENERGY IN THE FOOD INDUSTRY

Since the food and kindred products industry is diverse, there are many different types of operations dependent on energy. The food industry generates a significant amount of waste per year. Waste and energy use can be decreased through process optimization, operating techniques, and scheduling. Wastewater can be processed and reused. Waste can be converted to byproducts and reused or sold. Changes made to improve quality or safety often result in energy savings. For example, improving an air filter, necessary to meet health regulations, also benefits the environment, although health regulations were the motivation behind air improvement. Thus, many opportunities exist for waste and energy reduction in the food industry.

Energy use in the food processing industry could be decreased significantly by 2010. Four processes that offer particularly good opportunities for improvement include:

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 extractive drying.
4. Chilling, cooling and refrigeration by controlled atmosphere packaging.

The food products industry currently supplies fuels produced from its byproducts to other industries. The substitution of such fuels for fossil fuels can reduce hydrocarbon and carbon monoxide emissions. 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.

The Food Industry has unique environmental concerns. Research is needed in key areas to reduce environmental damage:

- uses of by-products
- by-product reduction
- improved, rapid analytical methods
- sanitizing and cleaning agents and procedures
- wastewater treatment technologies
- refrigerants
- packaging technologies

Energy efficiency improvements are currently being made by food industries to be more competitive with each other. Potential economic advantages and environmental benefits exist in waste and water efficiency improvements.

Energy efficiency can be achieved by improving existing plants, developing energy-efficient process technology, creating informed and reasonable energy policies, and further research in the possibilities of zero-discharge plants.

Government policies can:

- set standards for environmental quality, fuel quality, emissions, fuel use, zoning and licensing
- economically intervene by issuing taxes, subsidies or creating markets for pollution rights
- organize campaigns to educate target groups and share technical information about key issues

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. This paper discusses many of these opportunities.

Section 1: Introduction to the Food and Kindred Products Sector

The food and kindred products industry sector is a grouping of all food related manufacturing industries in the United States. This sector is identified by Standard Industrial Classification (SIC) code 20. This sector can be broken down into nine three digit SIC numbered industry groups:

201: Meat Products
202: Dairy Products
203: Preserved Fruits and Vegetables
204: Grain Mill Products
205: Bakery Products
206: Sugar and Confectionery Products
207: Fats and Oils
208: Beverages
209: Miscellaneous Food and Kindred Products.

This section examines the role of the food industry in the United States economy, provides a description of the structure of the industry and key energy using operations, and identifies processing and marketing trends.

Section 1.1: Role of the Food Industry in the United States Economy

The United States food and kindred products sector plays an important role in US economy due to its large, growing, and competitive nature. The food industry benefits the US economy by its size and growth, rank in domestic markets and because it is a crucial part of US foreign trade. The food industry is also a large consumer of energy due to its size.

The food industry sector is one of the largest manufacturers in the United States. Figure 1.1 shows the value of shipments of the six largest industries. This figure shows that in 1994 the food industry had the second highest value of shipments when compared to all other industry sectors. The food industry is not only large, but is also growing. Figure 1.2 shows the food industry's growth by value of shipments, which has increased from $309 billion in 1986 to $431 billion in 1994.

The US food industry sector has fared well compared to other industries. Individual food processing companies have also been successful. Moody's Industry Review (1994) shows that the composite stock price of major food processing companies rose above the New York Stock Exchange composite index in the second quarter of 1986 and has continued to stay above average. The food industry is important to the United States economy because it is a large and stable sector of US industry. The food and kindred products sector is also an indispensable component of United States foreign trade.

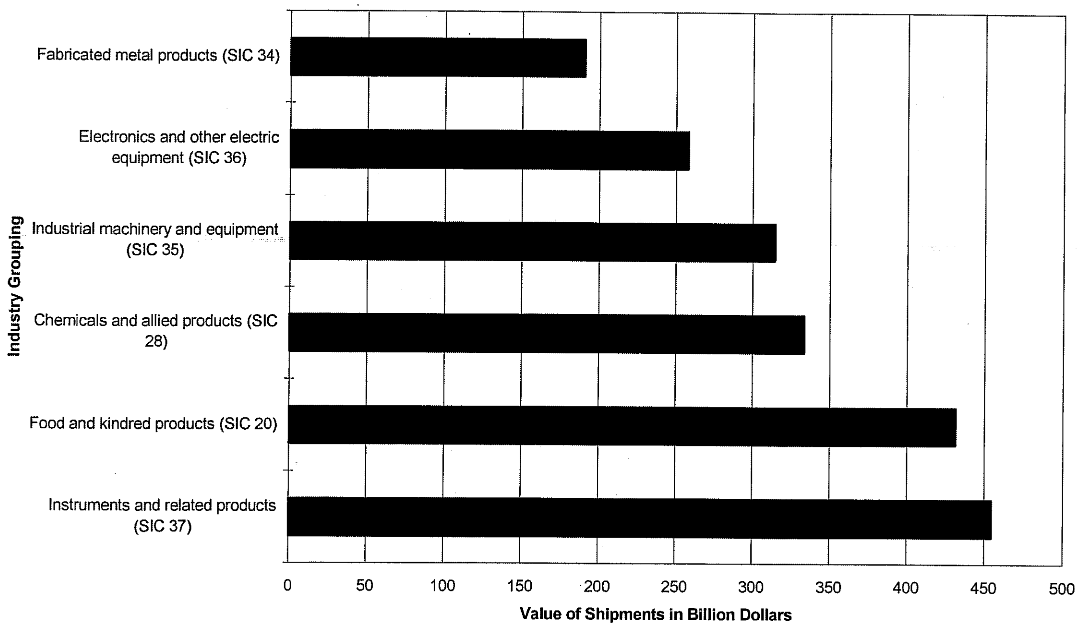

Figure 7. Industry Groupings Value of Shipments (1994). (Source: Bureau of Census, 1994).

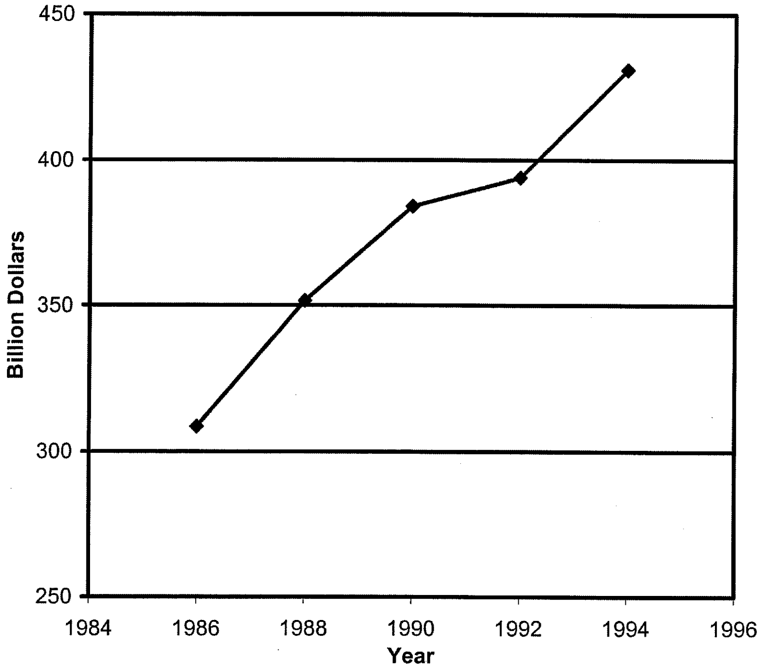

Figure 8. Growth in SIC 20 Industry Shipments 1986-1994. (Source: Bureau of Census, Various Issues.)

The food industry is significant to United States Foreign Trade because exports outnumber imports. Few trading categories display this phenomenon. The Survey of Current Business (1996) groups exports and imports into six sectors: food, feeds, and beverages; industrial supplies and materials; capital goods; automotive vehicles, engines, and parts; and consumer goods and other goods. Figure 1.3 shows the average US exports and imports from 1994-1996 of goods in the six trade categories. The United States has exported more consumer goods and foods, feeds, and beverages from 1994-1996 than it has imported.

Exports of foods, feeds, and beverages not only outnumber imports, but also have increased from 1994 to 1996 (Survey of Current Business, 1996). This pattern began in 1991 (US Industrial Outlook, 1994). Food and beverage processors have emphasized export sales because US demand for food and beverages grew less rapidly during the 1980's. One reason for the popularity of the United States food industry may be the diverse products manufactured.

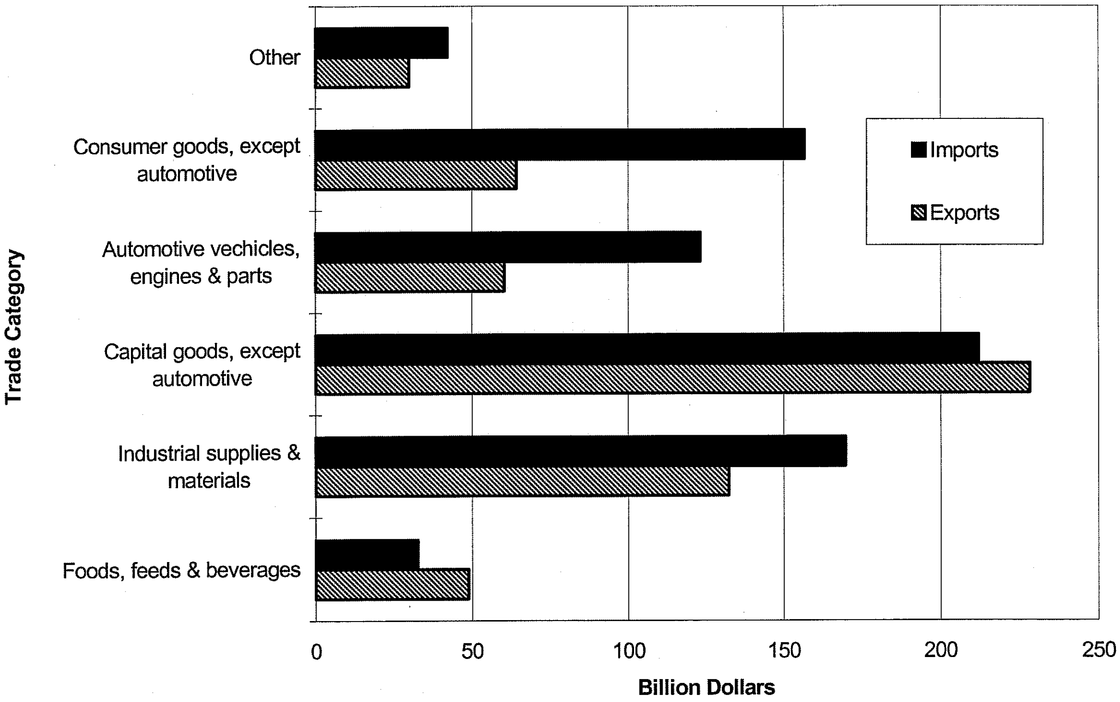

Figure 9 Average US Exports and Imports for 1994-1996 (Source: Survey of Current Business, 1996)

Section 1.2: Products of the Food and Kindred Products Sector

The food and kindred products industry sector (SIC 20) manufactures an array of foods and beverages for human consumption, as well as related byproducts (Elliott, 1994). SIC 20 industries process raw materials produced by the agro-fisheries sectors (SIC 01 - crop production, SIC 02 - livestock production and SIC 09 - fisheries production). The products of these sectors are marketed and distributed through the commercial sectors (SIC 51, 54, 58 and 70). Byproducts of the food industry are employed for agricultural, industrial, and commercial use as livestock feeds, natural gas, and dry ice. From the description of the individual sector industries in the following pages it will become clear that the food industry produces a variety of products which are marketed and sold worldwide. Many new products are constantly being developed to keep food industries competitive and tested for consumer approval (Resource Dynamics Corp., 1990).

Section 1.3: Processing and Marketing Trends in the Food Industry

In 1991, the typical US household devoted 15 percent of after-tax income to the purchase of food and beverage products, according to the Bureau of Labor Statistics Consumer Expenditure Survey. How this percentage of income, or food budget, is utilized depends on the consumer. Consumers are influenced by current trends. The food industry spent an estimated $2 billion in 1988 on research and development to create new products that satisfy consumers desires (Resource Dynamics Corp., 1990).

Industry is dependent on energy for the processes required for food freshness and safety (Resource Dynamics Corp., 1990). Freshness, food safety, and appearance are linked categories. Correct preservation techniques not only ensure quality products but also control microbial growth that can cause sickness. Thermal processing and dehydration are the most commonly used techniques for food preservation. These two processes require significant amounts of energy. For example, process heating accounts for approximately 29.1 percent of total energy input in the food industry (Bureau of the Census, 1991). It is also necessary to cool and refrigerate processed food to ensure safe, quality products. In the food industry sector, process cooling and refrigeration demands about 15.5 percent of total energy inputs.

Proper packaging techniques are an essential part of product safety (Resource Dynamics Corp., 1990). Until recently, packaging was only designed to maintain freshness and prevent bacterial contamination during transportation of the product. Consumers now demand packaging that not only protects the product, but is also convenient. Now, packaging must maintain product freshness for long periods of time, be susceptible to microwave processing and look presentable. New techniques used to create modern packaging require energy intensive aseptic thermal processing.

Creating foods with greater nutritional value is another goal of researchers that can increase degree of processing. Although some nutritional value is lost during processing, the new trend is to fortify processed foods. According to A. Elizabeth Sloan (1994), sales of foods that advertise elevated nutrient levels have had recent success. Vitamins, minerals, protein, and antioxidants are some of the nutrients added during processing.

Foods that have undergone energy intensive processing have become increasingly popular in both domestic and foreign markets. According to the US Industrial Outlook (1994), 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 (US Industrial Outlook, 1994). Figure 1.4 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, defy the trend by having the greatest percent value-added and being the fifth largest energy user.

Like American consumers, foreign consumers also favor higher value-added foods. US Industrial Outlook (1994) states that US exports of higher value-added foods reached $7.5 billion in 1993, increasing 12% from 1992 to 1993. Higher value-added foods are beginning to comprise a larger portion of US food and beverage exports. Higher value-added foods represented 23% of total food exports in 1989, rising to more than 32% in 1993.

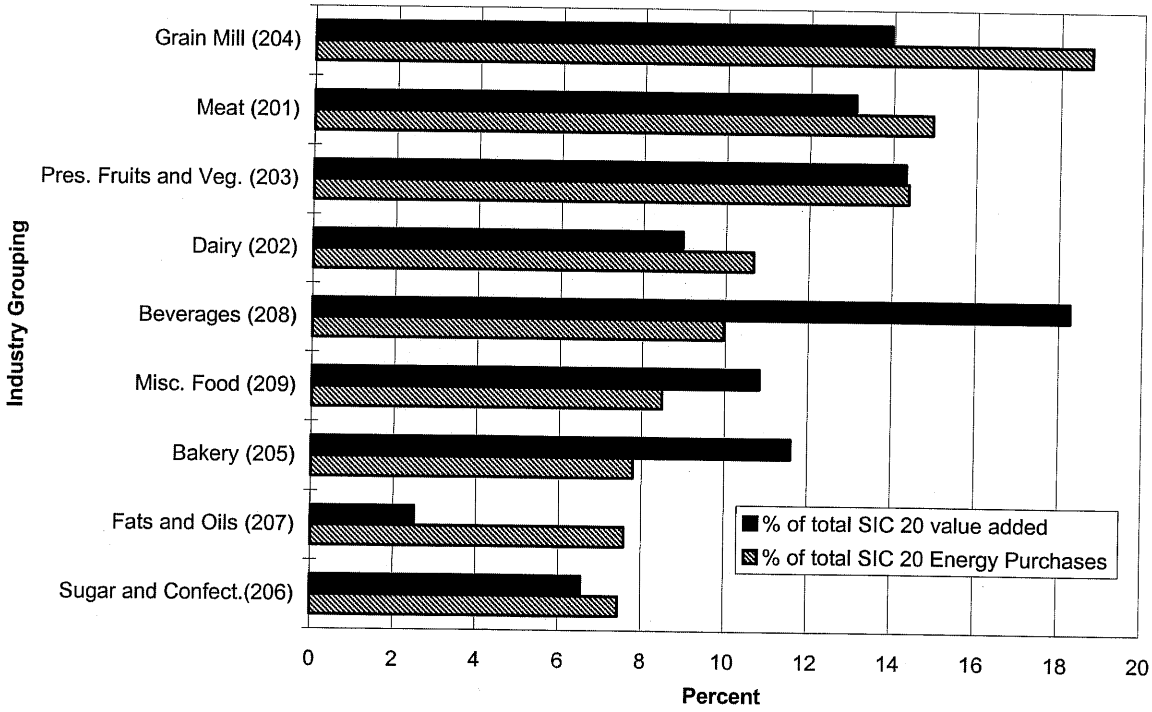

Figure 10. Percent of Total SIC 20 Energy Purchases and Value Added per Industry Grouping in 1991. Source: Bureau of Census, 1994

Section 2: Energy Use and Waste Production in the Food Industry

The environment has become a greater concern worldwide. Reducing industrial energy consumption and waste production is an important factor in all manufacturing sectors. The United States has adopted many policies to increase public awareness and regulate pollution in recent years. This section discusses strategic environmental issues specific to the food and kindred products industries, and provides data concerning energy usage in the industry.

Section 2.1: Strategic Environmental Issues Facing the Food Industry

Energy conservation and waste minimization are important issues in the United States and worldwide. The government provides energy policies to set standards and encourage compliance. These policies affect all industries including the food industry. Energy conservation and waste minimization directly relate to the issue of the preservation of the environment. According to the International Energy Agency (IEA) (1989), there are eleven major areas of environmental concern in which energy plays a key role:

- major environmental accidents
- water pollution
- maritime pollution
- land use and sitting impact
- radiation and radioactivity
- solid waste disposal
- hazardous waste disposal
- hazardous air pollutants
- ambient air quality
- acid deposition
- stratospheric ozone depletion
- global climate change

National environmental regulations are targeted at mitigating these concerns.

The Food Industry must comply with general industrial environmental regulations, but in addition has its own unique environmental concerns. Each step in food processing can have some negative effect on the environment (Cooper, 1993). Research is needed in key areas to reduce environmental damage:

- uses of by-products
- by-product reduction
- improved, rapid analytical methods
- sanitizing and cleaning agents and procedures
- wastewater treatment technologies
- refrigerants
- packaging technologies

There are many areas in by-product characterization and reduction that have not been investigated. These areas include:

- knowledge of types, quantities, and location of solid by-products generated and being disposed in the United States
- establishment of recycling and reuse regulatory criteria
- alternatives to water use
- improved brining and curing processes
- chemical extraction processes

Cooper (1993) claims that older studies on food processing by-products are outdated. Another problem is that there is no regulatory criteria concerning recycling and reuse operations. Minimum chemical and microbial standards and quality standards need to be investigated.

According to Kent, *et al.* (1995), energy use in the food processing industry could be significantly decreased by 2010. This major decrease depends on the development and use of advanced technology. Four examples of this substitution of an advanced technology for conventional technology in food processing operations are:

- Replacement of thermal pasteurization and sterilization, by cold pasteurization and electron beam sterilization.
- Replacement of evaporation and concentration, by supercritical extraction and protein separation.
- Replacement of thermal drying, by vapor recompression supercritical extractive drying.
- Product chilling, cooling, and refrigeration by controlled atmosphere packaging.

Continuing research is needed to identify new technologies and innovative applications of existing technologies.

Other unique concerns of the food processing industry have energy and environmental implications, and balancing these frequently competing concerns poses added challenges for companies.

Product safety is assured through strict voluntary adherence to industrial standards across SIC 20 and individual industries. Cleaning and sanitation are important aspects of product safety assurance. Cleaning consumes a major portion of energy in food processing plants (Casper, 1977). Food groups, such as dairy foods and egg products are exploring and practicing safety guidelines, such as the voluntary 3-A Accepted Practices approach to safeguarding public health (Gilmore, 1990). Product safety is achieved by designing and operating processing systems under parameters that have been experimentally shown to be safe. These guidelines have been formulated by the manufacturers and users of dairy processing and handling equipment, and by sanitation experts. 3-A criteria are now widely accepted by equipment makers, equipment users, sanitation experts, and enforcement officers in the health field.

Product safety can also be achieved by practicing techniques that allow food to be preserved while retaining the quality and nutritional value of the food. One such technique is Hurdle Technology, a process by which several gentle methods of food preservation are combined (Grijspaardt-Vink, 1994). The combination takes advantage of conditions or treatment of the food, which result in inhibition of microbial growth or killing of microorganisms. The sum of these "hurdles" effectively preserves the food while product quality is maintained by putting less processing stress on each of the food's attributes. Data on energy savings achievable through processing reduction or alternatives is unavailable.

Maintaining product quality is a concern that food shares with other manufacturing industries. The company can achieve this by applying disciplines such as Hazard Analysis Critical Control Point (HACCP), the Malcolm Baldrige National Quality Award, and ISO 9000 (Golomski, 1994). The Malcolm Baldrige National Quality Award has criteria for Total Quality Management (TQM). HACCP examines flow charts of a process to predict where food safety violations are likely to occur or get their start. Preventative measures are applied. ISO 9000 is a system of standards to systematically verify that all aspects of a process will result in products that meet specifications. It has many disciplines and is used internationally. ISO 9000 and HACCP are compatible. ISO 9000 and the Malcolm Baldrige National Quality Award overlap by about 15-25%.

These established methods of consistently assuring safety and quality of food products are (along with inspections of varying frequency) the means by which compliance with legislation is assured. The US regulatory system that encompasses food safety and quality involved as many as 35 different laws involving 12 agencies in 1992 (USGAO, 1992). The major legislation, responsibilities and inspection frequencies of primary federal food safety/quality agencies are summarized in Table 2.1. From the standpoint of energy use, some of these standards, practices, and legislation can be limits to energy efficiency improvements (Casper, 1977). As more technologies are developed, alternative means of maintaining food quality and safety standards can be implemented in energy savings plans. There is insufficient data to show how energy use is affected by compliance with food safety and quality guidelines.

Section 2.2: Energy Consumption in the Manufacturing Sectors

The food industry is the fifth largest energy consumer in the manufacturing sector (Energy Information Administration, 1994). The food industry was responsible for consuming 7% of the total electricity used by the manufacturing sectors. Most of this electricity (94%) was purchased, and 6% was produced through co-generation by the individual food industries themselves. Electricity usually meets about 15% of the food industry's total energy needs with most processes using electricity unable to substitute other forms of energy.

Fossil fuels account for the balance of the industry's energy use, with natural gas being the most widely used (Table 2.2). Most fossil fuel-burning equipment can operate using a variety of fuels with minimal loss of energy efficiency.

Table 2.1. Federal Food Safety/Quality Agencies: Legislation, Responsibilities, and Inspection Frequency

Agency	Major Legislation	Food Safety/Quality Responsibility	Inspection Frequency
FDA	Federal Food, Drug and Cosmetic Act.	Regulates safety of all food products, except meat, poultry and eggs.	Once every 3-5 years.
FSIS	Federal Meat Inspection Act	Regulates safety of meat products.	Continuous for slaughtering operations, Daily for processing operations.
	Poultry Products Inspection Act	Regulates safety of poultry products.	Continuous for slaughtering operations, Daily for processing operations.
AMS	Egg Products Inspection Act of 1970.	Regulates safety of egg products and controls the disposition of restricted eggs.	Continuous of egg-products-processing plants. Quarterly for hatcheries and egg packers.
	Agricultural Marketing Act of 1946	Facilitates marketing and grades the quality of meat, poultry, dairy, fruit, nut and vegetable products.	Varies, depending on contracts.
FGIS	US Grain and Standards Act and Agricultural Marketing Act of 1946.	Facilitates marketing and quality of grain, oilseeds, pulses, rice and related commodities.	All grain exports and, upon request, domestic grain and other products.
NMFS	Agricultural Marketing Act of 1946 and Fish and Wildlife Act of 1956.	Facilitates marketing and quality of fish and shellfish.	Varies, depending on contracts.

Source: United States General Accounting Office, 1992.

Table 2.2. Energy Consumption by Fuel in the Food Products Industries

Fuel	1991 Consumption (TBtus)	Fraction of Total (%)
Net Electricity	172	18.7%
Residual Fuel Oil	27	2.9%
Distillate Fuel Oil	17	1.8%
Natural Gas	512	55.5%
LPG	5	0.5%
Coal	154	16.7%
Other	35	3.8%
Total	922	

Source: Energy Information Administration, 1994.

Food manufacturers are important electric utility customers because most utilities have at least one food manufacturer customer, and food manufacturers generally have large electricity loads, resulting in intense competition for food industry loads (Research Dynamics Corp., 1990). A diverse array of products, steady growth of the industry, and customer interests maintain competition in the food industry. This competition provides room in the food industry for improvements in productivity and performance providing a potential driving force for improvements in energy efficiency. The food industry did implement energy conservation programs to save on energy costs during the energy crisis of the late 1970s and early 1980s (Energy Information Administration, 1994). However, the industry has been slow to adopt new energy technologies (Research Dynamics Corp., 1990).

Energy requirements can also be affected by climate. Some food manufacturers effectively utilize the climate to save energy. For example, ethanol producers located in areas with cold winters place their heat-generating fermentors outdoors so the winter air can cool them, reducing heat exchanger energy loads. Usually, the energy savings gained by efficient location are outweighed by the additional energy that would be required for the increased transportation of raw materials.

Some sectors of SIC 20 are located close to the source of their raw materials, such as dairy processors in Wisconsin and meat processors in Iowa. The Midwest represents the largest supplier of agricultural raw materials, and most of the energy use by the food industry occurs in this region.

Section 2.3: Energy Use in Food Production by End-Use

The food industry needs energy for various operations in order to function. In order for efforts to effectively target efficient energy use, it is important to identify which specific industries consume the most energy, for which end-uses, and in which processes.

Figure 2.1 summarizes the costs of purchased fuels and electricity for all of the individual food industry groups in 1994. Meat, grain mill products and preserved fruits and vegetables spent the most money on electricity and purchased fuels 1994 (of three-digit SIC codes in SIC 20).

Figure 2.2 summarizes the top ten food industries. Wet corn milling is a high user of coal. Although the use of distillate fuel oil and diesel fuel is typically low in the food industry, meatpacking plants are significant users of this type of fuel. According to the Energy Information Administration (1994), wet corn millers, frozen fruits and vegetable processors, meat packing plants, and the malt beverage industry were the highest users of electricity. Natural gas supplies a large portion of fuel for the food industry, and wet corn millers, canned fruits and vegetable processors and meatpacking plants used the most natural gas. The amounts of fuels and electricity used by various sectors within the food industry are summarized in Table A8, Appendix A.

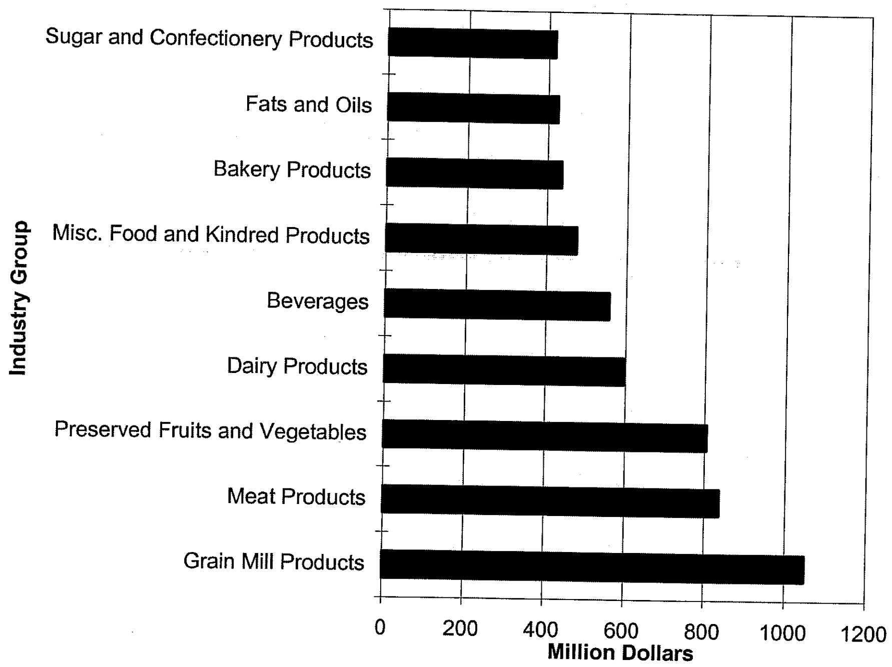

Figure 11. Food Industry Energy Purchases in 1994. (Source: Bureau of Census 1994)

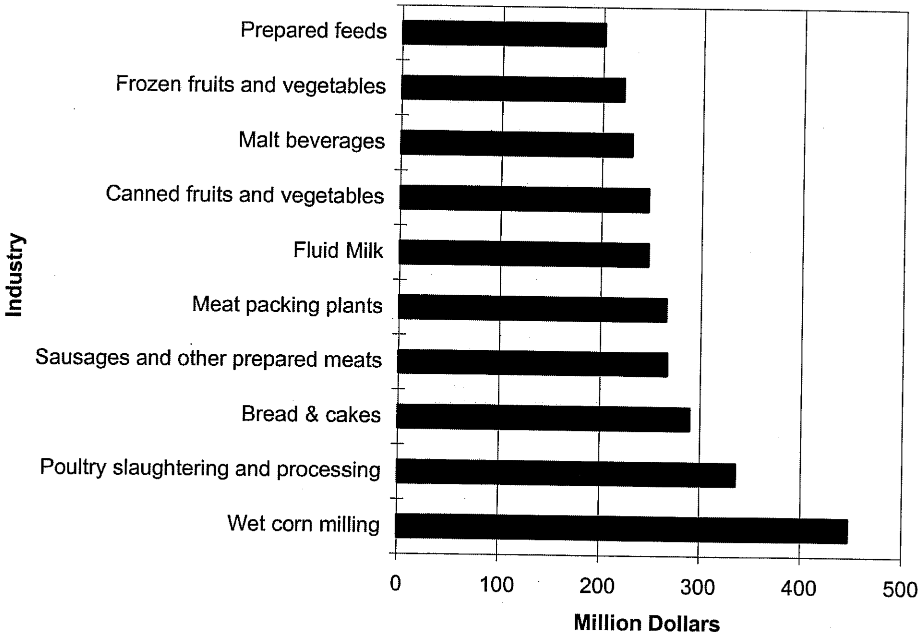

Figure 12. Top Ten Energy Consuming Food Industries in 1994. (Source: Bureau of Census 1994.)

Energy cost increased significantly from 1973 to 1986 (Singh, 1986). There was also an increase in equipment costs during this time, but it was not as large as the increase in the cost of energy. This increase prompted many industries to buy more energy efficient equipment during this time.

The Energy Information Administration (EIA) (1994) defines three major industrial end-use categories, which this report uses:

1. indirect uses: boiler fuel
2. direct uses: process uses, non-process uses
3. unallocated end-use

Boiler fuel represented nearly one-third of 1991 end-use consumption. This energy was transformed into another energy source, steam. While transformation of energy is not always considered a use of energy, EIA uses transformation of energy as a specific end-use category because the potential from steam is dependent on physical conditions, and is very difficult to measure and quantify the final end-use.

The two direct end-use categories are process and non-process use. In the manufacturing industry, approximately one-half of all end-use consumption is used to change raw materials into products. Process uses include:

- process heating
- process cooling and refrigeration
- machine drive (mechanical energy)
- electro-chemical processes
- other process uses

The non-process category includes:

- facility heating, ventilation, and refrigeration
- facility lighting
- facility support
- on-site transportation
- conventional electricity generation
- other non-process uses

Less than 8% of the energy consumed in manufacturing industry is for non-process uses.

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.

Table 2.3 presents fuel end-uses for the entire food and kindred products industry. Processing accounts for 78% of the electricity used, with 48% used for machine drive and 25% for process cooling and refrigeration. Non-process uses accounted for 16% of electricity use. Lighting, heating, ventilation and air-conditioning accounted for 12-16%. Approximately 90% of residual fuel oil was used as boiler fuel, with 6% used for process heating. Distillate fuel oil was used mainly for boiler fuel (42%) and non-process uses (42%), with onsite transportation consuming the most distillate fuel oil in the non-process category. Processing consumed 9% of total distillate fuel oil, mostly by process heating. Like residual fuel oil, natural gas was mostly consumed as boiler fuel (62%), with process heating accounted for 27% of the 28% used for processing. Of the LPG used, 42% went for non-process uses, mainly onsite transportation (37% of total LPG use), with 20% used for process uses, and 30% was used for boiler fuel. Of the 6,913,000 short tons (6,271,000 metric tons) of coal (excluding coke and breeze) used in SIC 20, 93% of it was used as boiler fuel.

Tables A10 - A17, found in Appendix A, list detailed information about end-use by fuel type for eight industries. These industries were chosen by the EIA because they are major consumers of energy. These eight food industries represent approximately 50% of all SIC 20 energy inputs:

1. wet corn milling (SIC 2046): 15% of SIC 20 energy inputs
2. beet sugar (SIC 2063): 7% of SIC 20 energy inputs
3. soybean oil mills (SIC 2075): 5% of SIC 20 energy inputs
4. malt beverages (SIC 2082): 5% of SIC 20 energy inputs
5. meat packing plants (SIC 2033): 5% of SIC 20 energy inputs
6. canned fruits and vegetables (SIC 2033): 5% of SIC 20 energy inputs
7. frozen fruits and vegetables (SIC 2037): 4% of SIC 20 energy inputs
8. bread, cake and related products (SIC 2051): 3% of SIC 20 energy inputs

According to the EIA, most industries consume the majority of energy by direct process uses. Most industries use a much smaller percentage of energy on non-process uses, unless the process is highly automated or the building is environmentally controlled.

Table 2.3. End-Use by Fuel Type for SIC 20 in 1991

Source: Energy Information Administration (1994)

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.

Section 3: Energy and Waste in the Food Industry

The food industry is dependent on energy to perform unit operations and processes. Because the food and kindred products industry is diverse, there are many different types of operations. The food industry generates a significant amount of waste per year. Waste and energy use can be decreased through process optimization, operating techniques, and scheduling. Wastewater can be processed and reused. Also, waste can be converted to byproducts, and reused or sold. Thus, plenty of opportunities exist for waste and energy reduction in the food industry.

This section gives an overview of the major unit operations used in the food industry that are dependent on energy, lists examples of wastewater reuse technologies, and discusses waste conversion. This section also analyzes processes and opportunities for energy conservation and waste reduction for several industries with significant potential for expanded efficiency. The industries addressed in this section are wet corn milling industry, soybean oil mills, bread and cakes, canned fruits and vegetables, and candy. The entire dairy industry is examined because it produces large amounts of wastewater.

Section 3.1: Major Unit Operations in the Food Industry

The food industry is dependent on energy for key processes such as food preservation, safe and convenient packaging, and storage (Resource Dynamics Corp., 1990). Food preservation is dependent on strict temperature controls. Fuels and electricity are used in heating processes. Heating processes 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. Lund *et al.* (1981) studied the opportunities for using solar energy in food processing. Cooling processes such as freezing, cooling, and refrigeration are almost completely dependent on electricity. Zall *et al.* (1981) investigated using winter weather as a supplement to existing cooling systems. Safe and convenient packaging is extremely important in food manufacturing and is also energy intensive. Newer packaging must not only meet safety requirements, but also meet convenience demands. The newest packaging techniques require aseptic techniques and electro-chemical changes. Proper storage is also energy dependent. Freezing and drying are the most crucial methods of food storage. Freezing operations require a large portion of electricity used by industries. Drying procedures usually depend on fossil fuels. Older dehydration systems were designed to operate with maximum throughput, disregarding energy efficiency (Groh & Thompson, 1981). Newer systems are designed with recirculating dampers and thermal energy recovery equipment to cut energy use 40%. Table 3.1 summarizes the most energy consuming operations/processes in the various SIC 20 industry groups, while Table 3.2 presents a detailed breakup for the individual industries based on energy end-use activity.

Energy efficiency improvements are made by food industries to be more competitive with each other. Potential economic advantages and environmental benefits exist in waste and water efficiency improvements. Each process varies in the flexibility and constraints of their energy and water requirements and waste generation. Energy consumption issues are discussed below for the major unit operations and processes in the food industry. The major unit operations include size reduction, mixing, filtration, extraction, crystallization, heat processing, evaporation, dehydration, freezing, and packaging.

Table 3.1. Main Energy Using Operations In The Food Sectors

SIC Code	Industry Group	Main Energy Using Operations/Processes
201	Meat Products	Hot water production/cleanup, Boiler losses, Ovens, Refrigeration
202	Dairy Products	Drying, Condensing, Boiler Losses, Hot water cleaning
203	Preserved Fruits and Veg.	Processing, Preparation, Warehousing/Receiving
204	Grain Mill Products	Mechanical Power, Drying, Conditioning
205	Bakery Products	Ovens, Space heating, Boiler losses
206	Sugar and Confec. Prod	Evaporation, Vacuum pans, Boiler losses, Mechanical power
207	Fats and Oils	Extraction, Boiler losses
208	Beverages	Distillation, Kilns, Evaporation/dehydration, Boiler losses
209	Misc. Food and Kindred	Processing, Preparation, Warehousing/Receiving

Source: Casper (1972)

Size Reduction - Energy requirements for methods of size reduction vary with particle size and existence of fissures on the food particles (Brennan *et al.*, 1990). Energy is required for stressing the product until it breaks. Since this energy is lost upon its release when the particle is broken, disintegration operations are extremely energy inefficient. Grinding is one of several modes of size reduction in the food industry. It involves mechanical energy inputs and physical changes in the food. Types of grinding include open and closed circuit. Open circuit grinding is the simplest form of milling. Power consumption is inefficiently high and poor distribution of product results. In closed circuit grinding, the residence time in the mill is small, and products are separated out of the recycle stream once they are small enough. Power consumption is minimized in closed mill grinding. In wet milling, stocks are in suspension in a liquid -- usually water, and the fractions of desired size can be separated by the following hydraulic classification techniques: elutriation, sedimentation and centrifugation. Energy requirements are significant in maintaining slurry temperature for the required residence time. Slicing and dicing requires mechanical energy to run the slicers and convey the fruits. Shredding is accomplished by using hammer mills. Shredding often precedes dehydration. The increase in surface area to volume ratio of the food material reduces the energy required for dehydration. Pulping also requires mechanical energy, which can be reduced by pretreating the material by heating it.

Mixing Operations are classified by the phases (gas, liquid and solid) of the materials they mix. Mixing is done by interspersing two or more components in space with another and removing non-uniformities in the properties for materials in bulk. Mixing processes require achieving a uniform distribution of components. The means by which this is achieved is mechanical energy. Agitation by using impellers is a common method of mixing for materials of low to moderate viscosity. There are many choices for mixing agricultural materials in gas, liquid, solid phase, even highly viscous pastes and plastic materials.

Table 3.2. Main Energy Users Based On Energy End Use

		Energy End Use Activity		
SIC Code	**Industry Group and Industry**	**Direct Use**	**Boiler Use**	**Electricity**
201	**Meat Products**			
2011	Meat packing plants	Smoking/Cooking (30), Singeing/Burners (40)	Losses (26), Rendering (25)	Refrigeration (37), Cooking (18), Lights (14)
2013	Sausages and other prepared meats	Ovens/Smokehouse (45), Afterburners (30)	Process steam/hot water (37), Losses (26)	Refrigeration (30), Cooking (25), Preparation (19)
2015	Poultry slaughtering and processing			
2016	Poultry dressing plants	Space heating (50)	Hot water (37), Losses (26)	Refrigeration (60), Poultry Dressing (15)
2017	Poultry and egg processing industry	Space heating (40), Ovens (15), Afterburners (10)	Hot water (34), Losses (26)	Refrigeration (30), Cooking (15), Preparation (13)
202	**Dairy Products**			
2021	Creamery Butter	Milk dryers (90)	Condensing (38), Losses (43)	Equipment/Cleaning (42), Refrigeration (17)
2022	Cheese	Whey drying (96)	Condensing (35), Losses (43)	Equipment/Cleaning (50), Refrigeration (20)
2023	Dry, condensed & evaporated dairy	Spray drying (99)	Condensing (55), Losses (30)	Equipment/Cleaning (60), Refrigeration (10)
2024	Ice cream and frozen desserts	Whey drying (60), Carton filler (30)	Losses (50), Hot water cleaning (22)	Refrigeration (54), Equipment (18)
2026	Fluid Milk	Milk drying (67), Carton filler (31)	Losses (47), Hot water cleaning (24)	Equipment (32), Refrigeration (30)
203	**Preserved Fruits and Vegetables**			
2032	Canned specialties	Receiving/Warehousing (100)	Processing (52), Preparation (45)	Processing (27), Preparation (29)
2033	Canned fruits and vegetables	Receiving/Warehousing (100)	Processing (96)	Processing (23), Preparation (19)
2034	Dehydrated fruits, vegetables & soups	Receiving/Warehousing (100)	Processing (71), Preparation (24)	Processing (28), Preparation (22)
2035	Pickles, sauces & salad dressings	Receiving/Warehousing (100)	Processing (95)	Processing (23), Preparation (31)
2037	Frozen fruits and vegetables	Receiving/Warehousing (100)	Processing (97)	Processing (37), Warehousing (35)
2038	Frozen specialties	Receiving/Warehousing (100)	Processing (53), Preparation (45)	Processing (26), Warehousing (30)

Table 3.2. Main Energy Users Based On Energy End Use (Continued)

		Energy End Use Activity		
SIC Code	**Industry Group and Industry**	**Direct Use**	**Boiler Use**	**Electricity**
204	**Grain Mill Products**			
2041	Flour and other grain mill products	Drying (100)	Drying (49), Tempering/milling (23)	Mechanical power (95)
2043	Cereal breakfast foods	Drying (100)	Drying (39), Conditioning/Cooling (29), Losses (25)	Mechanical power (95)
2044	Rice milling	Drying (100)	Parboiling (55), Losses (25)	Mechanical power (95)
2045	Prepared doughs and flour mixes		Building heat (46), Losses (25)	Mechanical power (95)
2046	Wet corn milling	Feed dryers (70), starch dryers (25)	Process steam (39), evaporators (26)	Mechanical power (95)
2047	Dog and cat food	Drying (100)	Conditioning/pelleting /flaking (59), losses (30)	Mechanical power (95)
2048	Prepared feeds	Drying (100)	Conditioning (62), Losses (30)	Mechanical power (95)
205	**Bakery Products**			
2051	Bread & cakes	Ovens (75)	Losses (35), Space heating (20)	Lighting (30), Mixing (16)
2052	Cookies & crackers	Ovens (80)	Space heating (100)	Lighting (35), Refrigeration (30)
206	**Sugar and Confectionery Products**			
2061	Raw cane sugar		Losses (42), Evaporators (15), Vacuum pans (14)	Mechanical power (96)
2062	Cane sugar refining	Kiln (100)	Vacuum pans (50), Losses (27)	Mechanical power (95)
2063	Beet sugar	Pulp dryer (87), Lime kiln (13)	Evaporators/Process steam (56), Losses (24)	Mechanical power (93)
2066	Chocolate and cocoa products	Roaster (51), Press (27)	Canning (67), Losses (25)	Mechanical power (63), A/C (22)
2067	Candy & chewing gum		Process (60), Losses (25)	A/C (50), Mechanical power (35)
207	**Fats and Oils**			
2074	Cottonseed oil mills		Extraction/Oil recovery (40), Seed Conditioning (30)	Mechanical power (98)
2075	Soybean oil mills	Dryer (100)	Desolventizer/ Toaster (30), Losses (30)	Mechanical power (96)
2077	Animal and marine oils	Space heating (55), Dock vehicles (15)	Cooking/Evaporating (46), Losses(26)	Mechanical power (71)
2079	Edible fats and oils	Hydrogenation (100)	Hydrogen production (45), Losses (32)	Mechanical power (97)

Table 3.2. Main Energy Users Based On Energy End Use (Continued)

		Energy End Use Activity		
SIC Code	Industry Group and Industry	Direct Use	Boiler Use	Electricity
208	**Beverages**			
2082	Malt beverages	Drying (53), Transportation (23)	Steam/Hot water (53), Losses (23)	Mechanical power (43), Refrigeration/Air (27)
2083	Malt	Kiln (95)		Mechanical power (95)
2084	Wines and Brandy	Pomage drying (50), Transportation (25)	Distillation (66), Losses (25)	Mechanical power (49), refrigeration (46)
2085	Distilled and blended liquors	Space heating (96)	Process steam (51), Losses (26)	Mechanical power (81), Lighting (19)
2086	Bottled and canned soft drinks	Space heating (50), Fork lifts (30), can wash (20)	Steam heating (35), can washing/filling (31)	Lighting (29), Compressors(29)
2087	Flavoring extracts and syrups	Evaporation (90)		Mechanical power (95)
209	**Misc. Food and Kindred Products**			
2091	Canned and cured fish seafoods	Plant vehicles (100)	Processing (48), Preparation (45)	Preparation (31), Processing (28), warehousing (25)
2092	Fresh or frozen prepared fish	Plant vehicles (100)	Preparation (98)	Warehousing (30), Preparation (29)
2095	Roasted Coffee	Roasters (56), Spray dryers (26)	Losses (36), Coffee extraction (25)	Mechanical power (33), Lights (26)
2097	Manufactured ice	Space heating (70), hot water (30)		Freezing (70), Storage refrigeration (25)
2098	Macaroni and spaghetti	Space heating (90)	Dryers (60), Losses (35)	Extrusion (35), Dryers (25), Lighting (22)

Source: Casper (1972)

Solid-liquid extractions are based on differences in the properties of the two components to be separated. It may occur in one or several stages. The rate of extraction is affected by the area of solid-liquid interface, concentration gradient, temperature, rate of flow of solvent.

Crystallization process are used to separate a liquid into a solid and liquid phase where one or both of the fractions become products, or where the solid is not separated and both of the fractions are retained in the product. The process can be initiated by cooling or by evaporation. Crystallization involving separation is usually used in the food industry for fat fractionation, freeze concentration, salt manufacture, and sugar manufacture. Crystallization that does not involve separation is used in the food industry for the crystallization of sucrose in foods, the crystallization of ice in foods, lactose crystallization in foods, fat crystallization.

Heating - Heat exchangers include swept surface, double pipe, shell and tube, plate (Toledo, 1991), parallel flow, counter flow, cross flow, jacketed pan, and scraped surface

(Earle, 1883). Pasteurization is a highly controlled heating process that ensures adequate microbial control, destruction of undesirable enzymes, and lower oxygen tension in food. Example uses of pasteurization include high temperature short time (HTST) (dairy) (Earle, 1983), steam heating (fruit juices), and blanching (vegetables). Immersion and steam blanching are the two methods used in the food industry. Microwave blanching is also used. It offers microbial cleanliness and low loss of nutrients, but is very costly. Effluent disposal is often a problem with blanching. Since baking often is used to invoke several complex chemical and physical changes, it must be carefully controlled. Heating methods for baking include indirect by solid fuel, oil, gas or electricity, where heat transfer occurs by radiant heat transfer to heat the walls or radiators of the oven and direct by gas, air or electronically, where heat transfer is by a combination of radiation and natural convection. Convection ovens use these principles (Singh & Heldman, 1984).

Other thermal processes include in-can processing, stationary retorts, hydrostatic cooker, agitating retort, crateless retort, flame-sterilization, and continuous flow sterilization (aseptic) (Toledo, 1991).

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. More specifically, the following design considerations should be evaluated to achieve the best compromise for fuel choice:

1. lowest fuel cost per unit of useful heat generated
2. lowest capital and maintenance costs for combustion and transfer equipment
3. lowest direct labor costs per unit of useful heat generated
4. lowest fire and explosion hazard (in dusty conditions)
5. lowest risk of product contamination by the fuel and its byproducts
6. maximum flexibility in operations and control
7. maximum reliability in continuity of supply
8. compliance with environmental standards

Evaporation is used to concentrate a solution by boiling off a solvent. Types of evaporators include batch type pan, rising film, falling film, and agitated thin film (Singh & Heldman, 1984). Evaporation is highly energy intensive, but very flexible in the types of energy saving options that are offered. Energy requirements are lowered when multiple effect evaporators are used instead of single effect systems. It is possible to use the steam from one effect as the heating media for another effect provided that the "second" effect operates at a lower pressure and boiling point than the "first" effect. The steam economy is generally increased as the number of effects increases. The optimal number of effects can be obtained by balancing the capital cost of the number of effects against the operating costs required by that number of effects. A rule of thumb is that the capital cost of *n* effects is *n* times the capital cost of a single effect.

The properties of moisture migration throughout the food and water activity in the food are extremely significant in the amount of external heat and airflow needed to achieve a product of desired properties. There are numerous types of dehydrators, including tray, tunnel, roller, drum, fluidized bed, spray, pneumatic, rotary, trough, bin, belt, vacuum, freeze (Earle, 1983), cabinet, tunnel, and puff (Singh & Heldman, 1984). Dehydration methods can be classified as heated air, direct contact with a heated surface, the application of energy from a radiating, microwave or dielectric source, freeze-drying.

Freezing and Refrigeration require mechanical energy of compression. Types of refrigeration methods include controlled atmosphere storage and modified atmosphere storage (Toledo, 1991). Common refrigerants are ammonia, methyl chloride, Freon 22, Freon 12 (Singh & Heldman, 1984). Freezing can be accomplished by plate, air blast, and immersion methods.

Packaging requires large amounts of mechanical energy. Heat is also sometimes used in packaging.

Section 3.2: Energy Efficient Wastewater Re-use Technology

Waste reduction helps the environment, lowers health risks, is more economical for manufacturers, and can increase the competitiveness between manufacturers (Oldenburg & Hirschhorn, 1987). Waste reduction is defined as in-house processes that reduce, avoid, or eliminate hazardous contaminants. Waste minimization is a much more common practice than reduction and includes recycling and treatment before external disposal.

Manufacturing in the United States alone uses 10 billion gallons of water a day for various processes (DeSilva, 1996). Several food industries that are not energy intensive use and waste large amounts of water. Water must be purified before use in processing and before reuse. Typically, water used in processing is purchased from a purifying facility or pumped from a well and pretreated at the plant. Wastewater must be disposed of properly. Processing wastewater can be directly sent to a treatment facility, or can be pretreated. Other options are available, such as ponds and lagoons, but may cause a threat to the environment and must be strictly regulated. Water treatment facilities can use several different methods for purifying water. Methods of water purification include clarification, filtering, ion exchange, ultrafiltration, and reverse osmosis.

Clarification removes turbidity from water with a lime or lime soda softening method (DeSilva, 1996). There are generally three steps to settle out the unwanted particles: rapid mixing to distribute chemical coagulants, gentle mixing to develop flocs, and quiescence to allow the flocs to settle. Hardness, caused by calcium and magnesium ions, can also be removed with a clarifier, along with silica, free carbon dioxide, and iron. A two-stage process using a hot lime softener first and then a sodium-cycle softener can be used to treat higher temperature and higher pH waters. Lime is the only chemical needed in the first stage since hardness is easily removed in the second stage. Alkalinity is kept low because soda ash is not required in the process. Hot, sodium-cycle softeners are used to treat water that has a high concentration of silica. Sludge-blanket and sludge-recirculation tanks are the two types of sedimentation tanks utilized. Sludge-recirculation tanks are the most preferred.

Filters use entrapment and adhesion to remove suspended oil, solids, flocs, or fibers through a bed of granular media (DeSilva, 1996). If the media are too fine, a large pressure drop will build up and cause cake formation. To minimize this problem, graded beds are designed with coarser media on top and sand on the bottom. Since filtration also operates by adhesion, the charges of the particles and the media have to be taken into consideration. Most particles are negative as well as the media, therefore, polyelectrolytes are often added to increase flocculation. When designing a filter, the following characteristics must be specified: filter configuration; media sizes, depths, materials, and strainers; terminal head loss; method of flow control; backwashing design features; and filtration rate.

Ion exchange reduces undesirable products in water by using charge, molecular weight, or solution concentration (DeSilva, 1996). Resins, either in gel form or macroporous beads, show some affinity for some ions over others. Gel resins cost less, are more efficient, have improved kinetics, and a higher ion exchange capacity, however, the macroporous molecules are sturdier and more resistant to stresses and fouling. Types of ion exchange resins are strongly acidic cation resins to remove salts, weakly acidic cation resins to reduce hardness and alkalinity, strongly basic anion resins for waters high in alkalinity and silica, and weakly basic anion resins that absorb strong acids and high levels of sulfates or chlorides. An ion exchange process undergoes a service cycle, a backwash cycle, and a regeneration step. Ion exchange systems can be modified to offer demineralizing and degasification options.

Ultrafiltration, used for waste water treatment and concentrating, is a sieving process that uses membranes (El-Gazzar & Marth, 1991). These membranes need to have the ability to create a hydrogen bond with water to allow water to enter the membrane and a high wet strength. Membranes are usually made of polymers made of cellulose acetate, polyamides or polysulfones. The membranes have small pores that let the desired molecules through, but hold back larger molecules and microorganisms. Membranes can be tubular, flat, or wound spirally. Tubular membranes are easiest to clean, but tend to have a high hold-up volume per membrane area. Spiral membranes are the most energy-efficient because pumping energy is saved. However, these membranes are difficult to clean if they are badly fouled. Usually, water pretreatment is needed to remove oil and grease to avoid causing the membranes to clog (Sheridan, 1994).

Reverse osmosis uses membranes that operate under the principle of osmotic pressure (El-Gazzar & Marth, 1991). Osmotic pressure is produced by solutes in the product. The solvent dissolves in the membrane and passes through by diffusion. The solute does not dissolve, and is held back. The membranes used in reverse osmosis do not need to have pores. Equipment often used with reverse osmosis includes ion exchange softener to reduce scaling, activated carbon units which remove chlorine and some organics, cartridge filters to reduce suspended matter and biomass, or a sun-filament depth filter (DeSilva, 1996).

The use of reverse osmosis as a substitute for evaporation has been shown to be energy efficient (Hallstrom, 1986). Table 3.3 shows a comparison of energy consumption by evaporation and reverse osmosis systems.

Table 3.3. Energy Requirements of Evaporators and Reverse Osmosis Systems

Operation	Energy Input (kWh/kg)
Evaporation	
TVR 3 Effect	0.17-0.20
5 Effect	0.11-0.14
7 Effect	0.07-0.10
MVR	0.046-0.11
Reverse Osmosis	0.015-0.048

Source: Hallstrom (1986).

Other technologies that exist for industrial water purification include advanced oxidation processes, bioremediation, chemical clarifiers, vapor-compression evaporation, crystallization, and staged cooling. Organic chemicals can be reduced by advanced oxidation processes which combine ultraviolet light with ozone (Sheridan, 1994). It is also possible to convert nonbiodegradable organics into substances that can be consumed by microorganisms. Bioremediation is the process of letting microbes digest harmful chlorinated solvents and can be implemented to aid with large-scale cleanups. Chemical clarifiers employ chemical precipitation and remove 50-80% of solids (Cappos, 1995). However, bulk chemicals have to be added and disposal of generated sludge costly. Vapor-compression evaporation can remove up to 99% of the remaining dissolved solids in a falling-film evaporator and is the preferred method of treatment in western power plants (Strauss, 1994). A crystallizer is responsible for dewatering the brine slurry and forming a cake from the solids, which is disposed in a landfill. Stage cooling is a newer method of wastewater treatment that operates with at least two hydraulically isolated loops where more loops are added according to wastewater demand. The first stage is where the evaporator is replaced with a cooling tower in a conventional system. The last stage softens blowdown from the cooling tower with soda ash and caustic. It has been reported that compared to evaporators, this system is less labor-intensive.

In their study of a Michigan dairy plant, Thomas & Carey (1992) found that a daily hydraulic load of 300,000 gallons per day could be recovered and processed from condensate from triple-effect evaporators. The condensate was processed by reverse osmosis and purified by ultraviolet light. The purified water was used for clean in place (CIP) systems, flushing products out of evaporators, washing other equipment, and as boiler feed. Savings were realized in: usage of well water, chemical usage to soften well water, minimized phosphorous waste disposal, energy requirements because warm water was available for CIP systems, effectiveness of cleaning systems due to use of warm water, and reduced hydraulic load on waste water disposal systems. Wastewater treatment plays a crucial part in developing a zero liquid discharge plant.

Because of the worsening state of the environment, the concept of zero discharge may become a requirement of processing plants in the future. In fact, zero discharge status was mandated for Mulberry cogeneration to maintain permit insurance (Solar, 1995). True zero discharge plants do not discharge heat, emissions, and wastewater. Eliminating water waste from processing facilities requires the sophisticated water treatment technologies discussed above. Greatly increased level recycling and reduced pollution are two benefits gained from zero discharge wastewater systems (Montague, 1989). Presently, society depends on the "prove harm" alternative to zero discharge, which is waiting for pollution buildup to cause harm before implementing. However, "prove harm" is very uneconomical because compensation for pollution victims must be compensated and it is more cost effective to design a zero discharge system than remedy problems that arise. Examples of the "prove harm" method include acid rain, greenhouse effect, ozone depletion, and chemical and radioactive waste cleanup. Zero discharge is the only way to break the cycles of pollution, save significant amounts of money used to compensate victims, and solve the problems caused by pollution.

A zero discharge system for wastewater treatment might be desirable for several reasons. Designing a zero discharge system may be preferable to relocating in an area where the groundwater supply is limited. The water quality before any treatment might be close to that of available water. Other reasons could be that it is more economical to reduce the dependency on raw water, or releasing wastewater is too much of a burden and also carries the possibility of citation for noncompliance with wastewater management (Byers, 1995). In some cases, however, it is thought that water reuse is not possible because of the need of higher quality water than could be provided through on-site treatment. Included in this category are the pharmaceutical, food, beverage, and electronic industries.

An organized, step-by-step approach is beneficial when attempting to design a water reuse system (Byers, 1995). First, goals are set depending on the benefits desired for the plant from the reuse program. A large part of improving efficiency depends on gathering information on the present water system of the plant. Important factors that need to be determined include available water quality, true water-quality requirements (using higher quality water than needed will result in added costs), variability of water quality and flow (accommodation of variations can prevent inefficient operation), physical flow configuration, and a plant-wide water balance. The water balance can be consulted to see the impact of effects of operational changes on different areas of the plant.

The next step is to identify areas where water reuse is feasible (Byers, 1995). A good place to start is to broadly categorize each water stream, which will simplify correlating water needs with water availability in the plant. Within the categories, determining a high/low range of limits can help match water streams. It is also possible to upgrade selected streams either by treatment after discharge or adjusting conditions at the source to produce water at the quality needed. High strength streams are a good place to recover resources for reuse, and it may be better to segregate and treat before joining the rest of the wastewater streams. Finally, a master plan is developed, implemented, and followed. However, since the process is continuous, there are always ways to improve the system and become more efficient with water reuse.

Reverse osmosis is an excellent method of waste water treatment for zero liquid discharge systems because it can remove a high concentration of impurities and dissolved solids with a minimal amount of energy (Cappos, 1995). Wastewater is separated into a large reusable volume of water and a small concentrated stream of solids for further processing. An advantage of reverse osmosis is that it discharges water, which is more easily treated, than sludge. One problem with this system is if the solids concentration is too high, fouling of the membranes can occur. When used with ultra-low pressure membranes, reverse osmosis systems can reduce cost by 50%.

Reverse osmosis has been effective in the case of The Cedar Bay generating plant (Anonymous, 1995). The coal-burning cogeneration facility has achieved a zero discharge water treatment system as well as a full-scale ash pelletization procedure and a low-emissions operation of large circulating fluidized-bed boilers. A pretreatment reverse-osmosis unit upstream from the demineralizer has helped with the zero discharge status. Additionally, nanofilters were placed in front of the blowdown reverse osmosis units. Cedar Bay also has the capability to burn waste fibers from the mill to keep them out of the waste stream; however, the burning as of this date has not been tested. A full-scale ash pelletizing operation is used by Cedar Bay to eliminate fugitive dust.

The key to maximizing water reuse and achieving zero discharge in a plant is to reduce makeup and blowdown, or the rate of water moving through the cooling tower (Boffardi & Smith, 1995). Recirculating water has replaced once-through cooling water systems; however, corrosion on plant metallurgy from the dissolved salt concentrate creates major problems. The water must undergo some sort of treatment to help control the scaling and deposition of the salts, which reduces heat transfer efficiency. Options for processing include lime-soda side-stream softening, vapor compression, and chemical treatment.

Suspended solids and hardness ions are removed in a clarifier by maintaining a sludge blanket (Boffardi & Smith, 1995). The softened effluent is pH balanced, which additionally reduces total dissolved solids and ions in the water. An advantage of this method is that overall water usage is reduced by minimizing cooling water blowdown and recycling treated effluent. There is a 95% recycle using the evaporation-vapor compression process. The pH is adjusted before the water is boiled in a heat exchanger. This water is used to evaporate some of the brine in the untreated cooling water. A vapor compressor adds more heat that is transferred to the cooling water causing the hot water to condense into makeup water. Chemical treatment can help eliminate the corrosion and biological problems that can accompany a process that uses a majority of recycled water. Substances utilized in this method are calcium carbonate, calcium sulfate, calcium phosphate, silica, and foulants. Foulants are deposits from the water that interfere with heat transfer by settling on heat transfer equipment.

It was mandated that the Mulberry cogeneration plant had to maintain zero discharge status in their wastewater as a condition for permit insurance (Solar, 1995). In order to achieve this requirement, several steps were integrated into the wastewater management plan: using softened water as cooling tower makeup, a recycle system for the makeup demineralizer, and segregated wastewater streams. Plant and equipment drains, storm-water runoff, equipment-washdown water, and boiler blowdown can be reused with no chemical treatment. Concentrated wastewaters (cooling tower blowdown, filter-backwash wastes, and neutralized chemical wastes) collect in a wastewater tank. The wastewater tank is where the zero discharge system begins. The wastewater is pumped to a clarifier where hardness and silica are removed and then it is sent to a sludge thickener for further concentration. Solids from the filter press are removed periodically to be trucked off site for landfill disposal while the water is routed back to the storage tank. Suspended solids are removed by a gravity filter and then treated by a reverse-osmosis system.

The reverse osmosis system is a process where the feedwater passes through a membrane under high pressure while the salts carried in the water exit the membrane as concentrate (Solar, 1995). The reverse osmosis water is part of the cooling tower makeup while the concentrate continues on to the crystallizer, which produces a clean product water and a slurry of the salt concentrate. After additional separation, liquid is extracted by a centrifuge and the solids are taken to an off site landfill. From the centrifuge and filter press, about two tons/day of solids are collected during a full-load operation. At the same time, 120,000 gallons/day of plant wastewater are treated and recycled.

There are several techniques employed to obtain a zero discharge waste system where the blowdown and other wastes streams are recycled while converting the total dissolved solids into a disposable cake (Strauss, 1994). These techniques include mechanical evaporation, crystallization or spray drying, membrane treatment, and staged cooling.

When efficient waste reduction programs are implemented, savings are not only realized in reduced environmental costs, but also raw materials, energy, and labor (Oldenburg & Hirschhorn, 1987). One step in incorporating a waste reduction system is to inspect and label each stream on all processes. Future developments include computerized inventory systems for each process stream and a method of calculating liability costs of waste management.

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 (Bhesania & Reklatis, 1992). 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. The goal of the authors is to model a dairy plant that can reduce waste production by one order of magnitude. In the simulation, FOODS and BATCH are used in addition to WEEP. FOODS is a food process flowsheeting and design program which individualizes each system and its unit operations. BATCH is a dynamic simulation software that 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, the freezing process takes up 79% of the electricity and 81% of the refrigeration load.

Section 3.3: Waste Conversion

The food products industry currently supplies fuels produced from its byproducts to other industries. The substitution of such fuels for fossil fuels can reduce hydrocarbon and carbon monoxide emissions (Anonymous, 1989). 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 (Anonymous, 1989;

Gradassi & Green, 1995; Walls, 1993). In 1990, the World Energy Council estimated that 18% of the world's energy demands were met by renewable energy sources (Bevan, 1995).

Clark (1982) stated that food processors could fulfill a large portion of their energy requirements by converting their own wastes. He found that alcohol can be produced from wastes containing more than 1% sugar or starch, biogas can be produced from wastes containing less than 1% sugar or starch, cellulose can be converted to butanol, and essential oils such as d-limonene can be recovered from fruit and vegetable processing and used as fuel.

Biogas can be produced from waste streams from a wide variety of organically rich sources such as nearly all food processing waste streams (Clark, 1992; Ghaley, 1989; Tentscher, 1995), municipal wastes (Rautenbach, 1994) and agricultural wastes (Tentscher, 1995; Tafdrup, 1994). Miller et al (1994) found that a gas burner could be economically installed in conjunction with the common coal stoker-fired boilers to reduce emissions such as nitrogen oxides (NOx).

The economic feasibility of producing other alternative fuels such as ethanol and methanol from food processing wastes has been described by Qureshi (1995), Hall & House (1995), Jefferson (1994), and Morris (1985). It has been theorized that the prices of gasoline and oil would have to rise in order for fuels from biomass to compete in this market (Anon. 1989). Technologies for fuel-using equipment must be readily available in case of another energy crisis, when use of alternate fuels may be absolutely necessary. Hall & House (1995), and Viscusi *et al.* (1994) have both stated that the social and environmental benefits of fuels from renewable resources cannot be overlooked in feasibility analyses.

Section 4: Opportunities for Energy and Waste Reduction

There are opportunities for reducing energy consumption and waste production in nearly every sector of the food and kindred products sector. This section examines various industries, both energy and waste efficient and energy and waste intensive. The industries examined are representative of the grain mill products, fats and oils, bakery products, preserved fruit and vegetables, sugar and confectionery products, and dairy industry. Wet corn milling, soybean oil mills, bread and cake production, and canned fruits and vegetables were studied because they are energy intensive industries. The dairy industry was studied because it generates a significant amount of wastewater per year. The candy industry is not energy intensive or wasteful, but it was included for variety.

Each section begins with an overview of the industry. The basic processes of the production of each product are then described and the chemistry of each product is briefly discussed. Suggestions for improving energy consumption and waste production are discussed in detail.

Section 4.1: 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 (Segado, 1995). 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 112×10^{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. Therefore, there is ample room for energy efficiency improvements for many wet corn millers.

The size of the corn industry was estimated to be 575 million bushels in 1979. This industry showed growth which loosely followed but was greater than the population growth over the following years. This increase was due to the introduction of new products by the milling industries (Anderson & Watson, 1982).

The process starts by steeping the corn in recycled process water. This usually occurs in countercurrent batteries. Extracted solubles are continuously or intermittently removed and evaporated into a thick syrup called corn steep water or steep liquor. Sulfur dioxide is added to the steeping tanks achieving a sulfuric acid solution, which, along with maintaining the temperature at 120 to 125°F, promotes the growth of indigenous lactic acid bacteria. Many processing steps are involved in milling and separation. Approximately 38 liters (10 gallons) of water is used per (US) bushel (1 US bushel = 35.24 liters) of corn processed. Only fresh water is used at the final starch washing station.

The milling and separations steps yield six fractions from which the final products are produced. The following five fractions are produced from the milling and separation steps:

1. solubles (steepwater)
2. germ
3. fibers (mostly hulls or pericarps)
4. starch
5. gluten (protein in the endosperm)

Products of the wet corn milling industry include glucose syrup (corn syrup, high fructose corn syrup, glucose syrup solids), dextrose monohydrate, dextrose anhydrous, manufactured corn starch, dextrin, corn oil (crude, once-refined, fully refined), wet process corn byproducts (steepwater concentrate, corn gluten feed and meal) (Anderson & Watson, 1992).

The difference in energy use among wet corn millers has been contributed to differences in product mix and has been found not to be affected by geographic area (Casper, 1977). Many but not all wet corn millers produce a large part of their own electricity. The heat from the exhaust steam of this electrical generation cannot usually be completely used for process heating because it exceeds process heating requirements.

The following opportunities for energy efficiency improvements have been found to be technologically feasible and economically practicable by Casper (1977):

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 that recycle exhaust gases can save 10% of the fuel to fire the furnaces. Capital investments required would amount to approximately \$3 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*: Relative low rates of return are possible 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, and heat recovery for plant heating.
3. *Purchased electricity*: Significant savings can be achieved in both plant-generated and purchased electricity. Proper sizing and improvement on the power factor of motors have both been proposed to be feasible energy-saving techniques. Conversion to fluorescent lighting and improvements in overall management practices can also save energy. In most plants, increasing the power factor was found to reduce the practicability of installing the necessary facilities.

Recently discovered opportunities in energy conservation for the wet corn milling industry include decreasing steep times for soft-endosperm, high-lysine corn (Fox, 1993), and reducing lactic acid bacteria in feedstocks for ethanol fermentation (corn steep liquor or stillages) (Lawford, 1992). Experiments on decreasing steep times for soft-endosperm, high-lysine corn resulted in less solids in the steepwater, increased germ yields, constant starch yield, constant starch protein content, increased gluten protein content, increased filtered solids, and decreased TS released into process water. Results for fiber separation and starch tabling were similar for typical dent corn and also showed that a steep time of 8 hours is sufficient for soft-endosperm, high-lysine corn.

Lawford (1992) found that ethanol yields are possibly decreased by the presence of lactic acid bacteria. If techniques to sufficiently decrease lactic acid bacteria do not require as much energy as the energy lost from inefficient ethanol fermentation, energy can be conserved. Further investigation is needed in this area.

Section 4.2: Soybean Oil Mills (SIC 2075)

Soybeans are one of the most useful and economic crops because almost every part of the seed can be utilized (Berk, 1992). In the United States, 3,373 million pounds of soybean oil are consumed per year. Illinois had the highest value added ($367 million) and value of shipments ($2,590 million). It also had the highest number of plants (16). Production and energy usage data for the entire fats and oils industry is not available by state. However, the total number of soybean oil mills in the nation has decreased and redistributed, with states such as Illinois, Indiana, and Georgia gaining plants and Alabama, Arkansas, Ohio, and Iowa losing plants. Value added and value of shipments increased for these states during the respective time period. Production and energy consumption have remained fairly constant (Bureau of Census, 1988-1996).

Soybean oil is widely used throughout the world in many different aspects. It is the leading source of vegetable oils in the US, holding 70% of total oil consumption, with the balance of total oil consumption divided among tallow/lard, corn, cornseed, coconut, and palm oils. Worldwide, in 1990 soybean oil made up 27% of total oil consumption, while palm, rapeseed, and sunflower made up 20%, 14%, and 14%, respectively. Soybean oils are used in salad oils, baking and frying, and margarines (Soystats, 1991).

When extracting oil from soybeans, the following by-products are produced: lecithin (sold to companies for use in food products), water soluble salts, and acidified soap stock (used as a caloric component in animal feed). This process yields virtually no solid waste. Liquid waste, on the other hand, is produced and is rich in organic nutrients. These nutrients can suffocate plant and water life when high levels of waste are dumped into lakes and streams without prior treatment.

The only ingredients used in soybean processing are the soybeans and the solvent used for extraction. In most cases, hexane is the solvent, and it is removed before the final product is sent to market. The process uses steam and air for processing, but these items are not considered ingredients, therefore the only ingredient in soybean oil is the oil itself. The waste leaving the plant is only wastewater. The biological oxygen demand (BOD) of the wastewater is monitored, and regulations dictate that it can not be greater than 250 mg/L. Usually the BOD loading is only about 100 mg/L.

In soybean processing, three main stages exist: pre-extraction, extraction, and post extraction. The pre-extraction stage prepares for extraction. Extraction is a single-step stage, in which the oil is removed from the soymeats. In the post-extraction stage, the solvent (if one is used in the extraction stage) is removed from the oil and flakes (Berk, 1992 & Markley, 1950).

The pre-extraction process begins after the soybeans have been received in bulk and stored in vertical storage silos. The steps for preparing soybeans for extraction are cleaning, drying, tempering, classification, cracking, conditioning, and flaking. The soybeans must be cleaned to reduce the risk of contamination by metal, sand, and stones, etc. This step will reduce, or eliminate, the cases of damage to machinery such as flaking machines and cracking mills. A common method for cleaning uses air aspiration to trap light debris such as trash and hull particles in cyclones. An alternative is to use a two-deck vibrating screen (Markley, 1950). In this method, the top screen is used to separate large debris, such as rocks, from the soybeans by allowing the soybeans to sift through the smaller diameter screens. The soybeans are then further cleaned by allowing the second screen to remove minuscule particles, such as dirt and sand, by using a screen with a diameter smaller than that of soybeans. Magnets, both permanent and electromagnetic, can be used to remove stray iron pieces from the soybeans.

The moisture content of soybeans must be reduced from about 14% to 10% in order for the beans to be dehulled before extraction. The lower moisture content aids in the separation of the hulls. Drying can take place in vertical gas or oil fired forced circulation dryers (Berk, 1992). The beans must then be cooled before proceeding to the next step. Tempering is a process of allowing moisture to diffuse equally throughout the beans by storing in bins a few days. Classification removes whole beans by sifting from those that have split and separated. In the cracking step, the seeds should be broken into 4 to 6 equally sized pieces in order to prepare the beans for flaking. The machines used to crack the beans consist of pairs of counter-rotating, corrugated rolls. In order to create the shear necessary to crack the beans, one of the rollers must rotate at a faster rate. The average diameter of the rolls is 25 cm. Roller length depends on the output of product desired. The broken particles are separated at the end of cracking and either cleaned, returned to cracking, or continued on to the next step (Berk, 1992 & Markley, 1951). Conditioning is done to increase the plasticity of the soybean meats by cooking. Direct steam injection provides the energy necessary to heat the beans to 65-70°C for 15 minutes and increases the moisture content to 10.5-11%. A pair of horizontal, counter-rotating smooth steel rolls are used for flaking, with diameters ranging from 60-80 cm. A vertical stacked cooker can be used instead of the horizontal screw conveyor type heated reactor. The rolls are held close together by springs or hydraulic systems (Berk, 1992).

After preparing the soybeans for extraction, a suitable and economical extraction method needs to be chosen. The chemical extraction method is most commonly used (Erickson, 1980). The choice is contingent upon a number of factors, including:

- size of solid particle - determines rate of diffusion (rate-limiting step)
- temperature - rate of extraction increases as temperature increases.
- porosity of solid material - determines ease of diffusion and percolation
- agitation - can increase rate of extraction, but must be careful because too much agitation can disintegrate the flakes, making extraction difficult
- concentration gradient - needs to be kept high because it is the driving force for moving the oil out of the solid

The "ideal" solvent should exhibit good solubility of the oil, low boiling point, low viscosity, chemically inert to oil and soybean's other components, non-toxigenic, non-carcinogenic, non-inflammable and non-explosive, low cost, and high availability (Berk, 1992). Percolation is a common method to bring the solvent and oilseed material into contact. Solvent drips through the flake bed creating a rapidly flowing film of solvent over the surface of the flakes (Erickson, 1980). This removes the oil that has diffused out from the internal structure of the solid particles.

Hexane is the major solvent used for soybean oil extraction in the United States. Hexane is a six-carbon alkane formed from low-boiling hydrocarbon fractions from petroleum. The boiling point of hexane is 65-70°C. The disadvantages of hexane are its flammability and explosiveness. Due to these facts, strict quality specifications are implemented. These include boiling range, flash point, maximum sulfur and cyclic hydrocarbons, color and specific gravity. Also, due to hexane's explosive nature, buildings in which extraction is housed are subject to special safety standards (Perry, 1994).

Two streams leave the extraction process including an oil-rich fluid extract (full micella) and a solvent laden stream (spent flakes). The purpose of the post-extraction procedures is to remove and recover the solvent, and to prepare for storage or packaging (Berk, 1992). The post extraction procedures include micella distillation and metal desolventizing. Some criteria for a good micella distillation system are minimal heat damage to the crude oil and its components, energy efficient, efficiently remove final traces of solvent from the oil, and are safe. The modes of solvent vaporization include flash evaporation, vacuum distillation, and steam stripping. Spent flakes contain nearly 35% solvent, therefore metal desolventizing is necessary. The removal and recovery of the solvent portion is most crucial. It determines the quality of the meal and its derivatives. The most common type of desolventizing-toasting (DT) consists of a vertical cylindrical stack of pans, fitted with stirrers. Spent flakes are fed in at the top of the cylinder and move their way through the DT. Direct steam heating is injected into the mass through the spargers. This effect is necessary in order to remove the last traces of the solvent. After the hexane solvent has been removed from the products, the oil is sent to storage silos while the spent flakes are further processed for soymeats (Berk, 1992).

Soybean oil milling involves very few solid waste products. The remaining parts of the soybean from oil extraction are by-products. The by-products of the process can be reused indirectly in other processing or directly into animal feed. However, the soybean processing plants do have liquid wastes. Liquid waste is the wastewater that has BOD loading. A majority of the water usage during processing is indirect, such as indirect heating during conditioning. The BOD that is produced comes from the extraction stage of the process. Steam comes into contact with the oil during solvent extraction. This steam contains particulates from the soybean oil. It condenses and flows out as wastewater. The wastewater can be sent to a treatment facility or the sludge can be skimmed off the top of the water via a rubber hose and collected for future disposal. Hexane can be removed from the air via a mineral oil stripping column. This reduces the harmful chemical emissions associated with ozone depletion.

Section 4.3: Bread and Cakes (SIC 2051)

The bakery products industry consumed 13,630,000 million Btu in 1994. Energy consumption increased 13% from 1987 to 1992, while production of bakery items (pounds per year) increased 2%, and the value added increased 18%. Another 11% valued-added was added in the next two years. The number of plants operating in the United States in 1992 was 3,152. (Bureau of Census, 1987-1994).

Looking at the narrower category of bread and cake products, production actually decreased 2% between 1987 and 1992. Breads and cakes make up the bulk of the bakery industry with 2,539 plants or 81%. Value added (dollars) increased from 1987 to 1992 by 9% and an additional 6% by 1994. From 1992 to 1994, value of shipments grew by 8%. Energy requirements expanded 7% from 1987 to 1992 and then increased another 3% by 1994 (Bureau of Census, 1987-1994).

Seven major ingredients go into the production of bread. Each has a function in the final process (Table 4.1).

Table 4.1. Bread Ingredients and Their Functionality.

Ingredient	Function
flour	absorb water
yeast	leavening, responsible for flavors and aromas
water	mixes with gluten in flour to form starch granules
salt	flavor enhancer, regulates yeast growth
sugar	food for yeast
shortening	flavor and aroma enhancer, responsible for crust characteristics
milk	flavor and texture enhancer, responsible for crust

Sources: Hoseney, 1991; Pomeranz, 1991; Matz, 1992; & Clayton, 1973.

The transformation of these ingredients into the final product is a tedious process, and requires attention to the variables that affect the production (Table 4.2). The production of white bread begins with a system that meters the amounts of ingredients into the mixer. The ingredients are mixed and allowed to ferment in a bulk fermentation tank resulting in the production of the sponge. The sponge, along with remaining ingredients, is transferred to a second mixing operation which is monitored by time. The dough is unloaded into a dough trough and transported to the divider. It is then divided, or sectioned into pieces, giving a suitable finished product weight. The cut piece of dough is then conveyed through the rounder which is shaped into a ball. The balls of dough are proofed, the gluten relaxes, gassing continues, and the moisture is redistributed. Next, the dough pieces are sent to the molder, which shapes the dough into a cylinder ready for baking. The cylinders of dough are placed in the baking pans and the dough is once more allowed to relax in a pan proofing stage where it is readied for baking. During baking, energy is inputted in the form of heat by radiation, convection, and conduction (Matz, 1992). The final steps include cooling, slicing, and wrapping of the loaves.

Table 4.2. Bread Processing Steps, Purpose and Alternatives.

Process Step	Purpose	Alternatives
Sponge Mixing	incorporate ingredients, develop gluten structure, and distribution of gas bubbles	Horizontal mixers Vertical Mixers
Bulk Fermenting	gas production due to yeast fermentation	chemical leavening or steam leavening
Dough Mixing	incorporate remaining ingredients, further develop gluten structure	same as sponge mixing
Dividing and Rounding	separates the dough into suitable size for finished product weight	none
Proofing	further expansion of gluten mesh and moisture redistribution	none
Baking	denature the gluten and gelatinize starch	none
Cooling	lower the temperature of the final product for the remaining operations	none
Slicing and Wrapping	prepare the product for consumer usage	none

Source: Matz, 1992.

There are two basic processing schemes to produce bread items on a large scale. These methods consist of the Straight Dough method and the Sponge-and-Dough method. The Straight Dough method is simple, but cannot tolerate production variables as adequately as the Sponge-and-Dough method. All ingredients are mixed and fermented at the same time in the Straight Dough method. The Sponge-and-Dough method requires two separate mixing steps. The first mixing combines flour, water, yeast, salt, sugar, shortening, and non-fat dry milk (optional). This mixture, forming the sponge, is fermented for 4.5 hours at 18.3°C. To the fermented sponge, the following ingredients are added in a mixing and developing step: 35% bread flour, 20% water, 2% sugar, 2% shortening, 2% salt, 5% non-fat milk (optional) (Matz, 1992).

The following reactions occur during yeast bread production: dough development, size distribution of bubbles, dough conditioning, and fermentation. Mixing the ingredients causes proteins to hydrate and form a matrix of gluten fibers. The mixing is an important function since it combines all ingredients, developing the gluten mesh that becomes the structure of the baked bread. The best mixing motion is one in which the dough is stretched and folded, which causes the gluten fibers to line up along side one another. As the dough, or gluten structure, becomes more developed it incorporates amounts of air that decrease the density of the dough. Development of dough is sensitive and has many effects on the finished product. A well-developed dough has a high specific volume, a fine texture, and a longer shelf-life (Matz, 1992).

The most energy consuming operation is the oven. While indirect-fire may not be as efficient, it is preferred in the baking industry to direct-fire because it gives a consumer-desired product. The bakery uses natural gas for all of the unit operations since it is more efficient than diesel, which was the previous fuel. In addition, the electrical controls on the oven were upgraded to achieve a more consistent heating temperature.

Inefficient slicing machinery, such as drum rollers, that operate at relatively high temperatures produce a large volume of crumbs that accumulate because the bread has a tendency to adhere to the blades. New slicing machines run at lower temperatures and slice at higher rates, which cuts down on crumb production. However, crumbs are a salable commodity and are sold to a manufacturer that recycles them as animal feed.

Other by-products include alcohol and carbon dioxide from the fermentation process. The carbon dioxide and alcohol in its vapor state are released into the atmosphere. These volatile organic compounds (VOCs) require a permit issued by the state in compliance with Indiana Department of Environmental Management (IDEM). These regulations restrict concentrations emitted, which has a direct effect on the quantity produced and the number of hours the plant can operate.

All of the bakery waste is routed to the city waste system with little or no pretreatment. The BOD level is at 800 PPM after adding culture which reduces the concentration of carbohydrates in the wastewater. The bakery is charged for BOD levels in excess of 250 PPM. However, a pretreatment step is not cost effective compared to paying this fee. An alternative has already been implemented to reduce the BOD level further by not washing dry raw ingredients that accumulate on the floor into the waste system. Instead, the dry ingredients are swept up and disposed of in solid form. This also cuts down on water usage since the floor is not hosed down as often and there isn't as much to wash down the drain into the sewer. Reclaiming the flour from the sprinkling operation is another way to minimize waste.

Zero-discharge is not planned for the bakery, since the waste production has not reached critical levels that make it necessary to install this type of system. Other emissions of concern are VOCs, which were discussed previously. Wastes produced in the bakery industry come from two general sources. One source is from the baking pans, which are washed periodically after baking to remove grease, flour, sugar, and other materials. The other major source of waste water is from the clean up process. Wastewater flow is about 30,270 gallons per day, the bulk of this occurs during cleanup. Water consumption for the average bread bakery is 6,010 to 6,470 gallons of water per day during production (Lee & Ettelt, 1974).

According to the literature, the biggest problem in the bakery industry is discharge from pan water. Pans are cleaned in hot (180°F) detergent water. By the end of a production day the water contains a large quantity of solids and emulsified grease. In a study, samples were taken from a Chicago bakery and results ranged between 2.5 and 8% hexane solubles, which includes fats, oils, and grease, 6.8 and 10.4% suspended solids and 1,200 to 1,690 mg/l BOD (Lee & Ettelt, 1974). Most cities have limits on the amount of hexane that can be discharged, but do not have limits on the amount of BOD and solids. The limit on the disposal of hexane is usually around 100 mg/l. There are surcharges on the BOD and solids if the flow exceeds 10,000 gallons per day. Surcharge liabilities exceed $1,500 per month based on the average bakery.

Table 4.2 shows bakery waste characteristics for two bakeries that produce approximately 32 million pounds of bread and operate on a five-day production week with peak production on Sundays and Mondays, and normal production Wednesdays through Fridays (Grove, 1993).

Table 4.3. Bakery Waste Characteristics.

Characteristics	Bakery 1	Bakery 2
pH	7.8	6.9
BOD (mg/l)	155	600
Grease (mg/l)	68	60

Source: Grove (1993).

Section 4.4: Canned Fruits and Vegetables (SIC 2033)

Preserved fruits and vegetables (SIC code 203) are a very important area in the food industry. Preserved fruits and vegetables are a $45 billion per year industry in the United States. There are over 2000 plants in this industry, and they add a value of $23 billion to food products. Yearly electrical energy usage of plants in this industry is over two billion Btu, and $355 million is spent each year on fuel. More information on this industry, including waste data, is shown in Table 4.4. (US Bureau of the Census, 1992)

Table 4.4. Industry Group 203 Preserved Fruits and Vegetables.

Production, Energy, and Waste	**Amount**
Number of Production Plants[1]	2,052
Value of Shipments (millions of $)[1]	$44,836
Value Added (millions of $)[1]	$22,827
Electrical Energy Usage (BTU)[1]	2,364,899
Cost of Fuel for Energy (millions of $)[1]	$355
Wastewater BOD (millions of gallons)[2]	83,100
Wastewater BOD (millions of lbs.)[2]	800
Waste Suspended Solids (millions of lbs.)[2]	392
Waste Solid Residuals (millions of lbs.)[2]	8,561

Source: US Bureau of Census (1968, 1992). ([1]1992 data, [2] 1968 data).

The preserved fruit and vegetable industry can be further broken down into six smaller industries: canned specialties; canned fruits and vegetables; dehydrated fruits, vegetables, and soups; pickles, sauces and salad dressings; frozen fruits and vegetables; and frozen specialties. Information from literature on each of these industries is in Table 10, including the number of plants, value of shipments, and energy usage. Of the six industries, canned fruits and vegetables (SIC code 2033) is the largest, accounting for over one-third of the total value of shipments in the preserved fruits and vegetables industry. It also uses over one-third of the fuel in the industry, but less than 20% of electrical energy (US Bureau of the Census, 1992).

Table 4.5. Canned Fruits and Vegetables Industries Data

	1992	1987	1992	1992	1992 Energy Use	
Industry	**# of Plants**	**# of Plants**	**value of shipments (millions of $)**	**value added (millions of $)**	**Electricity (BTU)**	**Fuel (millions of $)**
Canned Specialties	220	211	$5,708	$3,618	186,480	$38
Canned Fruits and Vegetables	683	647	$15,175	$6,959	449,687	$138
Dehydrated Fruits, Vegetables., and Soups	155	132	$2,786	$1,515	154,536	$45
Pickles, Sauces, and Salad Dressings	376	382	$6,531	$3,749	182,905	$22
Frozen Fruits and Vegetables	255	258	$7,416	$2,910	931,289	$80
Frozen Specialties	363	288	$7,220	$4,076	459,973	$33

Source: Bureau of Census (1992).

Canned sauerkraut (SIC code 20332 76) is a $47 million industry and 57 million kg of sauerkraut were produced in 1992 (*Almanac*, 1996). Sauerkraut production data is shown in Table 4.6. The main ingredient in sauerkraut is fresh cabbage (97.75%). Cabbage is cut into thin strips. Salt, at a usual level of 2.25%, is then added (VonLoesecke, 1942). This mixture is then fermented, pasteurized, and packaged.

Table 4.6. Sauerkraut Production (SIC 20332 76) Data.

1992 Sauerkraut Production	Amount
Production (cases)	6,378,600
(millions of lbs.)	126.3
(millions of kg)	57
Value of Shipments (millions of $)	$47
Number of companies with over $100,000 in shipments	10

Source: The Almanac of the Canning, Freezing and Preserving Industries (1996).

Cabbage is the major component and a fermentation substrate. It contains the initial lactic acid bacteria, such as *Leuconostoc mesenteroides, Lactobacillus planitarium or Lactobacillus cucumeris, and Lactobacillus brevis or Lactobacillus pentoaceticus*, which ferments the cabbage (Weiser, 1962 & Wood, 1985). The turgid cabbage also produces the water that is used in the fermentation step, which is drawn by osmotic pressure created by salt. This water also contributes to moistness, texture, and distribution of flavor within the product. Salt is used as a preservative and as flavor. It has high osmotic potential which is used in the fermentation stage.

Sauerkraut processing involves deleafing the cabbage, removing or mutilating the core and shredding the cabbage into a slaw. This slaw is then salted and placed in vats. Pressure is added in the vats by placing a plastic sheet with water on top to further remove water from the cabbage. The favorable bacteria then ferment the sugars in the cabbage and create lactic acid, which preserves the cabbage. Fermentation takes place over a specific amount of time (usually three to four weeks). (Considine, 1982)

Part of the fermented cabbage may be stored awaiting further processing. The rest is then separated into sauerkraut and excess juice (waste). The sauerkraut then undergoes pasteurization. It is finally placed in jars or cans and then sent for distribution.

Though this process is relatively simple, each step provides a specific purpose that is integral to an acceptable product. Deleafing, coring, trimming, and shredding of cabbage are done to produce desired appearance and eating quality. Salt is added in order to draw moisture from the cabbage through osmosis in preparation for fermentation. The cabbage is filled into vats, covered, and sealed in preparation for fermentation. Fermentation is performed to produce the correct flavor and texture of the product. Pasteurization is used to extend the shelf-life of the kraut by killing any viable microorganisms that may cause spoilage. It also changes the flavor of the kraut, giving a cooked flavor that is known to consumers. The sauerkraut is then canned to protect the food until it reaches consumers.

There are alternatives to some processing steps that would benefit the design of a processing plant. The cabbage could be fermented with a starter culture, which might speed up the fermentation process. In addition, pasteurization of the sauerkraut could be replaced by thermal processing of the cans or aseptically processing the sauerkraut. This would extend the shelf-life of the product. This leads to the possibility that plastic or polyethylene could be used instead of cans and jars. Using these alternative packaging materials may allow for a cheaper packaging system, in terms of energy conservation and cost of material. Lastly, flavor-enhancing ingredients, such as caraway seed, juniper berries, sugar, or MSG may be added to provide product variety that may be attractive to consumers.

During the production of sauerkraut, key chemical and processing issues need to be observed and resolved. First, the salt level must be optimum, dependent upon production time desired. This level ranges from 1.5% - 2.5%. If the salt level is too low, the product softens because competitive microorganisms (towards the desired lactic acid culture from normal microflora) are not inhibited and may cause soft rot of the cabbage. If the salt level is too high, the microbial sequence may not be obtained because growth of the desired lactic acid culture from natural microflora is inhibited due to high osmotic pressure (Considine, 1982). Second, the cabbage variety and source are key product issues. Cabbage with the least amount of green leaves and the highest amount of solids is desired. This is due to consumer preference for white cabbage kraut and the want for more product and less brine. Third, the anaerobic environment at which fermentation takes place needs to be preserved, usually by placing a plastic sheet over the vats weighted with water or brine. According to Wood (1985), most of the problems dealing with discoloration (autochemical oxidation), loss of acidity, off-flavor and odors (moldy, yeasty and rancid), sliminess, and softness of kraut are caused by growth of aerobic molds and/or yeast. Fourth, processing time and temperature, especially during fermentation and pasteurization, should be controlled at optimum conditions. For fermentation, the normal time is three to four weeks and the temperature range is 60 to 75°F (Considine, 1982). For pasteurization, the target temperature is 165°F (Johnson *et al.,* 1974). These parameters determine the length and success of the fermentation and pasteurization step. Deviation from optimum time and temperature may affect product safety and integrity. Lastly, cleaning chemicals must be eliminated from the pipes and equipment.

For every ten tons of raw cabbage used, 30% (three tons) of the cabbage produced during the trimming and coring of the cabbage is waste (Hang, Downing, *et al.*, 1972). A portion of the fermented sauerkraut is also discarded as waste. At the top of the fermenting vats, the sauerkraut is undesirable due to aerobic spoilage. These wastes are usually ground and disposed of by spreading the grindings onto a field as fertilizer for the next season or by composting. Brine waste is also produced during the addition of salt to the shredded cabbage and during fermentation. As soon as salt is added to the cabbage, water from the cabbage is extracted. Some of the brine is removed right away to allow the tank to be fully filled with shredded cabbage. In addition, brine is separated from the sauerkraut at the end of the fermentation. Brine totals about 29% of the fermented product. Most of this brine is kept and packaged with the sauerkraut, the remainder must be disposed as waste. Brine has Biological Oxygen Demand of 12 pounds per ton of sauerkraut. It also has 0.6 pound of nitrogen, 0.1 pound of phosphorous, and up to 4.5% salt. Because of the high BOD, high salt content, and high acidity, sauerkraut brine cannot be disposed of by conventional methods. Some extra brine is used for canning in glass jars, which require more liquid for appearance (Hang, Downing, *et al.*, 1972).

Sauerkraut production has few sources of water use, waste production, and power consumption. External water is only used to clean the fermentation tanks and processing lines. This use can be minimized mainly through proper cleaning techniques. Since only processes directly related to making sauerkraut were used in the wastewater analysis, this water use will not be discussed in more detail. Water waste generated from this cleaning is very small compared to that of the brine.

The first source of waste originates from trimming cabbage and disposing of undesirable sauerkraut (top layer formed during fermentation). Green cabbage leaves must be discarded, because US consumers prefer white cabbage in the sauerkraut. This waste is disposed by composting and using it for fertilizer on the cabbage fields. The waste could also be used as animal feed. However, since animals need feed throughout the year and cabbage is a seasonal product, the waste supply cannot meet the demand at all times. The cores can also be disposed of in this manner or mutilated and left in the cabbage. Because the cores are high in sugar, they can aid in the fermentation. This alternative reduces the solid waste produced. Any sauerkraut that is not desirable is discarded in the same manner as the green leaves.

The second and main source of waste is brine from fermentation. This brine has a BOD of 5,875 PPM and about 2% salt (Hang & Downing, 1972). This waste, of course, cannot be simply disposed. The BOD can be chemically or biologically reduced, but the salt remains. One possible solution is to aerobically grow yeast in the brine solution. Because of the high content of organic matter that creates the BOD, the brine can also serve as a nutrient source for yeast like *Candida utilis, Sacchromyces cervisiae,* and *S. fragilis.* (Hang & Splittstoesser, *et al.,* 1972). This process reduces the BOD by tenfold. This may reduce the brine BOD to approximately 500 PPM, which is twice the acceptable discharge of 250 PPM. The salt is left, but it is not as critical as lowering the BOD. Yeast produced by this process can be used as animal feed or in fermentation processes like ethanol production or food production.

Another possible idea for waste minimization is to convert the brine waste to a solid matter. This solid substance will be high in salt and biological matter from the fermentation. The solid would be of great use as a nutrient source for animals. The brine would first have to be neutralized to make it edible. These solids could either be made into a salt block or added directly to feed. These processes would most likely be preferred over paying for wastewater treatment or government fines.

Another improvement in waste management is to use high solid's content cabbage. This would reduce the amount of water extracted from the cabbage and therefore reduce the amount of brine present in the fermentation (Stamer & Dickson, 1975). A 2% increase in total solids has been shown to produce a threefold decrease in waste brine.

The only major area for energy reduction occurs during canning. The energy used in processing raw cabbage is minimal compared to the energy needed for the canning process. The canning process involves thermal processing of sauerkraut and cooling of the canned product. One possible conservation method is to separate any brine from the sauerkraut, heat the brine in a heat exchanger, and combine it back with the solids. This would be beneficial because heat transfer through the brine occurs more easily than through the sauerkraut itself. If the brine is heated to a high enough temperature before it is combined back with the solids, the entire product could be pasteurized. This would reduce the amount of steam required and lower costs of production.

Another possible method of sterilization is by treating the sauerkraut with UV light irradiation. This would only alter the usual cooked flavor of the sauerkraut that comes with canning to a fresher flavor, which may or may not be desirable. A problem with irradiation would result from inconsistent distribution of the sauerkraut. UV rays would not be able to pass through the kraut evenly.

One other alternative is not to can the product but to bag and refrigerate it. This would preserve desired qualities and eliminate energy usage from pasteurization. Refrigeration costs would be incurred but are thought to be less than that of pasteurization. After pasteurization, cooling the product involves using a cold liquid or air medium. The energy used to cool could be eliminated by using one of the above methods that does not use heat treatment of the sauerkraut.

By conducting this study and design on the sauerkraut industry, a large amount of information was learned about this unique product and process. The process is relatively simple, but there remains much to be learned about perfecting the operation. Little change has occurred in the sauerkraut industry over the past several decades, but there are several areas for improvement. One of these areas is waste minimization. The solid waste can be disposed of very easily by returning it to the fields. Liquid waste or brine creates a problem of disposal. Several methods are outlined in this paper, most of which include neutralizing the acid and using the solids of evaporation as feed or as fertilizer. These are possible ways to improve the problem..

Another area which may be improved on is energy consumption. By reducing energy requirements in the canning operation, the cost of production could be improved. Energy is not the major cost in manufacturing, but is an area which could be improved. The best way would be to know the amount and types of microorganisms present throughout the product. Then only the necessary amount of heat would have to be applied to produce a safe product. But until the time that this technology is developed, alternate methods of packaging (discussed previously) could be tried. The process design for sauerkraut production is not always uniform. Since cabbage is a seasonal product and different lengths of fermentation may be desired depending upon the quality of the cabbage and the demand for sauerkraut, processing conditions may change accordingly. Canning is the historical and most common method for packaging sauerkraut, but other methods have become more common in recent years. Through it all, the production of sauerkraut remains more of an art than a science, but these methods could help improve its quality and production costs.

Section 4.5: Sugar and Confectionery Products (SIC 206)

The sugar and confectionery products industry group (SIC code 206) section is broken into three parts: industry overview, a regional overview and waste production information. The industry overview includes a number of establishments, value of shipments, value added by manufacturer, quantity of finished goods, electric energy usage, and cost of fuel as seen in Table 4.7. The regional overview includes the same information broken down by state. This information is given in both overviews for raw cane sugar (SIC code 2061), cane sugar refining (SIC code 2062), beet sugar (SIC code 2063), candy and other confectionery products (SIC code 2064), chocolate and cocoa products (SIC code 2066), and salted and roasted nuts and seeds (SIC code 2068).

The confectionery industry spans the United States from the east coast to the west, the north to the south, catching 12% of the manufacturing sector (Darnay, 1994). A table of the leading states for total millions of dollars made in shipments and percentage of the United States the candy or confectionery products are shipped to is shown in Table 4.8.

Candy and Other Confectionery Products (2064)

Although the candy industry is expansive and profitable, changes need to be implemented, namely in the bulk ingredients sector. The constant need for improvement is forcing marketers and, in turn, manufacturing plants to implement lower fat and cholesterol ingredients into their products in order to continue making the candy industry lucrative. Some of these changes can be directly related to making whey-based caramels. The first shift in consumer's preferences is the increased demand for low calorie products made with sweeteners such as Aspartame. Products such as caramels may need to implement the use of these noncaloric sweeteners to capture potential profits (Senauer et al, 1991). The second shift in consumers' preference related to caramel is the decreasing desire for foods made with saturated fats such as vegetable oils, specifically palm and coconut.

Table 4.7. Sugar and Confectionery Products Industry Overview.

SIC Code	Industry	# of Establishments	Value of Shipments (Million $)	Value Added by Manufacture (Million $)	Quantity of Finished Goods (1000 tons)	Electric Energy (million Btu)	Cost of fuels (Mil.$)
206	Sugar and Confectionery Products	1130	22718.3	22718.3	-	9487836	252.8
2061	Raw Cane Sugar	45	1459.8	1459.8	4804.3	420036	21.4
2062	Cane Sugar Refining	17	2822.9	2822.9	5412.3	361006	39.4
2063	Beet Sugar	40	2282	2282	6676.7	1435152	136.2
2064	Candy and Other Confectionery Products	762	10219	10219	386.1	4876992	35.4
2066	Chocolate and Cocoa Products	156	3106.4	3106.4	1460.6	1463473	12.2
2068	Salted and Roasted Nuts and Seeds	110	2828.3	2828.3	1757.3	931177	8.2

Source: Bureau of Census, 1994

Table 4.8. Regional Distribution of Confectionery Production.

State	Number of Establishments	Total (millions) in Shipments	Percentage of the United States
Illinois	61	1854.4	26.6
Pennsylvania	87	1135.8	16.3
New Jersey	31	635.2	9.1
New York	48	250.1	3.6
Ohio	27	165.3	2.4
Minnesota	12	142.1	2.0
Virginia	15	118.4	1.7
Washington	13	61.5	0.9

Source: Manufacturing USA (1994).

According to Alikonis (1979), a commercial whey caramel recipe is typically of corn syrup (37.4%), sugar (12.5%), sweetened condensed whey (28.6%), invert sugar (6.2%), soy protein (3.6%), vegetable fat (11.2%), vegetable lecithin (0.2%), and salt (0.3%). Caramel is a syrup-phase confectionery (Jeffery, 1993). Syrup-phase confectioneries are held together by syrups made of water-soluble sugars. Other materials are dispersed in this syrup and add to the texture and flavor of the product. In whey caramels, sugar and corn syrup create the syrup phase. Sugar and corn syrup not only create the structure of caramels, but also add to flavor and stability. Sugar adds sweetness to confections. Sweetness can be enhanced or controlled by gelling agents or fat. Sugar also gives caramels a soft texture (Alikonis, 1979). Boiling milk proteins in a sugar-corn syrup solution results in the Maillard reaction (Jeffery, 1993). Sugar is highly soluble and can produce microbially stable products. Sugar alone can not reduce water activity to low levels that inhibit growth of microorganisms, but syrups must have at least 75% sugar to be stable. However, corn syrups are highly viscous and exhibit plastic flow properties. These rheological properties help to create a stable base in confections. A stable syrup base is crucial to inhibit the growth of molds and bacteria and to prevent fermentation by lowering the water activity out of the range for microbial growth.

Whey protein, added to caramels in the form of whey powder or sweetened whey concentrate, is heated with sugars to achieve the Maillard reaction (Jeffery, 1993). This reaction creates the characteristic caramel flavor and color. Milk solids also contribute to the "body" of the candy (Alikonis, 1979). Candies that do not have enough milk solids tend to lose their original shape over time. Soya protein can also be added to whey caramels. Proteins enhance moisture retention and control water activity of the candy (Campbell & Pavlasek, 1987). In caramels, proteins also inhibit formation of large sucrose crystals that cause graininess. Proteins also act as emulsifiers and improve blending and stability. Fats are added to caramels to control stickiness (Alikonis, 1979). Caramels that are too sticky may stick to wrappers or the consumer's teeth. Excessive stickiness may also be caused by using scrap candies that contain acid or high humidity. Salt is added to caramels to bind water and decrease water activity of the final product. Rework is added to the recipe to activate the graining process and is defined as defective or over-produced product (US, 1994).

The main chemical issue found in the process is the caramelization, browning, or Maillard reaction. The extent of color and flavor development is controlled by the rate at which the batch is boiled. If a caramel premix is fed into a microfilm type of cooker, the issuing product is white and flavorless. This is due to the boiling time being too short for the browning reaction to be successfully completed. It is therefore necessary to hold the product from the microfilm in a heated vessel fitted with scrapers until the desired flavor and color have developed (Lipscomb, 1965).

Common browning of foods on heating or on storage is usually due to a chemical reaction between reducing sugars, mainly D-glucose, and a free amino acid or a free amino group of an amino acid that is part of a protein chain. The Maillard reaction is important in the production of caramel, during which reducing sugars also react with milk proteins. Heating of carbohydrates, in particular sucrose and reducing sugars, without nitrogen-containing compounds effects a complex group of reactions termed caramelization (Fennema, 1996).

The caramel making process begins with mixing and cooking all ingredients, including rework, in a cooking kettle. It is necessary to add rework to the process in order to begin the graining process. From the cooking kettle, the white caramel-like product is pumped into a falling film evaporator to remove excess water in order to increase the viscosity of the product. It is then pumped into the holding kettle where it is kept until the caramelizer is emptied of the previous batch. The Maillard reaction takes place at this time. The product then enters the caramelizer where it is cooled. Agitator blades in the caramelizer keep the product moving and decrease the amount of product which adheres to the sides. When the product reaches the desired color, it is poured into a large funnel. The product falls by gravity feed into plastic trays and it is stacked onto a cart to be placed in the hot graining room. The purpose of this room is to facilitate the graining process by increasing the temperature and therefore speeding up the reaction. The graining process is necessary to initiate crystal growth in the new caramel product by utilizing the crystals already found in the rework which facilitates the domino effect with respect to the flavor, texture and mouth feel of the final product. From the hot graining room, the product is wheeled into the cold graining and storage room where it is kept until packaging.

Steam is used in the cooking kettle, holding kettle, Caramelizer and in the steam tracing of the corn syrup lines. The heat tracing is necessary to keep the viscosity of the product low enough to allow the corn syrup to flow easily through the piping. Energy from the vapor evaporated from the product could be recovered by using a heat exchanger. Shell and tube heat exchangers are used as piping to return condensate to the boiler and deliver the caramel to the next processing step. This condensate water can be re-heated and re-used as steam.

Boilers consume several times their capital cost in fuel annually. Waste heat from the boiler can be minimized in several ways by controlling boiler stack temperature, specifying fuels, maintaining excess air levels, controlling ambient air temperature and relative humidity, and by insulating (Coerper, 1995). Boiler stack temperatures that are too high are an indication of poor efficiency. Controlling the stack temperatures in the boiler also minimizes waste heat from the boiler. A minimum temperature of 200°C should be maintained in order to avoid inadequate updraft and condensation, which cause corrosion in the heat exchanger and the stack. If temperatures in the combustion chamber are too high, the ash converts into slag, a glass-like substance, which deposits and reduces heat transfer. Fuels with high hydrogen content produce large amounts of water vapor during combustion. The vapor uses energy that would otherwise be used to produce steam, resulting in a loss of efficiency. Excess air levels must be maintained to ensure complete combustion of fuels. Inadequate excess air results in unburned carbon and carbon monoxide leaving the stack, and unburned carbon remaining in the ash. Ambient air conditions, such as temperature and relative humidity also affect efficiency. Insulation of boilers, kettles, and pipes minimizes heat loss to the environment (Tierney & Fishman, 1994). An energy efficient method of steam production is by utility production. Steam can be purchased directly from utility companies. Proper cleaning procedures should minimize fouling or buildup of residue on heat exchanging equipment. This step would ensure efficiency of the process by providing the proper flow rates through the process equipment.

Non-process energy costs make up approximately 8% of energy costs in manufacturing industries (EIA, 1991). Installing efficient lighting, heating, and air conditioning systems can decrease a plant's overall energy consumption. Proper insulation can minimize the effect of seasonal temperature changes on a process's energy requirements.

Several water conservation and reuse technologies are seeing wider application in industry. One technique is vapor-compression evaporation. This can concentrate wastewater or cooling tower blowdown and can concurrently produce high-purity water. However, it cannot be used for organics that form azeotropes or for steam-distilling. Also, fouling of the operation must be controllable. The capital costs and operating costs are both high for this operation. Another technique is reverse-osmosis or ultrafiltration. This operation can be used to remove ionized salts plus many organics, to recover heavy metals and colloidal material, and to produce ultrapure water. However, this operation is also fouling sensitive, stipulates that the steam used must not degrade membranes, and includes a high volume reject stream. Capital costs and operating costs are mediocre for this operation. Another method is combination wet/dry cooling towers. This operation can reduce fogging, however it is costly compared with the wet cooling tower. Yet another method would be that of a stainless steel microfiltration unit. The use of aerobic, anaerobic, coagulation, and membrane treatment systems has been aimed at removing organic constituents (fats, carbohydrates, proteins) from waste streams. This coagulation system is designed to remove colloidal materials, particularly fats and proteins, through flocculation and separation of the flocculated material.

In order to conserve the resources such as the steam used to heat the kettles and to heat trace the lines, insulation should be used. The kettles, lines, and boiler which produce steam should also be well insulated.

Section 4.6: Dairy Industry

The products of the dairy industry include fluid milk, cheese, butter, dry milk, and ice cream. The dairy industry consumes energy in the form of fuel and electricity. Fuel is used for running the process and space heating. Electricity usually provides mechanical energy for equipment like pumps and fans (Miller, 1986). Table 4.9 shows a breakdown of fuel and electricity consumption for selected dairy products. According to Miller (1986), roller-dried milk powders use the most fuel and electricity per ton of production. This is due to the loss of water by evaporation and the large amount of energy necessary to heat the rollers.

Table 4.9. Fuel Consumption and Electricity Consumption for Various Dairy Products.

Product	Fuel Consumption per Ton of Production (BTU/1000 gal)	Electricity Consumption per Ton of Production (BTU/ 1000 gal)
Pasteurized bottled milk	3,157	718
Butter	15,320	1,615
Cheese	15,930	2,870
Spray Dried Milk	64,940	4,951
Roller Dried Milk Powders	110,757	5,705
Casein	91,311	5,741
Anhydrous Milk Fat	15,176	1,902

Source: Miller (1986).

The dairy industry, in addition to being a major consumer of energy in the food industry, is also a major generator of wastewater. According to a study by Roy E. Carawan (1976) of the North Carolina Cooperative Extension Service (year), the average Grade A dairy plant produces 5 pounds of BOD per 1,000 pounds of milk processed. This results in an annual BOD load of 400 million pounds. Focusing on fluid milk, butter, cheese, ice cream, and dry milk, the BOD load and total soluble solids (TSS) are summarized in Table 4.10.

Table 4.10. Average Daily Waste Limitations for Dairy Products

Product	BOD (lbs/day)	TSS
fluid milk products	0.37	0.46
butter	0.08	0.10
cheese (cottage and cultured)	0.74	0.93
ice cream, novelties, and other desserts	0.47	0.59
dry milk	0.18	0.23

Source: Carawan (1976)

There are many opportunities for energy conservation and waste minimization in the dairy industry. The dairy industry is both waste and energy intensive. About 3 to 10 gallons of water are used to process each gallon of raw milk. Most of the water is used for cleaning, so opportunities to reduce waste can be found in changing cleaning strategies. The dairy industry is a good candidate for a case study on waste and energy loss minimization. Since it has a wide array of types of unit operations there are many standards with which to comply for food safety, and subsequently there are considerable opportunities for waste reduction, utilization and conversion.

The dairy industry was chosen for a case study on the feasibility of retrofitting an existing dairy processing plant to be zero-discharge (i.e., producing zero waste in the form of heat and mass). When devising a design, it was useful to categorize the levels of waste and energy minimization as follows:

Level I: Minimize the water and energy used through process optimization, improved operating techniques, and optimized process scheduling.

Level II: Reuse process waste water with minimal processing (to purify it to meet specifications of further plant use).

Level III: Convert remaining wastes to byproducts that can either be reused in the plant or sold.

There is a trade-off between the degree of waste reduction and the amount of additional energy required to minimize the waste. The goal of the case study was therefore to minimize waste from a particular dairy plant. The additional required energy (such as for purification, conversion, and transport) was obtained from the implemented energy recovery design.

United States industries use energy-efficient equipment to increase productivity, lower production costs, and decrease pollution (Jones & Verdict, 1995). Many firms look internally for energy efficiency improvement ideas. Some companies encourage energy efficiency ideas by committees designed to solicit ideas from employees. Other firms have created gains-sharing programs to encourage personnel to suggest projects that would optimize energy use and improve the performance of plant operations.

Section 5: Conclusions

The United States food and kindred products sector plays an important role in US economy, because it is large, rapidly growing, and competitive. The food industry benefits the US economy by its size, growth, and rank in domestic markets, and because it is a crucial part of US foreign trade.

The food and kindred products industry sector manufactures an array of foods and beverages for human consumption, as well as related byproducts. Byproducts of the food industry are employed for agricultural, industrial, and commercial use as livestock feeds,

The typical US household devotes a significant portion of after-tax income to the purchase of food and beverage products. Consumers are influenced by current trends, and food industry spends a significant amount of money on research and development to create new products.

The food industry is also a large consumer of energy due to its size and energy-using processes. The food industry is the fifth largest energy consumer in the manufacturing sector. Food manufacturers are also important utility customers, because most utilities have at least one food manufacturer customer and food manufacturers have a large utility load, resulting in intense competition for food industry loads.

The food industry is dependent on energy to perform unit operations and processes. Because the food and kindred products industry is diverse, there are many different types of operations. Energy-dependent processes preserve freshness and food safety. Thermal processing and dehydration are the most commonly used techniques for food preservation. Process heating accounts for approximately 29.1% of total energy input in the food industry. It is also necessary to cool and refrigerate processed food to ensure safe, quality products. In the food industry sector, process cooling and refrigeration demands about 15.5% of total energy inputs.

Safe and convenient packaging is extremely important in food manufacturing and is also energy intensive. Newer packaging must not only meet safety requirements, but also meet convenience demands. Consumers tend to favor food products that have a higher value added by processing. New techniques used to create modern packaging require energy intensive aseptic thermal processing and electro-chemical changes. A higher level of processing requires a greater number of unit operations and therefore energy.

Proper storage is also energy dependent. Freezing and drying are the most crucial methods of food storage. Freezing operations require a large portion of electricity used by industries. Drying procedures usually depend on fossil fuels. Older dehydration systems were designed to operate with maximum throughput, disregarding energy efficiency. Newer systems are designed with recirculating dampers and thermal energy recovery equipment to cut energy use 40%.

The environment has become a greater concern worldwide, thus creating an imperative for reducing industrial energy consumption and waste production in all manufacturing sectors.

The United States has adopted many policies to increase public awareness and regulate pollution in recent years. Environmental control approaches can include direct regulatory instruments, economic instruments, and consultative approaches. In addition, the Food Industry has unique environmental concerns. Industry-specific research is needed in key areas to reduce environmental damage:

- uses of by-products
- by-product reduction
- improved, rapid analytical methods
- sanitizing and cleaning agents and procedures
- wastewater treatment technologies
- refrigerants
- packaging technologies.

There are many areas in by-product characterization and reduction that have not been investigated. These areas include:

- knowledge of types, quantities, and location of solid by-products generated and being disposed in the United States
- establishment of recycling and reuse regulatory criteria
- alternatives to water use
- improved brining and curing processes
- chemical extraction processes

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 other priorities in industries.

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. More specifically, the following design considerations should be evaluated to achieve the best compromise for fuel choice:

1. lowest fuel cost per unit of useful heat generated
2. lowest capital and maintenance costs for combustion and transfer equipment
3. lowest direct labor costs per unit of useful heat generated
4. lowest fire and explosion hazard (in dusty conditions)
5. lowest risk of product contamination by the fuel and its byproducts
6. maximum flexibility in operations and control
7. maximum reliability in continuity of supply
8. compliance with environmental standards

The food industry generates a significant amount of waste per year. Waste and energy use can be decreased through process optimization, operating techniques, and scheduling. Wastewater can be processed and reused. Also, waste can be converted to byproducts and reused or sold. These are opportunities for waste and energy reduction in the food industry.

Waste reduction helps the environment, lowers health risks, and is more economical for manufacturers. Waste reduction is defined as in-house processes that reduce, avoid, or eliminate hazardous contaminants. Waste minimization is a much more common practice than reduction and includes recycling and treatment before external disposal. Manufacturing in the United States alone uses 10 billion gallons of water a day for various processes. Several food industries that are not energy intensive use and waste large amounts of water. Water must be purified before use in processing and before reuse, both energy intensive operations. Typically, water used in processing is purchased from a purifying facility or pumped from a well and pretreated at the plant. Methods of water purification include clarification, filtering, ion-exchange, ultrafiltration, and reverse osmosis. Other technologies that exist for industrial water purification include advanced oxidation processes, bioremediation, and chemical clarifiers, vapor-compression evaporation, crystallization, and staged cooling.

Because of the increasing pressures on the environment, the concept of zero discharge may become a requirement of food processing plants in the future. True zero discharge plants do not discharge heat, emissions, and wastewater. Eliminating water waste from processing facilities requires the sophisticated water treatment technologies discussed above. Greatly increased level recycling and reduced pollution are two benefits gained from zero discharge wastewater systems. Some advocate making decisions on the basis of "prove harm" as an alternative to zero discharge. Proven harm requires that pollution build up to a level that causes harm before implementing measures. However, this concept is uneconomical -- it is more cost effective to design a zero discharge system than remedy problems that arise once the pollution builds up. Zero discharge is the only way to break the cycles of pollution, save significant amounts of money used to compensate victims, and solve the problems caused by pollution.

A zero discharge system for wastewater treatment is desirable from the company's standpoint for several reasons:

- designing a zero discharge system may be preferable to relocating in an area where the water supply is limited,
- the water quality before any treatment is close to that of the available recycled water,
- it is more economical to reduce the dependency on raw water, and
- the paperwork of releasing wastewater is too much of a burden and also carries the possibility of citation for noncompliance with wastewater management.

In some cases, however, it is thought that water reuse is not possible because of the need for higher quality water than could be provided through on-site treatment.

Energy efficiency can be achieved by improving existing plants, developing energy-efficient process technologies, improving and expanding demand-side management programs, creating informed and reasonable energy policies, and further researching the possibilities of zero-discharge plants. Government policies including:

- set standards for environmental quality, zoning and permitting,
- set tax and other economic policies,

- support and encourage research, and
- educate target groups and share technical information about key issues,

can have significant impacts on energy use and emissions from the food industry. These impacts must be balanced with the intended goals of the policies if government is to facilitate greater efficiency and reduced environmental impacts from this important industry.

References

Alikonis, J. J. (1979). Candy Technology. AVI Publishing, Westport, Connecticut.

Almanac of the Canning, Freezing, Preserving Industries, The. (1996). 79th ed. Daniel P. Judge, Westminster, MD, 565-567, 661.

Anonymous (1995). Cedar Bay 'pushes envelope' to reduce environmental impact. Power.

Anonymous (1989). Ethanol, Methanol Fuels Use to Climb in Canada. *Oil and Gas Journal,* **87**, Feb 13, 1989, p24.

Anderson, R. A. and Watson, S. A. (1982). The Corn Milling Industry. In *CRC Handbook of Processing and Utilization in Agriculture, Vol. II, part 1, Plant Products,* ed. Ivan A. Wolff. CRC Press, Inc., Boca Raton, Florida.

Appelbaum, B. (1995). Bridging the Gap: The Role of Industry Consultants. *ACEEE 1995 Summer Study on Energy Efficiency in Industry,* August 1-4, Grand Island, New York.

Bartsch, C. & DeVaul, D. (1993). Demand Side Management: A Bright Idea for Industry. *Public Utilities Fortnightly*, May 1.

Beck, R. (1996). US Demand for Oil, Gas Set to Grow Again in '96. *Oil & Gas Journal*, Jan 29.

Berk, Z. (1992). *Technology of production of edible flours and protein products from soybeans*. FAO Agricultural and Service Bulletin. Rome, Italy.

Bevan, G. Developing Role of Renewable Energy Sources. *Power Engineering Journal*, **9**, 4.

Bhesania, P. S. and Reklaitis, G. V. (1992). Minimizing Waste, Water, and Energy Use in a Dairy Plant. *Presented at ASAE winter mtg., Nashville, TN, Dec. 15 -18, 1992.*

Boffardi, B. P. and Smith, A. L., (1995). Chemical Treatment Makes Cooling Water Reusable. *Chemical Engineering* 106-108.

Boyd, R. & Uri, N. D. (1994). Effects of a Broad-Based Energy Tax on the United States Economy. *Energy Sources,* **16**.

Brennan, J. G., Butters, J. R., Cowell, N. D. & Lilley, A. E. V. (1990). *Food Engineering Operations,* 3rd ed. Elsevier Applied Science, London and NY.

Brown, H. L., Hamel, B. B. & Hedman, B. A. (1985). Energy Analysis of 108 Industrial Processes. *Library of Congress Cataloging-in-Publication Data.*

Bureau of Labor Statistics. Consumer Expenditure Study. *US Department of Labor,* Washington, DC 20212. Telephone: (202)606-6900.

Bureau of the Census. (Various Years). Annual Survey of Manufacturers.

Byers, B. (1995). Zero Discharge: A systematic Approach to Water Reuse. *Chemical Engineering* 96-100.

Cambell, L.B. & Pavlasek, S. J. (1987). Dairy Products as Ingredients in Chocolate and Confections. *Food Technology,* Oct.

Cappos, S., (1995). Membranes Minimize Liquid Discharge. *Chemical Engineering.*

Carlin, A., Dreyfus, M. K., Magat, W. A. & Viscusi, W. K (1993). Environmentally Responsible Energy Pricing. *The Energy Journal,* **15**, 2.

Casper, M. E., ed. (1977). *Energy Saving Techniques for the Food Industry.* Noyes Data Corporation, New Jersey.

Chapman, P. A., Olabode, H. A. & Standing C. N. (1977). Total Energy to Produce Food Servings as a Function of Processing and Marketing Modes. *Journal of Food Science,* **42**, 3.

Clark, C. W. (1992). Energy Recovery by Production of Fuel from Citrus Wastes. *Food Technology Overview Energy Conservation in the Citrus Industry. Outstanding Symposia in Food Science and Technology.* Institute of Food Technologists, May 1992. 253-254

Clayton, B., Jr. (1973). *Complete Book of Breads.* Simon and Schuster, Inc. New York, New York.

Coerper, P. (1995). Evaluating Boiler Efficiency. *Plant Engineering*, January 9.

Considine, D.M., ed. (1982). *Foods and Food Production Encyclopedia.* Van Nostrand Reinhold Co., New York, 314-315.

Crowley, J. C. & Donoghue, J. P. (1993). The Energy Efficiency Partnership: Kraft General Foods and Boston Edison Company. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Darnay, A. J., ed. (1994). Manufacturing USA. Volume 1. Gale Research Inc., Detroit.

DeSilva, F. (1996). Tips For Process Water. *Chemical Engineering* 80.

DeVaul, D. (1993). Building Better Partnerships for Industrial Energy Efficiency Technology Transfer. *ACEEE Workshop on Partnerships for Industrial Productivity through Energy Efficiency*, Sept. 19-22. Portland, Oregon.

Earle, R. L. (1983). *Unit Operations in Food Processing*. Pergamon Press.

El-Gazzar, F. E. & Marth, E. H. (1991). Ultrafiltration and Reverse Osmosis in Dairy Technology: A Review. *Journal of Food Protection*, **54**, 10.

Elliot, R. N. (1994). Electricity Consumption and the Potential for Electric Energy Savings in the Manufacturing Sector. ACEEE, Washington D.C. & Berkley, CA.

Energy Information Association (1994). *Manufacturing Consumption of Energy 1991.* US Government Printing Office.

Erickson D. *et al.* (1980). *Handbook of Soybean Oil Processing and Utilization*. America Soybean Oil Association and America Oil Chemists Society. Champaign, Illinois.

Fennema, O. R., ed. (1996). Food Chemistry. Marcel Dekker, Inc., New York.

Fluck, R. C. (1981). Fundamentals of Energy Analysis for Agriculture. *Agricultural Energy, Vol. 1, Solar Livestock Production.* ASAE, St. Joseph, MI.

Fox, E. J. & Eckhoff, S. R. (1993). Wet milling of soft-endosperm, high-lysine corn using short steep times. *Cereal Chemistry,* **70** (4) 402-404

Futterer, E., Mohr, T. & Munsch, M. (1993). Analysis of Exergy and Evaluation of Process Plants with a Flowsheeting System. *International Chemical Engineering,* **33**, 2, p. 197-206.

Ghaley, A. H. (1989). Biogas Production from Acid Cheese Whey Using a Two-Stage Digester. *Energy Sources*, **11**.

Gilmore, T. M. (1990). Cleanability Requirements of Dairy Processing Equipment Meeting 3-A Sanitary Standards. *Dairy, Food, and Environmental Sanitation,* **9**, 2, p75-76.

Golomski, W. A. (1994). ISO 9000-The global perspective. *Food Technology*, **48**, 12, p. 57-59.

Good, L., C.E.M & D. R. Williams (1994). *Guide to the Energy Policy Act of 1992.* The Fairmont Press, Inc, Lilburn, GA.

Geller, H. S. (1993). The Case for Industrial Energy Intensity Reduction Targets. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Gradassi, M. & Green, N. (1995). Economics of Natural Gas Conversion Processes, *Fuel Processing Technology,* **42**.

Grijspaardt-Vink, C. (1994). Food Preservation by Hurdle Technology. *Food Technology,* December, p 28.

Groh, J. E. & Thompson, T. L. (1981). Energy Conservation in Fruit Dehydrators Utilizing Recirculation of Exhaust Air and Heat Recovery Heat Exchangers. *Selected Papers and Abstracts from the 1980 ASAE National Energy Symposium.* ASAE St. Joseph, MI.

Grove, C. S. *et al.* (1993). *Design of a Treatment Plant for Bakery Wastes.* Annual Waste Conference, Purdue University Vol. 43.

Grundy, R. (1994). A Congressional Perspective. In *Guide to the Energy Policy Act of 1992,* ed. Dan R. Williams & Larry Good, C.E.M. The Fairmont Press, Inc, Lilburn, GA.

Hall, D. O. & House, J. (1995) Biomass: An Environmentally Acceptable Fuel for the Future. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy.* 209. 3. 203-213

Hallstrom, B.. (1986). Energy Consumption in Membrane Processing of Foods. *Energy in World Agriculture: Energy in Food Processing.* R. P. Singh, ed. Elsevier.

Hang, Y. D., Splittstoesser, D. F., & Landschoot, R. L. (1972). Sauerkraut Waste: a Favorable Medium for Cultivating Yeasts. *Applied Microbiology*, **24**, 1007-1008.

Hang, Y. D., Downing, D. L., Stamer, J. R., & Splittstoesser, D. F. (1972). WastesGenerated in the Manufacture of Sauerkraut. *J. Milk Food Technol.*, **35**, 432-435.

Heldman, D. R. & Singh, R. P. (1984). Energy Management in Food Processing. In *Engineering and Food Processing Applications*, ed. Brian McKenna. Elsevier, NY, 2nd ed.

Hoseney, C. M. (1994). *Principles of Cereal Science and Technology.* American Association of Cereal Chemists, Inc., St. Paul.

Houston, D. A. (1993). Demand Side Management: A Losing Proposition for Consumers. *Public Utilities Fortnightly*, May 1.

International Energy Agency (IEA) (1989). *Energy and the Environment: Policy Overview.* Copyright OCED/IEA.

Jefferson, M. (1994). Global Prospects for Renewable Energy. *Proceedings of the World Renewable Energy Congress. Part 1. Renewable Energy.* Aug 5-11.

Jeffery, M. S. (1993). Key Functional Properties of Sucrose in Chocolate and Sugar Confectionery. *Food Technology,* Jan.

Johnson, A.H. & Peterson, M.S. (1974). *Encyclopedia of Food Technology.* Vol. 2. AVI, Westport, CT, 782-784.

Jones, T. & Verdict, M. (1995). Understanding the Energy Efficiency Investment of Smaller Manufacturers: A Report on a Series of Energy Efficiency Industry Roundtables. *ACEEE 1995 Summer Study on Energy Efficiency in Industry,* August 1-4, Grand Island, New York.

Jordan, J. & Nadel, S. (1993). Industrial Demand-Side Management Programs: What's Happened, What Works, What's Needed. *American Council for an Energy-Efficient Economy,* Washington, DC

Kent, R., Mowris, R. J. & Ross, M. (1995). Using the Long-Term Industrial Energy Forecasting (LIEF) Model to Assess Core Industrial DSM Potential for Southern California Gas Company. *ACEEE 1995 Summer Study on Energy Efficiency in Industry, Vol. II.* August 1-4, Grand Island, New York.

Lawford, H. G. and Rousseau, J. D. (1992). The effect of lactic acid on fuel ethanol production by Zymomonas. *Applied-Biochemistry-and-Biotechnology.* **34/35** 205-216.

Lee, A. W. & Ettelt, G. A. (1974). *Dual Polymer Treatment of Variety Bakery Products Wastewater.* Tenco Hydro Aerosciences, Icn. Countryside IL.

Lewis, T. R. & Sappington, D. E. M. (1992). Incentives for Conservation and Quality-Improvement by Public Utilities. *The American Economic Review,* **82**, 5.

Lipscomb, A.G. (1965). Developments in the Manufacture of Toffees and Caramels. In *Twenty Years of Confectionery and Chocolate Progress.* Ed. committee of the P.M.C.A. Annual Production Conference Committee. Avi Publishing, Westport , Connecticut.

Lund, D. B., Singh, R. K., Buelow, F. H. & Duffie, J. A. (1981). Economic Performance Evaluation for Solar Heating of Hot Water in Food Process Operation. *Selected Papers and Abstracts from the 1980 ASAE National Energy Symposium.* ASAE, St. Joseph, MI.

MacLeod, G. A. (1993). Environmental Partnerships: A Path to the Future. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Manufacturing USA, 4th ed. 1990. Various Sections. Vol. 1.

Markley K. (1950). *Soybean and Soybean Production.* Volume I. Interscience Publishers, Inc. New York.

Markley K. (1951). *Soybean and Soybean Production.* Volume II. Interscience Publishers, Inc. New York.

Matz, S. A. (1992). *Bakery Technology and Engineering, 3rd ed.* Van Nostrand Reinhold. New York, New York.

Meadows, K., P. E. and T. Usibelli (1993). How Can Government Best Promote Energy-Efficient Practices and Process Innovation in Industry. *ACEEE Workshop on Partnerships for Industrial Productivity through Energy Efficiency.* Sept. 19-22, Portland, Oregon.

Meyer, A. (1993). Facilitating Industrial Energy Efficiency. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Meyers, E. M. (1993). Making the Right Energy Choices in America. *Public Utilities Fortnightly,* July 15.

Miller, E. J. (1986). Energy Management in Milk Processing. *Energy in World Agriculture: Energy in Food Processing.* R. P. Singh, ed. Elsevier.

Miller, N. & Govan, F. (1994). Cofiring Natural Gas with Coal in Stoker-Fired Boilers, *Consulting-Specifying Engineer*, **26**.

Montague, P. (1989). Zero Discharge: The Right Goal. Environmental Research Foundation, Annapolis, MD.

Moody's Industry Review (1994). Food Processing-Major. *Moody's Industry Review,* **14**, 34

Morris, C. E. (1995). Plant of the Year: Golden Cheese Company of California. *The Australian Journal of Dairy Technology.* Sept 1995, p79-83.

Oldenburg, K. U. and Hirschhorn, J. S. (1987). Waste Reduction. *Environment* **29**: 2, 16-20+.

Perry R. *et al.* 1994. *Perry's Chemical Engineers Handbook. Sixth Edition.* McGraw Hill Chemical Engineering Handbook. New York.

Pomeranz, Y. (1991). Functional Properties of Food Composition, 2nd ed. The Royal Society of Chemistry. Piccadilly, London.

Price, A. C. (1993). Effect of Utility Programs in Encouraging Industrial Efficiency. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Puga, N. (1993). Utility and Industrial Consumer Partnerships that Meet the Needs of both Parties. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Rautenbach, R. & Welsch, K. (1994). Treatment of Landfill Gas by Gas Permeation: Pilot Plant Results and Comparison to Alternatives. *Journal of Membrane Science*, 87.

Resource Dynamics Corp. (1990). Food Industry Scoping Study. *Resource Dynamics Corporation,* Vienna, Virginia.

Segado, R. R. (1995). Extraction Techniques in Food Processing. In *Bioseparation Processes in Foods,* ed. R. K. Singh & S. S. H.Rizvi. Marcel Decker, NY.

Senaver, B., Asp, E. & Kinsey, J. (1991). Food Trends and the Changing Consumer. Eagan Press, St. Paul, MN.

Sheridan, J. H., (1994). Pollution Solutions. *Industry Week* 243: 7, 32-42.

Singh, R. P., ed. (1986). *Energy in World Agriculture Vol.1: Energy in Food Processing.* Elsevier, NY.

Singh, R. P. (1978). Energy accounting in food process operations. *Food Technology,* **32** (4) 40-46

Singh, R. P. & Heldman, D. R. (1984). *Introduction to Food Engineering.* Academic Press, Inc.

Sloan, A. E. (1994). Top Ten Trends to Watch and Work On. *Food Technology's Top Ten Trends,* July.

Smith, W. M. (1993). EPRI Partnership For Industrial Competitiveness, EPIC. *ACEEE Workshop for Industrial Productivity through Energy Efficiency.* September 19-22, Portland, Oregon.

Smith, W. M. (1995). Industrial Competitiveness: Utility/Industry Partnership Successes. *ACEEE 1995 Summer Study on Energy Efficiency in Industry,* August 1-4, Grand Island, New York.

Solar, R. (1995). Zero Discharge and Large-scale DCS are Plant Highlights. *Power,* Apr.

Stamer, J.R. & Dickson, M.H. (1975). High Solids Cabbage for Sauerkraut Production: Its Effects upon Brine Reduction and Yield of Product. *J. Milk Food Technol.*, **38**, 688-690.

Steinmeyer, D. (1993). Good Government and Efficient Industry. *ACEEE Workshop on Partnerships for Industrial Productivity through Energy Efficiency.* Sept. 19-22, Portland, Oregon.

Strauss, S., D. (1994). Zero Discharge Firmly Entrenched as a Powerplant Design Strategy. *Power.* 42-48.

Sutherland, R. J. (1993). The DOE's Natural Gas R&D Portfolio. *Energy Policy,* July 1993.

Survey of Current Business (1996). May 1996 issue. *Survey of Current Business.*

Tafdrup, S. (1994). Centralized Biogas Plants Combine Agricultural and Environmental Benefits with Energy Production. *Water Science Technology,* **30**, 12, 133-141.

Tentscher, W. A. K. (1995). Biogas Technology as a Component of Food Processing Systems. *Food Technology*. January, p. 80-85

Thomas, S. M. & Carey, D. (1992). Purification of Evaporator Condensate for Re-Use in a Dairy Processing Plant. *Food Industry Environmental Conference, Atlanta, GA.*

Thrall, R. M., Thompson, R. G. & Holloway, M. L. (1983). Large Scale Energy Models: Prospects and Potential. *Am. Assoc. for Advancement of Science Selected Symp. 3.* Westview Press, Inc. Boulder, Co.

Tierney, T. M. & Fishman, C. J. (1994). Field Study of "Real World" Gas Steam Boiler Seasonal Efficiency. *ASHRAE Transactions: Symposia*. No. 94-9-3.

Toledo, R. T. (1991). *Fundamentals of Food Process Engineering.* 2nd ed. Van Nostrand Reinhold, New York.

Tuzel, T. (1993). *Waste Minimization in Food Processing Plants.*

United States General Accounting Office (USGAO) (1992). *Food Safety and Quality: Uniform, Risk-Based Inspection System Needed to Ensure Safe Food Supply.* DOC GA 1.13:RCED-92-152.

Unklesbay, N. (1983). Integration of Energy Data into Food Industry Decision Making. *Food Technology,* **37**, 12.

United States General Accounting Office (USGAO) (1992). *Food Safety and Quality: Uniform, Risk-Based Inspection System Needed to Ensure Safe Food Supply.* DOC GA 1.13:RCED-92-152.

US Code of Federal Regulations. (1994). Vol. 21, parts 170-199. Revised April 1, 1994. US Government Printing Office.

US Industrial Outlook (1994). Food and Beverages.

Viscusi, W. K., Magat, W. A., Carlin, A., & Dreyfus, M. K. (1994). Environmentally Responsible Energy-Pricing. *The Energy Journal*, **15**, 2, p. 23-42.

VonLoesecke, H.W. (1942). *Outlines of Food Technology.* Reinhold Publishing Co., New York.

Walls, D. (1995). An Econometric Analysis of the Market for Natural Gas Futures. *The Energy Journal*, **16**, 1, p. 71-83.

Weiser, H. H. (1962). *Practical Food Microbiology and Technology.* AVI, Westport, CT.

Wood, B. J., ed (1985). *Microbiology of Fermented Foods.* Vol. 1. Elsevier Applied Science Publishers, London.

Zall, R. R., Jordan, W. K., Chen, J. H. & Ludington, D. C. (1981). Using Winter Coldness to Provide Refrigeration. *Selected Papers and Abstracts from the 1980 ASAE National Energy Symposium.* ASAE, St. Joseph, MI.

APPENDIX A

DETAILED DATA TABLES

Table A1. Description of Products in SIC 20

Source: Energy Saving Techniques for the Food Industry (Casper, 1977)

SIC code	industry	raw materials	major energy consuming functions	products
20	**Food and Kindred Products**			
201	**Meat Products**			
2011	Meat packing plants	cattle, hogs, sheep, calves and lambs	heating (steam), smoke generation, singing (hogs) and space heating	carcass meats, primal cuts, boxed meats, sausage, lard and other proapared meats
2013	Sausages and other prepared meats	various meats	cooking, cooling, and boiler inefficiencies	sausages, cured meats, smoked meats, canned meats, frozen meats, natural sausage casings
2015	Poultry slaughtering and processing	SEE SIC 2017 and 2016		
2016	Poultry dressing plants	chickens, turkeys, pack rabbit, other small game	boilers, conveyers, refrigerators, defeathering	Meat for further processing
2017	Poultry and egg processing industry	poultry carcasses and eggs	cooking and refrigeration	poultry: cooked, smoked, deboned, canned, frozen or dehydrated; eggs: dried, frozen, broken
202	**Dairy Products**			
2021	Creamery Butter	whole milk	pasteurization and cooling, cleaning of equipment	creamery butter, anhydrous milkfat, butter oil, whey butter
2022	Cheese, natural and processed	milk	condensing and drying of resulting whey, pasteurization	natural cheese, except cottage; processed cheese; cheese foods; cheese spreads.
2023	Dry, condensed, and evaporated dairy products	milk	pasteurization, condensing, drying, and instantizing	condensed and evaporated milk, dry whole and nonfat milk, ice cream, ice milk mix.
2024	Ice cream and frozen desserts	milk, other ingredients	pasteurization, cooling, freezing	ice cream and other frozen desserts
2026	Fluid milk	raw milk	pasteurization, cooling and cleaning (thermal energy)	primary products: fluid milk, cream and related products including cottage cheese; secondary products: ice cream and frozen desserts, condensed and evaporated milk and creamery butter

Table A1. Description of Products in SIC 20, Continued.

203	**Preserved Fruits and Vegetables**			
2032	Canned specialties	fruits, vegetables, meats, beans, etc.	fruits and vegetables: washing, peeling, slicing; meats: chopping, cooking; boiler uses.	baby food, dried beans, ethnic foods, health foods, soups, not seafoods
2033	Canned fruits and vegetables	raw fruits and vegetables	vegetables: cutting, peeling or blanching, packing and retorting; fruits: trimming and dicing, peeling, pressing and pasteurizing (juices) and retorting	canned fruits, vegetables and juices, tomato sauces, jellies and preserves (does not include specialty products, pickeled products or non-tomato sauces)
2034	Dehydrated fruits, vegetables and soups	raw fruits and vegetables	dehydration, blanching, peeling, slicing, dicing	Dehydrated fruits, vegetables and soups
2035	Pickels, sauces, and salad dressings	fruits and vegetables	pickels: packing, syruping, pasteurizing, and cooling	salad dressings, vegetable relishes, non-tomato sauces, and seasonings
2037	Frozen fruits and vegetables	raw fruits and vegetables	vegetables: husking or vining, cutting, blanching, freezing; fruits: trimming, peeling, slicing and freezing; juice concentrate: extraction, finishing concentration, blending, and freezing	frozen vegetables, frozen fruits, frozen juice concentrate
2038	Frozen specialties	bakery ingredients, meat, other ingredients depending on product.	baked goods: mixing, forming, baking, finishing, packaging, and freezing; other frozen specialties: cooking, cutting, frying, mixing, blending, packaging	frozen dinners, pizzas, baked goods,
204	**Grain Mill Products**			
2041	Flour and other grain mill products	grains other than rice	tempering, drying, milling, motors are used for most operations.	flour and meal
2043	Cereal breakfast foods	grains	ovens, boilers	cereal breakfast foods and related preparations
2044	Rice milling	rough rice	motor power	polished rice, rice flour, rice meal
2045	Prepared flour mixes and doughs	flour	mechanical power	blended flour and flour mixes from purchased flour
2046	Wet corn milling	corn and sorghum grain (milo)	conveying, grinding and separating corn; evaporation and extraction	starch, syrup, oil, sugar, and by-products such as gluten, meal, and dry ice

Table A1. Description of Products in SIC 20, Continued.

2047	Dog and cat food	grains, sugar cane, meat	canned: grinding, blending, cooking, canning; Dry and moist: agitation, screening	dog, cat, and other pet food (canned, dry, and soft-moist)
2048	Prepared Feeds	alfalfa, grass, citrus pulp, feeds	drying, forming processes (pelleting, extrusion),	prepared feeds for animals and foul, feed ingredients and adjuncts, such as alfalfa meal and feed supplements.
205	**Bakery Products**			
2051	Bread, cake, and related products	ingredients for breads, pies, cakes and doughnuts (variable)	oven-baking processes, plant lighting and transportation of manufactured products (often not included in energy studies)	perishable products for sale through wholesale baleries, grocery chain bakeries, home service bakers and/or retail multi-outlet bakeries
2052	Cookies and crackers	flour, variable ingredients	receiving, mixing, forming, baking, cooling, finishing, packaging.	cookies, crackers, pretzels, other dry bakery products
2053	Frozen bakery products, except bread	SEE SIC 2051		
206	**Sugar and Confectionery Products**			
2061	Raw cane sugar	sugar cane	grinding, juice heating, evaporation, and crystallization	raw sugar, syrup, finished cane sugar
2062	Cane sugar refining	purchased raw cane sugar and sugar syrup	pumping, centrifugation and heat for solution, evaporation and drying	refined liquid or crystalline sugar
2063	Beet sugar	sugar	crushing, pumping, centrifugation, heating, evaporation, drying	sugar beets
2064	Candy and SIC 2067, chewing gum	SEE SIC 2065 and 2067		
2065	Confectionary products industry	corn syrup, liquid sugar, etc.	cooking, roasting, space heating.	Candy; including chocolate candy, salted nuts, not solid chocolate bars
2066	Chocolate and cocoa products	cocoa beans	roasting operation	chocolate liquor, cocoa powder and cocoa butter, chocolate bars and coatings
2067	Chewing gum industry	latex and additives	heating, mechanical power	chewing gum or chewing gum base
2068	Salted and roasted nuts and seeds	SEE SIC 2065		

Table A1. Description of Products in SIC 20, Continued.

207	**Fats and Oils**			
2074	Cottonseed oil mills	cottonseed	mechanical screw press and solvent extraction	cottonseed and by product cake, meal and linters
2075	Soybean oil mills	soybeans	drying, cracking, conditioning, extracting and desolventizing/toasting	soybean oil and by-product cake and meal
2076	Vegetable oil mills	peanuts, flaxseed, sunflower, and other seeds except corn, cottonseed, and soybeans	presses, and solvent extraction	vegetable oils and by product cake meal
2079	Edible fats and oils, n. e. c.	animal and vegetable oils	caustic refining, acidulation, bleaching, hydrogenation, winterization, and deoderization.	shortening, table oils, margarine, salad and cooking oils, salad dressings, and mayonnaise
208	**Beverages**			
2082	Malt beverages	grains, malt, hops and yeast	cooking, mashing, brewing, cooling, bottling and material and product conveyance	lager beer, malt liquor, draught beer, ale, porter or stout beer and bock beer
2083	Malt	barley or other grains	grain handling, steeping, germinating, kilning	malt or malt by-products
2084	Wines, brandy, and brandy spirits	grapes	heating processes	wines, brandy, brandy spirits, and blended wines
2085	Distilled and blended liquors	grain and malt, yeast	distilation process: cooking, fermenting, distilling, maturation, and bottling.	Alcoholic liquors, cordials and alcoholic cocktails
2086	Bottled and canned soft drinks	sugar, water, carbon dioxide, flavorings	mixing, bottle washing, cooling and filling	soft drinks and carbonated waters
2087	Flavoring extracts and syrups	sugars, etc.	mechanical power	flavoring extracts, syrups, fruit juices for soda fountain use; colors for bakers and confectioners
209	**Miscellaneous Food and Kindred Products**			
2091	Canned and cured fish and seafoods	raw fresh or frozen seafood	pre-cooking, resorting, and hot can wash	cooked and canned fish, shrimp, oysters, clams, crabs, and other seafood, soups, cured fish
2092	Fresh or frozen prepared fish	raw or frozen fish	freezing frozen storage, blanching, or frying	fresh and raw or cooked frozen packaged fish and other seafood, including soups

Table A1. Description of Products in SIC 20, Continued.

2095	Roasted coffee	green, unroasted coffee beans	all: roasting, grinding; dependent on product: hot water extraction, concentration, spray or freeze drying.	roasted coffee, coffee concentrates, extracts in powdered, liquid, frozen, or freeze dried form
2096	Potato chips and similar snacks	SEE SIC 2099		
2097	Manufactured ice	water	freezing, crushing	ice for sale

Table A2. Energy Consumption by Fuel Type: Top Consumers in 1991.
Source: Energy Information Administration, 1994.
Estimates in Trillion Btu.

SIC Code	Industry Grouping	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil and Diesel Fuel	Natural Gas	LPG	Coal (not coke and breeze)	Other
28	Chemicals and Allied Products	3040	440	48	12	1669	4	253	614
32	Petroleum and Coal Products	2987	105	87	21	838	63	*	*
26	Paper and Allied Products	2472	201	156	9	548	*	296	*
33	Primary Metal Industries	2292	499	33	11	686	3	46	1014
20	Food and Kindred Products	953	169	27	17	512	5	154	69
32	Glass, Stone, and Clay Products	894	105	8	19	380	2	293	86
	all Industry	15027	2370	414	139	5506	105	1184	5309

* Withheld to avoid disclosing data for individual establishments, data are included in totals.

Table A3. Cost of Purchased Fuels and Electricity in 1994.

Source: Bureau of Census, 1994.
In Million Dollars

SIC Code	Industry Group and Industry	Cost of purchased Fuels and Electricy	Cost of Purchased Electric Energy	Cost of Purchased Fuels
20	**Food and Kindred Products**	**5590.5**	**3206.2**	**2384.3**
201	**Meat Products**	**835.7**	**578.7**	**857.0**
2011	Meat packing plants	264.7	170.0	94.7
2013	Sausages and other prepared meats	266.1	157.0	69.1
2015	Poultry slaughtering and processing	334.9	251.7	93.2
202	**Dairy Products**	**596.4**	**394.2**	**202.2**
2021	Creamery Butter	7.9	4.1	3.8
2022	Cheese	167.9	96.5	71.4
2023	Dry, condensed & evaporated dairy	90.8	46.8	44.0
2024	Ice cream and frozen desserts	83.3	71.0	12.3
2026	Fluid Milk	246.5	175.7	70.8
203	**Preserved Fruits and Vegetables**	**804.2**	**448.9**	**355.3**
2032	Canned specialties	77.7	39.7	38.0
2033	Canned fruits and vegetables	246.1	108.0	138.1
2034	Dehydrated fruits, vetables & soups	78.0	33.4	44.6
2035	Pickles, sauces & salad dressings	60.6	38.9	21.7
2037	Frozen fruits and vegetables	220.2	140.4	79.8
2038	Frozen specialties	121.6	88.5	33.1
204	**Grain Mill Products**	**1047.9**	**603.0**	**444.9**
2041	Flour and other grain mill products	136.0	116.1	19.9
2043	Cereal breakfast foods	87.1	52.0	35.1
2044	Rice milling	36.0	26.8	9.2
2045	Prepared doughs and flour mixes	43.3	33.6	9.7
2046	Wet corn milling	446.1	197.8	268.3
2047	Dog and cat food	78.7	45.3	33.4
2048	Prepared feeds	200.7	131.4	69.3
205	**Bakery Products**	**435.1**	**242.3**	**192.8**
2051	Bread & cakes	289.2	156.9	132.3
2052	Cookies & crackers	98.4	55.2	43.2
2053	Frozen bakery products	47.4	30.1	17.3
206	**Sugar and Confectionery Products**	**416.2**	**163.4**	**252.8**
2061	Raw cane sugar	30.2	8.8	21.4
2062	Cane sugar refining	47.3	7.9	39.4
2063	Beet sugar	155.0	18.8	136.2
2064	Candy & chewing gum (SIC 2067)	118.8	83.4	35.4
2066	Chocloate and cocoa products	38.8	26.6	12.2
2068	Roasted nuts and seeds	26.2	18.0	8.2

Table A3. Cost of Purchased Fuels and Electricity in 1994, continued.

207	**Fats and Oils**	**424.0**	**180.1**	**243.9**
2074	Cottonseed oil mills	43.4	27.8	15.6
2075	Soybean oil mills	193.3	77.6	115.7
2076	Vegetable oil mills	10.5	5.9	4.6
2077	Animal and marine oils	120.7	42.0	78.7
2079	Edible fats and oils	56.1	26.8	29.3
208	**Beverages**	**556.8**	**340.3**	**216.5**
2082	Malt beverages	229.0	124.1	104.9
2083	Malt	39.7	16.7	23.0
2084	Wines and Brandy	46.0	34.8	11.2
2085	Distilled and blended liquors	24.9	12.4	12.5
2086	Bottled and canned soft drinks	185.2	133.5	51.7
2087	Flavoring extracts and syrups	32.2	18.9	13.3
209	**Misc. Food and Kindred Products**	**474.3**	**255.4**	**218.9**
2091	Canned and cured fish seafoods	16.9	7.0	9.9
2092	Fresh or frozen prepared fish	119.1	49.3	69.8
2095	Roasted Coffee	52.2	29.3	22.9
2096	Potato chips & snacks	92.1	40.4	51.7
2097	Manufactured ice	12.3	8.5	3.8
2098	Macaroni and spaghetti	21.2	15.9	5.3
2099	Food preparations	160.6	105.1	55.5

Table A4. Total consumption for all purposes by fuel type for all industry groupings.
(Estimates are in Trillion Btu)

Northeast Census Region

Sic Code	Industry Groups	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
20	Food and Kindred Products	79	19	7	5	42	1	2	0	3
21	Tobacco Products	NA	NA	NA	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	27	5	5	3	11	1	*	0	3
23	Apparel and Other Textile Products	5	2	*	*	2	Q	0	0	*
24	Lumber and Wood Products	NA	NA	NA	NA	NA	NA	NA	Na	NA
25	Furniture and Fixtures	5	2	Q	*	2	*	0	0	1
26	Paper and Allied Products	W	32	72	4	37	W	W	0	W
27	Printing and Publishing	23	11	*	1	9	*	0	0	1
28	Chemicals and Allied Products	135	32	19	W	59	*	W	0	14
29	Petroleum and Coal Products	74	10	10	8	29	2	3	0	11
30	Rubber and Misc. Plastics Products	37	19	3	1	W	Q	2	0	1
31	Leather and Leather Products	4	1	1	1	1	*	Q	0	*
32	Stone, Clay, and Glass Products	170	19	3	4	60	W	77	W	W
33	Primary Metal Industries	200	61	5	2	105	1	W	W	W
34	Fabricated Metal Industries	56	17	2	2	32	1	*	1	1
35	Industrial Machinery and Equipment	41	18	3	2	16	1	0	0	2
36	Electronic and Other Electric Equipment	42	22	3	2	14	1	*	*	*
37	Transportation Equipment	W	11	7	3	11	W	W	0	W
38	Instruments and Related Products	52	14	3	W	W	Q	W	0	*
39	Misc. Manufacturing Industries	W	4	1	W	W	W	1	0	*
all	Total	1226	300	145	45	458	12	167	17	83

* - 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 percent. Data are included in higher level totals.

Source: Manufacturing Consumption of Energy, 1991

Table A5. Total consumption for all purposes by fuel type for all industry groupings.

(Estimates are in Trillion Btu)

Midwest Census Region

Sic Code	Industry Groups	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
20	Food and Kindred Products	418	67	6	3	217	1	107	W	W
21	Tobacco Products	NA	NA	NA	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	NA	NA	NA	NA	NA	NA	NA	NA	NA
23	Apparel and Other Textile Products	NA	NA	NA	Q	NA	NA	NA	NA	NA
24	Lumber and Wood Products	29	10	Q	*	11	1	1	0	5
25	Furniture and Fixtures	W	5	*	1	W	*	Q	0	*
26	Paper and Allied Products	W	50	5	*	115	1	90	W	W
27	Printing and Publishing	43	18	*	*	23	*	0	0	2
28	Chemicals and Allied Products	390	116	W	W	186	W	63	*	22
29	Petroleum and Coal Products	138	23	5	W	88	2	W	0	16
30	Rubber and Misc. Plastics Products	93	45	2	*	42	1	3	0	1
31	Leather and Leather Products	4	1	*	*	2	*	0	0	*
32	Stone, Clay, and Glass Products	248	28	*	4	108	*	76	2	30
33	Primary Metal Industries	762	162	18	4	343	1	27	194	13
34	Fabricated Metal Industries	139	44	*	1	81	2	5	W	W
35	Industrial Machinery and Equipment	116	43	*	1	58	W	11	Q	W
36	Electronic and Other Electric Equipment	59	24	*	W	29	*	W	0	W
37	Transportation Equipment	168	57	2	2	72	1	27	1	6
38	Instruments and Related Products	11	6	Q	Q	W	*	W	0	*
39	Misc. Manufacturing Industries	9	3	*	*	5	*	*	0	*
all	Total	2948	707	42	22	1402	12	415	201	147

* - 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 percent. Data are included in higher level totals.

Source: Manufacturing Consumption of Energy, 1991

Table A6. Total consumption for all purposes by fuel type for all industry groupings.
(Estimates are in Trillion Btu)

South Census Region

Sic Code	Industry Groups	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
20	Food and Kindred Products	230	55	10	5	134	2	17	W	W
21	Tobacco Products	26	5	1	*	4	*	15	0	*
22	Textile Mill Products	234	93	7	3	89	2	30	0	9
23	Apparel and Other Textile Products	31	14	Q	*	12	*	2	0	*
24	Lumber and Wood Products	73	32	Q	W	15	1	1	0	19
25	Furniture and Fixtures	W	9	*	1	W	*	W	0	3
26	Paper and Allied Products	769	93	69	4	284	2	154	0	163
27	Printing and Publishing	28	16	Q	*	10	*	0	0	1
28	Chemicals and Allied Products	2009	285	25	6	1332	W	176	W	182
29	Petroleum and Coal Products	721	54	5	W	583	5	W	W	70
30	Rubber and Misc. Plastics Products	87	42	3	1	36	1	1	0	2
31	Leather and Leather Products	2	1	*	8	*	*	0	0	Q
32	Stone, Clay, and Glass Products	322	41	1	*	160	W	87	W	W
33	Primary Metal Industries	411	162	9	3	W	1	10	51	W
34	Fabricated Metal Industries	81	30	Q	2	43	1	0	1	2
35	Industrial Machinery and Equipment	57	28	*	1	27	W	Q	Q	W
36	Electronic and Other Electric Equipment	67	37	*	*	27	1	2	0	*
37	Transportation Equipment	W	29	W	2	28	*	W	*	2
38	Instruments and Related Products	17	11	Q	*	6	*	0	0	*
39	Misc. Manufacturing Industries	W	4	*	Q	W	*	0	0	*
all	Total	5258	1041	137	45	2972	22	498	57	487

* - 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 percent. Data are included in higher level totals.

Source: Manufacturing Consumption of Energy, 1991

Table A7. Total consumption for all purposes by fuel type for all industry groupings.

(Estimates in Trillion Btu)

West Census Region

Sic Code	Industry Groups	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
20	Food and Kindred Products	196	32	4	4	119	1	28	W	W
21	Tobacco Products	0	0	0	0	0	0	0	0	0
22	Textile Mill Products	6	1	0	*	5	Q	0	0	*
23	Apparel and Other Textile Products	NA	NA	NA	NA	NA	NA	NA	NA	NA
24	Lumber and Wood Products	83	23	1	7	10	1	0	0	41
25	Furniture and Fixtures	3	1	0	Q	1	*	0	0	*
26	Paper and Allied Products	262	47	11	1	111	1	0	0	W
27	Printing and Publishing	NA	NA	NA	NA	NA	NA	NA	NA	NA
28	Chemicals and Allied Products	140	41	W	W	88	W	W	W	4
29	Petroleum and Coal Products	205	27	4	3	129	16	0	0	25
30	Rubber and Misc. Plastics Products	19	10	*	Q	W	W	Q	0	*
31	Leather and Leather Products	Q	*	0	Q	Q	Q	0	0	*
32	Stone, Clay, and Glass Products	137	18	4	4	53	*	53	1	5
33	Primary Metal Industries	190	117	1	2	W	*	W	W	W
34	Fabricated Metal Industries	28	10	*	*	17	*	0	0	*
35	Industrial Machinery and Equipment	22	12	0	*	9	*	0	0	*
36	Electronic and Other Electric Equipment	29	19	0	Q	9	*	0	0	W
37	Transportation Equipment	47	24	W	1	20	W	0	0	W
38	Instruments and Related Products	17	11	*	*	6	*	0	0	*
39	Misc. Manufacturing Industries	2	1	0	*	1	*	0	0	*
all	Total	1404	404	26	22	659	22	95	7	168

* - 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 percent. Data are included in higher level totals.

Source: Manufacturing Consumption of Energy, 1991

Table A9. Total consumption of energy for all purposes by fuel type of selected SIC 20 industries by census region.

(Estimates are in trillion Btu)

SIC Code	Industry Groups and Industry	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
Total United States										
20	Food and Kindred Products	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 and Vegetables	44	5	2	1	36	8	Q	0	*
2037	Frozen Fruits and Vegetables	40	11	2	*	26	*	0	0	1
2046	Wet Corn Milling	141	14	*	*	52	*	68	W	W
2051	Bread, Cake, and Related Prod.	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	*
Northeast Census Region										
20	Food and Kindred Products	79	19	7	5	42	1	2	0	3
2011	Meat Packing Plants	1	*	W	*	1	Q	0	0	*
2033	Canned Fruits and Vegetables	6	1	1	*	4	*	Q	0	*
2037	Frozen Fruits and Vegetables	1	*	1	*	*	Q	0	0	*
2046	Wet Corn Milling	*	*	W	W	*	*	0	0	*
2051	Bread, Cake, and Related Prod.	7	1	*	W	W	*	0	0	*
2063	Beet Sugar	0	0	0	0	0	0	0	0	0
2075	Soybean Oil Mills	0	0	0	0	0	0	0	0	0
2082	Malt Beverages	8	2	W	*	4	*	W	0	*
Midwest Census Region										
20	Food and Kindred Products	418	67	6	3	217	1	107	W	W
2011	Meat Packing Plants	32	7	1	*	23	*	1	0	1
2033	Canned Fruits and Vegetables	10	1	0	*	9	*	0	0	*
2037	Frozen Fruits and Vegetables	4	1	*	*	2	*	0	0	*
2046	Wet Corn Milling	122	11	W	*	46	*	61	W	W
2051	Bread, Cake, and Related Prod.	9	2	0	W	W	*	0	0	*
2063	Beet Sugar	34	1	W	*	6	*	24	W	*
2075	Soybean Oil Mills	35	4	*	*	16	W	W	0	W
2082	Malt Beverages	11	2	*	*	W	W	W	0	*

See Source and Footnotes at end of table.

Table A9. Total consumption of energy for all purposes by fuel type of selected SIC 20 industries by census region, continued.

(Estimates are in trillion Btu)

SIC Code	Industry Groups and Industry	Total	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG	Coal	Coke and Breeze	Other
South Census Region										
20	Food and Kindred Products	230	55	10	5	134	2	17	W	W
2011	Meat Packing Plants	10	3	*	1	5	*	0	0	*
2033	Canned Fruits and Vegetables	7	1	*	*	6	*	0	0	*
2037	Frozen Fruits and Vegetables	8	2	1	*	6	*	0	0	*
2046	Wet Corn Milling	W	3	0	*	5	*	7	0	W
2051	Bread, Cake, and Related Prod.	11	3	0	*	7	*	0	0	*
2063	Beet Sugar	W	W	0	*	W	*	0	W	*
2075	Soybean Oil Mills	15	2	*	W	9	W	W	0	W
2082	Malt Beverages	14	3	W	*	8	*	W	0	*
West Census Region										
20	Food and Kindred Products	196	32	4	4	119	1	28	W	W
2011	Meat Packing Plants	5	1	W	*	3	Q	0	0	*
2033	Canned Fruits and Vegetables	20	2	1	*	17	*	0	0	*
2037	Frozen Fruits and Vegetables	26	7	Q	*	17	*	0	0	*
2046	Wet Corn Milling	W	*	0	W	2	*	0	0	1
2051	Bread, Cake, and Related Prod.	6	1	0	*	5	*	0	0	W
2063	Beet Sugar	W	W	W	*	W	*	18	1	*
2075	Soybean Oil Mills	0	0	0	0	0	0	0	0	0
2082	Malt Beverages	17	2	W	W	W	W	W	0	*

* - Estimate less than 0.5. Data are included in higher level totals.

W- Withheld to avoid disclosing data for individual establishmnents. Data are included in higher level totals.

Q- Withheld because relative Standard Error is greater than 50 percent. Data are included in higher level totals.

Source: Manufacturing Consumption of Energy, 1991

Table A10. End-Use by Fuel Type for Meat Packing Plants in 1991.

Source: Energy Information Administration (1994)

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)
2011	*Meat Packing Plants*								
Total Inputs		49	3410	170	252	31	157	27	2
Boiler Fuel		-	30	169	56	21	91	27	-
Total Process Uses		-	2858	c	31	6	47	0	-
	Process Heating	-	a	0	19	5	44	0	-
	Process Cooling and Refrig.	-	1749	0	b	c	1	0	-
	Machine Drive	-	1039	c	1	c	2	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	a	0	c	c	0	0	-
Total Non-Process Uses		-	403	c	132	3	10	0	-
	Heat, Ventilation, Air-Cond.	-	169	c	b	2	3	0	-
	Lighting	-	195	-	-	-	-	-	-
	Support	-	37	0	c	c	b	0	-
	Onsite Transportation	-	2	-	131	c	5	-	-
	Conventional Elect. Gen.	-	-	0	c	1	0	0	-
	Other	-	0	0	c	0	0	0	-
End-Use Not Reported		3	148	-	33	c	8	0	2

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A11. End-Use by Fuel Type for Canned Fruits and Vegetables in 1991.

Source: Energy Information Administration (1994)

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)
2033	*Canned Fruits and Vegetables*								
Total Inputs		44	1375	290	131	35	124	b	c
Boiler Fuel		-	23	289	b	28	c	b	-
Total Process Uses		-	1053	c	7	2	4	0	-
	Process Heating	-	27	0	0	1	c	0	-
	Process Cooling and Refrig.	-	236	0	c	c	c	0	-
	Machine Drive	-	785	c	7	c	4	0	-
	Electro-Chem. Processes	-	1	-	-	-	-	-	-
	Other	-	4	0	0	c	0	0	-
Total Non-Process Uses		-	249	0	70	4	118	0	-
	Heat, Ventilation, Air-Cond.	-	84	0	2	1	16	0	-
	Lighting	-	123	-	-	-	-	-	-
	Support	-	32	0	c	c	c	0	-
	Onsite Transportation	-	9	-	a	0	102	-	-
	Conventional Elect. Gen.	-	-	0	a	3	0	0	-
	Other	-	2	0	c	0	0	0	-
End-Use Not Reported		2	73	b	9	2	1	0	c

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A12. End-Use by Fuel Type for Frozen Fruits and Vegetables in 1991.

Source: Energy Information Administration (1994)

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)
2037	*Frozen Fruits and Vegetables*								
Total Inputs		40	3071	321	76	25	41	0	1
Boiler Fuel		-	248	259	28	17	7	0	-
Total Process Uses		-	2313	62	b	4	1	0	-
	Process Heating	-	150	62	3	4	c	0	-
	Process Cooling and Refrig.	-	1438	0	0	c	0	0	-
	Machine Drive	-	716	0	b	c	1	0	-
	Electro-Chem. Processes	-	2	-	-	-	-	-	-
	Other	-	7	0	0	c	0	0	-
Total Non-Process Uses		-	357	0	30	2	32	0	-
	Heat, Ventilation, Air-Cond.	-	157	0	b	1	c	0	-
	Lighting	-	167	-	-	-	-	-	-
	Support	-	25	0	0	c	c	0	-
	Onsite Transportation	-	9	-	24	0	31	-	-
	Conventional Elect. Gen.	-	-	0	3	1	0	0	-
	Other	-	1	0	2	0	0	0	-
End-Use Not Reported		3	401	c	b	2	1	0	1

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A13. End-Use by Fuel Type for Wet Corn Milling in 1991.

Source: Energy Information Administration (1994)

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)
2046	*Wet Corn Milling*								
Total Inputs		140	4054	29	30	51	1	3051	6
Boiler Fuel		-	142	29	a	25	0	a	-
Total Process Uses		-	3783	0	a	24	c	a	-
	Process Heating	-	a	0	a	24	0	a	-
	Process Cooling and Refrig.	-	29	0	0	0	0	0	-
	Machine Drive	-	3721	0	c	0	c	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	a	0	0	0	0	0	-
Total Non-Process Uses		-	129	0	3	1	1	a	-
	Heat, Ventilation, Air-Cond.	-	51	0	c	c	c	0	-
	Lighting	-	53	-	-	-	-	-	-
	Support	-	a	0	0	c	c	0	-
	Onsite Transportation	-	1	-	3	0	c	-	-
	Conventional Elect. Gen.	-	-	0	c	1	0	a	-
	Other	-	a	0	c	0	0	0	-
End-Use Not Reported		7	142	0	0	1	c	0	6

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A14. End-Use by Fuel Type for Bread, Cake and Related Products in 1991.

Source: Energy Information Administration (1994)

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)
2051	*Bread, Cake and Related Products*								
Total Inputs		32	2240	c	131	22	23	0	c
Boiler Fuel		-	38	c	41	5	3	0	-
Total Process Uses		-	1577	0	44	14	10	0	-
	Process Heating	-	143	0	a	13	10	0	-
	Process Cooling and Refrig.	-	415	0	0	c	0	0	-
	Machine Drive	-	1017	0	c	c	c	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	2	0	a	c	c	0	-
Total Non-Process Uses		-	521	0	38	2	9	0	-
	Heat, Ventilation, Air-Cond.	-	207	0	a	2	3	0	-
	Lighting	-	241	-	-	-	-	-	-
	Support	-	51	0	c	c	c	0	-
	Onsite Transportation	-	b	-	20	c	6	-	-
	Conventional Elect. Gen.	-	-	0	a	c	c	0	-
	Other	-	5	0	c	c	0	0	-
End-Use Not Reported		2	141	0	9	1	2	0	c

a =	Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b =	Witheld 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.

Table A15. End-Use by Fuel Type for Beet Sugar in 1991.
Source: Energy Information Administration (1994)

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)
2063	*Beet Sugar*								
Total Inputs		67	386	a	30	18	5	1901	a
Boiler Fuel		-	7	a	a	12	0	1590	-
Total Process Uses		-	343	140	a	6	1	311	-
	Process Heating	-	3	140	c	6	c	311	-
	Process Cooling and Refrig.	-	c	0	0	0	0	0	-
	Machine Drive	-	339	0	a	c	1	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	0	0	0	0	0	0	-
Total Non-Process Uses		-	36	a	23	c	5	0	-
	Heat, Ventilation, Air-Cond.	-	12	a	0	c	1	0	-
	Lighting	-	20	-	-	-	-	-	-
	Support	-	4	0	0	c	1	0	-
	Onsite Transportation	-	c	-	23	0	2	-	-
	Conventional Elect. Gen.	-	-	0	0	0	0	0	-
	Other	-	0	0	0	0	c	0	-
End-Use Not Reported		a	7	0	c	0	c	0	a

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A16. End-Use by Fuel Type for Soybean Oil Mills in 1991.

Source: Energy Information Administration (1994)

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)
2075	*Soybean Oil Mills*								
Total Inputs		50	1616	42	31	24	5	592	7
Boiler Fuel		-	111	42	a	17	c	592	-
Total Process Uses		-	1388	c	a	5	2	0	-
	Process Heating	-	22	0	a	5	2	0	-
	Process Cooling and Refrig.	-	23	0	0	0	0	0	-
	Machine Drive	-	1342	c	c	0	c	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	0	0	0	c	c	0	-
Total Non-Process Uses		-	96	c	8	1	3	0	-
	Heat, Ventilation, Air-Cond.	-	43	0	0	c	0	0	-
	Lighting	-	46	-	-	-	-	-	-
	Support	-	6	0	c	c	0	0	-
	Onsite Transportation	-	c	-	8	0	3	-	-
	Conventional Elect. Gen.	-	-	0	c	1	0	0	-
	Other	-	0	c	0	0	0	0	-
End-Use Not Reported		7	133	0	c	0	c	0	7

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.

Table A17. End-Use by Fuel Type for Malt Beverages in 1991.

Source: Energy Information Administration (1994)

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)
2082	*Malt Beverages*								
Total Inputs		50	2328	419	58	22	8	706	1
Boiler Fuel		-	33	417	a	20	c	706	-
Total Process Uses		-	1772	0	c	1	0	0	-
	Process Heating	-	67	0	0	1	0	0	-
	Process Cooling and Refrig.	-	769	0	0	c	0	0	-
	Machine Drive	-	935	0	c	0	0	0	-
	Electro-Chem. Processes	-	0	-	-	-	-	-	-
	Other	-	0	0	0	0	0	0	-
Total Non-Process Uses		-	460	2	a	c	a	1	-
	Heat, Ventilation, Air-Cond.	-	172	2	0	c	a	1	-
	Lighting	-	193	-	-	-	-	-	-
	Support	-	60	0	c	0	0	0	-
	Onsite Transportation	-	34	-	a	0	4	-	-
	Conventional Elect. Gen.	-	-	0	0	0	0	0	-
	Other	-	0	0	0	0	0	0	-
End-Use Not Reported		1	97	0	c	c	a	0	1

a = Witheld to avoid disclosing data for individual establishments. Data are included in totals.
b = Witheld 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.