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ENERGY CONSUMPTION:

PAPER, STONE/CLAY/GLASS/CONCRETE, AND FOOD INDUSTRIES

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by

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SECTION I

CONCLUSIONS

Energy consumption within the paper industry is concentrated in wood digestion (cooking), evaporation, furnace combustion, drying and kiln operations. The kiln operation is the primary energy consumer in the cementmaking process, while glass melting dominates energy consumption in the glassmaking process. The food industry consumes major amounts of energy in cooking, refrigeration, and drying operations. Losses in all of these operations can be decreased by employing conservation techniques. These techniques include:

- Design modifications to increase waste heat recovery from furnaces and kilns.
- Proper maintenance practices, especially with regard to insulation to limit heat losses.
- Greater use of insulation to limit heat losses.
- Research and development to improve press drying of paper, to increase yields of products and to develop submerged combustion for heating glass.
- Waste utilization by the recycle of paper and by the use of process wastes to fuel furnaces in the paper process.
- Process integration to optimize co-production of electricity and steam in the paper process and food processes.
- Process integration by increased combination of pulp and papermaking in one plant to eliminate pulp drying in pulp mills.
- Process modification such as substituting the dry process for the wet process in cementmaking, enriching of combustion air with oxygen in the glass melting operation and using agglomerated feed in the glassmaking process.

SECTION II

RECOMMENDATIONS

Energy conservation approaches suggested in this report could be further defined and specified in more detail. Unanswered questions which should be considered include:

- The economic feasibility of the conservation approaches.

- The difficulty of implementing the approaches.

SECTION III

INTRODUCTION

Purpose

The purpose of the total task is to provide a breakdown of energy consumption within the six primary industrial categories - primary metals, chemicals, petroleum, food, paper, and stone, clay, glass, concrete. The purpose of this portion of the total task covered by this report is to provide a breakdown of energy consumption within the paper, food, and stone, clay, glass, concrete industries only. This breakdown can give direction to subsequent conservation efforts.

Scope

This report analyzes high energy consumption operations within the paper (SIC 26) and the stone, clay, glass, concrete (SIC 32) industries. The principal pieces of energy intensive equipment used in these operations are identified. The causes of energy losses in these operations, the approximate magnitude of the losses, and possible approaches to decrease these losses are indicated. The analysis of the food (SIC 20) industry is more qualitative and does not include quantitative estimates of energy losses.

General Background

The National Academy of Engineering has been commissioned by the Environmental Protection Agency to conduct a comprehensive assessment of the current status and future prospects of sulfur oxides control methods and strategies. The agreement between the Environmental Protection Agency and the National Academy of Engineering states explicitly that special data collection projects may be required to provide the National Academy of Engineering panel with the background necessary for viewing all aspects of the problem in perspective. This report is one segment of the data collection project associated with the National Academy of Engineering assessment.

One method of limiting the amount of SO_x emissions arising from energy conversion is simply to decrease fuel use through energy conservation. In the year 1968, it has been reported that 41.2 percent of the total energy consumption in the United States was in the industrial sector.

More specifically, 28 percent of the national energy consumption was in the six industrial categories encompassed by this total task. Conservation efforts directed toward industries in these six categories should obtain the greatest impact.

General Approach

The major processes for producing paper, cement and glass were reviewed. Energy consumption block diagrams were drawn for each process. These diagrams indicate the operations within the processes where large amounts of energy are used. The approximate magnitudes and types of energy used are shown. Schematic diagrams show the physical and operational appearance of energy intensive equipment. Causes of energy losses in the energy intensive operations, the approximate magnitude of the losses, and possible conservation approaches are suggested.

Ten processes for producing products in the food industry have also been analyzed. The analyses are similar to those described above, except that the schematic diagrams of energy intensive equipment and quantitative estimates of energy consumption by operation have been deleted.

SECTION IV

ENERGY CONSUMPTION WITHIN THE PAPER, STONE-CLAY-GLASS-CONCRETE AND FOOD INDUSTRIES

Several observations need to be made concerning the analyses of energy consumption included in this report:

- The type of energy used in each energy intensive operation is included on the process block diagrams. Different types of energy are not equivalent. Approximately 3 kJ's of fuel energy are required to generate 1 kJ of electrical energy. Approximately 1.1 to 1.3 kJ's of fuel energy are required to generate 1 kJ of steam energy.

- Energy values for all processes are expressed in terms of energy per unit weight of product.

- The tables showing energy conservation approaches give estimates of losses in each operation of the process and in the overall process. The losses listed in each operation are additive. The losses listed in the overall process often overlap and are not additive.

- The values for energy input and losses are derived from a variety of sources as listed in the bibliography. The values are representative of published technology. New plants may already use conservation approaches recommended in this report and thereby, use less energy than indicated in the figures. [An exception to this is the paper process, in which the estimated energy usage is believed to represent very modern technology.]

- Energy conservation approaches are listed in the tables. In many cases a more specific explanation of the recommended energy conservation approach is listed along with the approach. An explanation of the conservation approaches is included in the appendix for those instances where the meaning of the term may be vague.

A. Paper by the Sulfate or Kraft Process

The paper industrial category (SIC 26) consumed approximately 67000 MW (2000 x 10^{12} BTU)* of energy in 1973. Pulp mills (SIC 2611), paper mills (SIC 2621), and paperboard mills

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*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

(SIC 2631) accounted for approximately 90 percent of this energy usage. Paperboard mills are similar to paper mills. Therefore, this report analyzes energy consumption in SIC 26 by analyzing energy consumption in the pulp and paper-making processes.

Figure 1 shows the primary steps in the manufacture of unbleached paper or paperboard using the sulfate or Kraft process. Pulp and paper mill energy consumption is highly dependent on the product mix. The process in Figure 1 is a low energy process because bleaching and coating operations are not included. Furthermore, the energy inputs are representative of modern, well-operated plants.

Approximately 70 percent of the paper and paperboard manufactured in the United States is made using the sulfate process. The primary energy consumption operations are digestion (cooking) of wood chips, evaporation of water from the cooking liquor, calcining of wet $CaCO_3$ to lime, and drying of paper. These highly energy intensive heating operations account for more than 70 percent of the energy input into the sulfate process shown in Figure 1.

The major energy sources for the energy intensive heating operations are process wastes, natural gas and fuel oil. Most of this fuel produces high pressure steam, which is then used to produce electricity and lower pressure steam for the process operations. The electricity is used in a number of operations, including barking, chipping, pumping, screening, draining, pressing, drying and calendering (dry pressing).

Figure 2 shows digestion (cooking) of wood chips, partial separation of pulp from water in a blow tank, and pulp washing. The digestion operation occurs at a temperature of 450°K (350°F) and at a pressure of 1150 kN/m^2 (165 psia). Pre-steamed wood chips and cooking liquor (approximately 7 percent sodium hydroxide, 3 percent sodium sulfide and 2 percent sodium carbonate) are fed to the top of the digester. Recirculating cooking liquor passes through steam heaters to provide heat for this operation. As the wood chips pass down through the digester, the organic lignins which hold the cellulose fibers of the wood together, are dissolved into the cooking liquor. The resulting black liquor is removed at an intermediate point in the column. Wash water is fed to the bottom of the column to further the separation of the delignified wood chips from the black liquor. Wash water plus delignified wood chips are then fed to a blow tank at atmospheric pressure. The rapid drop in pressure breaks up or defiberizes the cellulose chips and reduces them to pulp. The pressure drop also allows steam to be flashed from the blow tank. Next the pulp plus water mixture is fed to a

Figure 1. Paper energy consumption diagram
[1973 USA production: 56.2 x 10^9 kg (123.8 x 10^9 lb)]
[1973 energy consumption (process wastes, natural gas, fuel oil, electricity): 67,000 MW (2000 x 10^{12} Btu)]

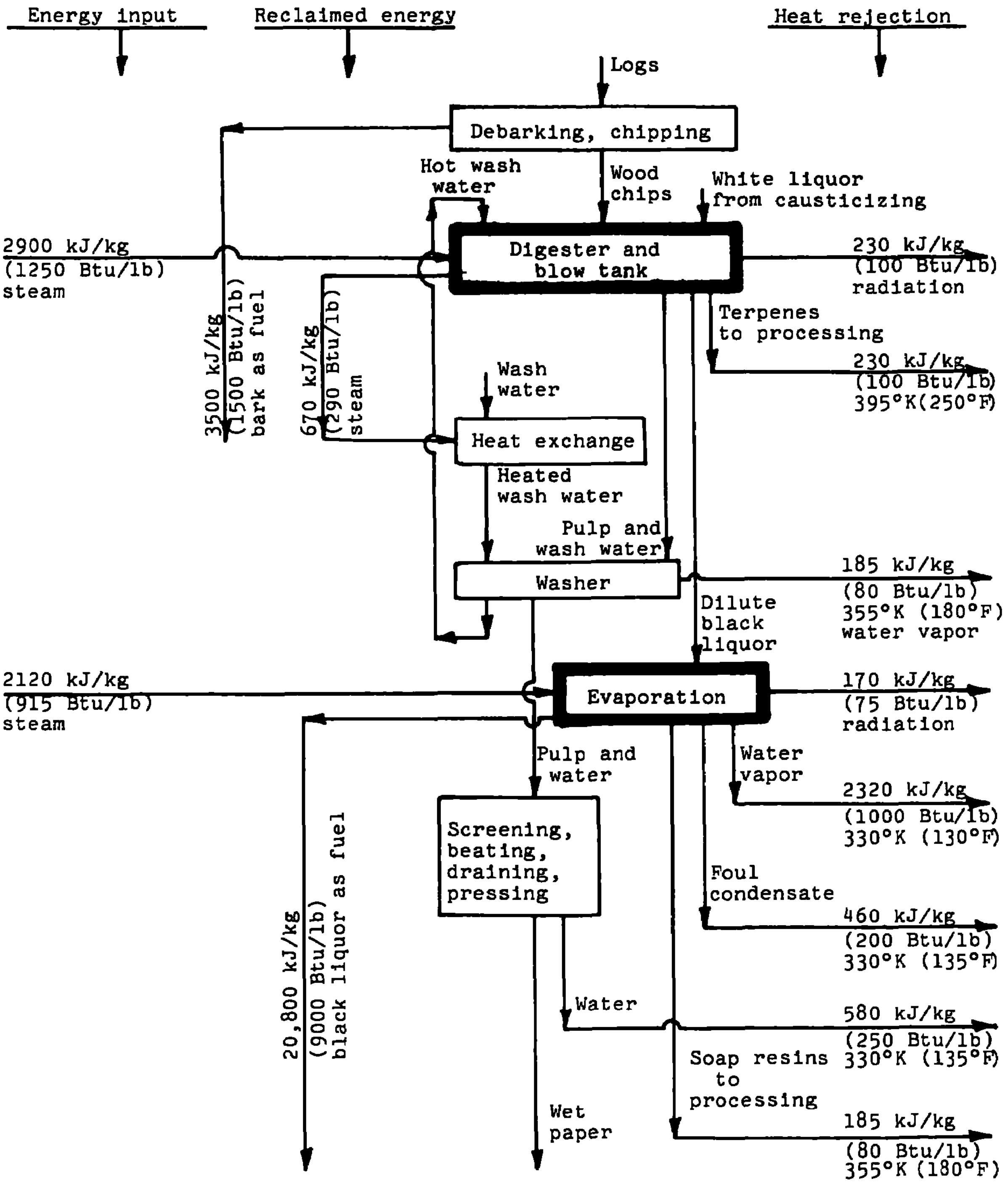

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Figure 1. (Continued)

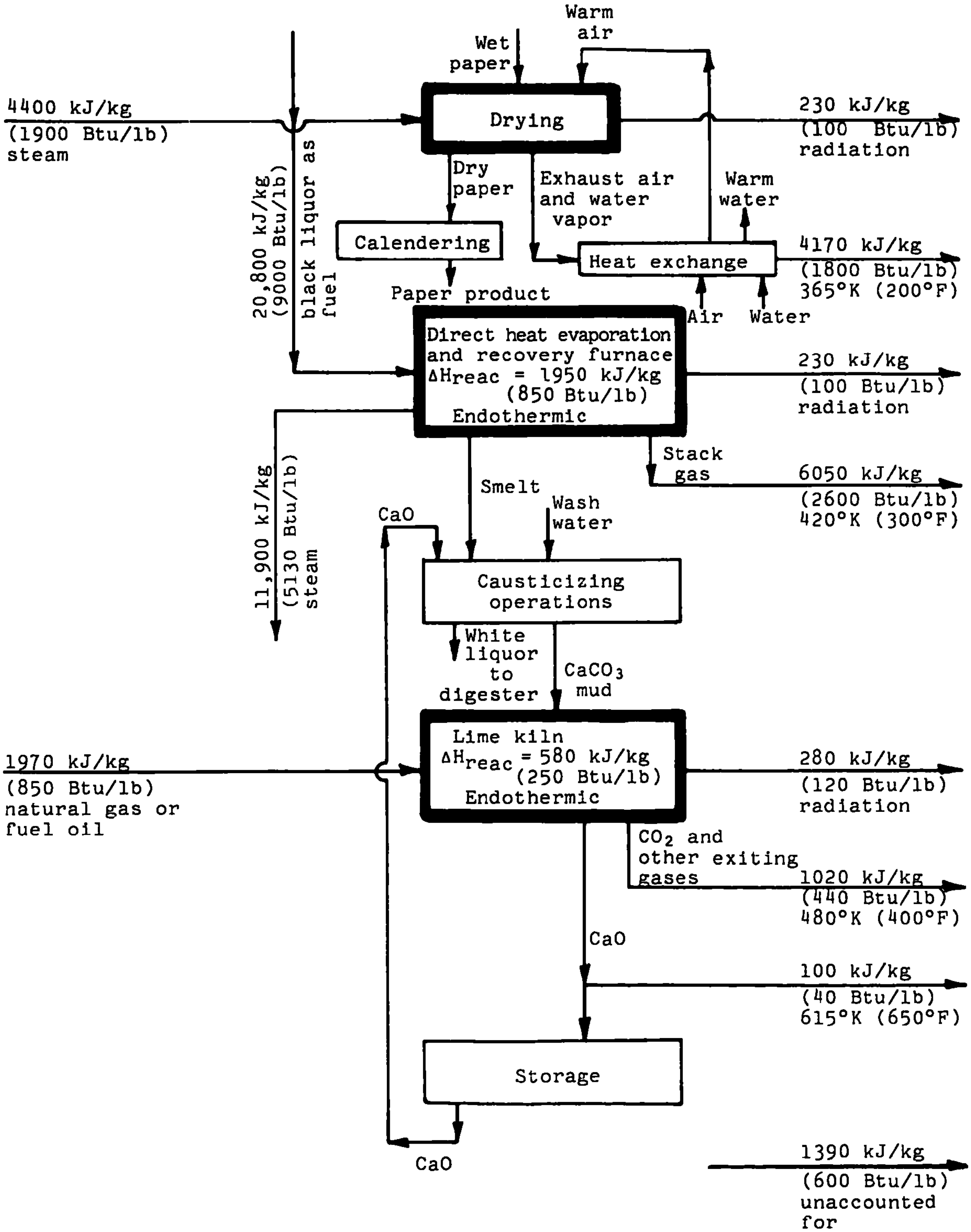
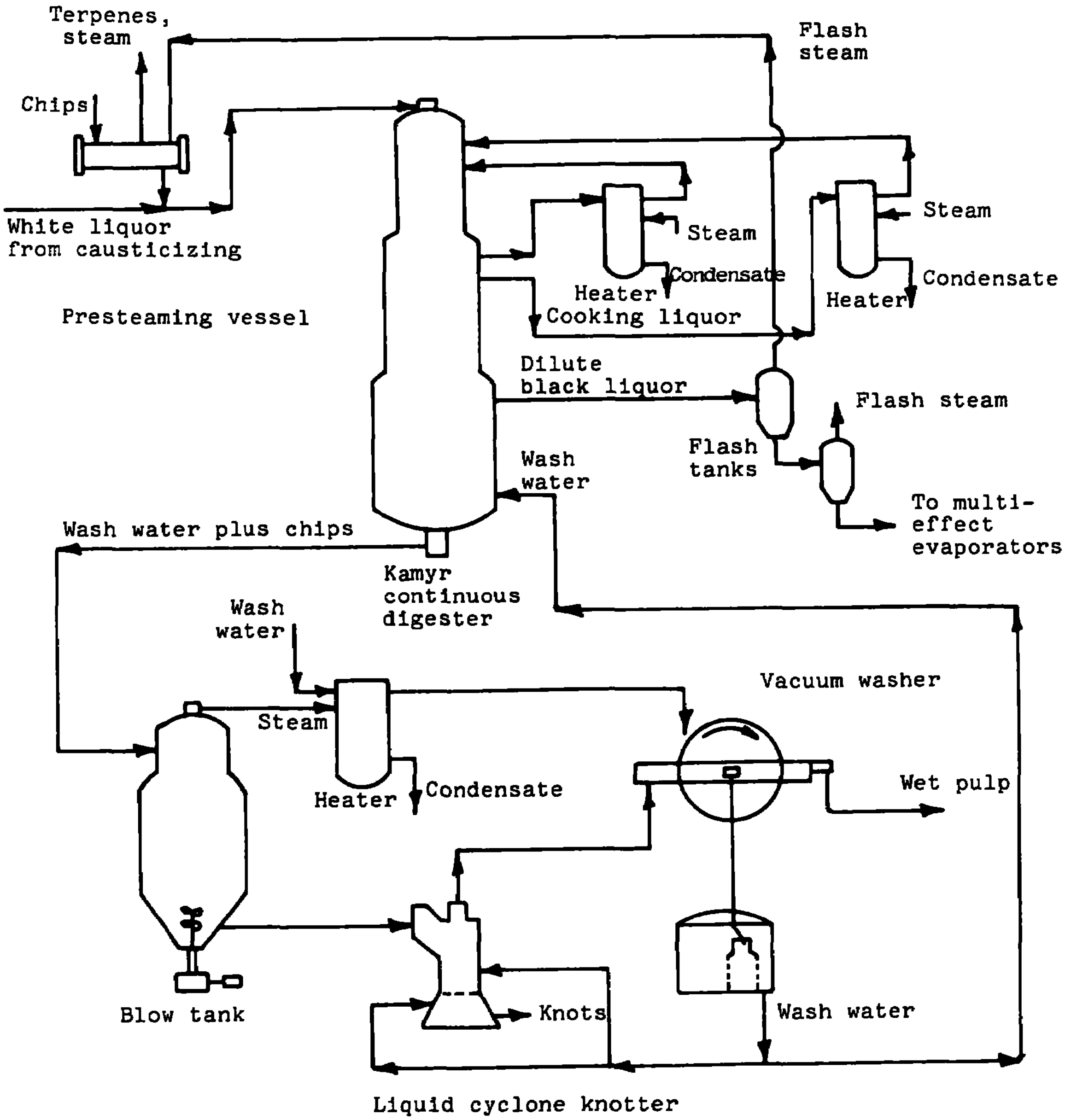


Figure 2. Paper energy intensive equipment diagram - digester, blow tank, and washer
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Terpenes stream - 230 kJ/kg (100 Btu/lb) at 395°K (250°F)
Water vapor off washer - 185 kJ/kg (80 Btu/lb) at 355°K (180°F)]



knotter (or prebreaker-knot breaker) where knots are separated from the pulp. Additional washing of the pulp removes cooking chemicals from the pulp. The wet pulp leaves the washer at a temperature of 350°K (180°F).

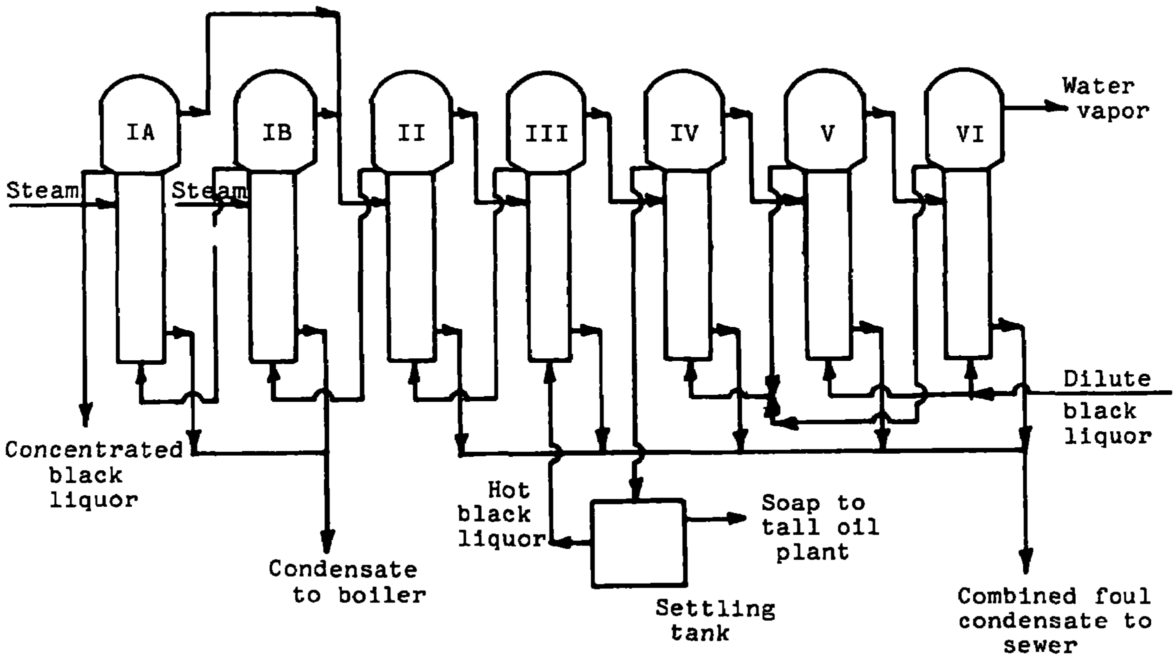
Figure 3 shows the concentrating of the dilute black liquor (∿15-20 percent solids) leaving the digester. Water is evaporated from the liquor in a multi-effect evaporation system until the solids concentration is approximately 50 percent. This step is necessary to allow later recovery of caustic and sulfide contained in the liquor and to allow the use of organics in the black liquor as fuel. In addition, as shown in the figure, soaps that are used to make tall oil are obtained in this processing step. Steam at a pressure of 240-550 kN/m^2 (35-80 psia) is used to provide heat for this operation.

Figure 4 shows additional concentrating of the black liquor to approximately 65 percent in a direct heat evaporator; combustion of the black liquor in a furnace; and reclaiming of caustic and sulfide in a dissolving tank. The burning of the oragnics in the black liquor supplies heat which is used to make high pressure steam. This steam is then used to produce electricity and process steam. Flue gases from the furnace are used to supply heat to the direct heat evaporator. Flue gases from the direct heat evaporator leave at 420°K (300°F). Approximately 10 percent of the heat produced in the furnace is used to reduce makeup sodium sulfate to sulfide in the bottom of the furnace.

Figure 5 shows a rotary kiln which is commonly used to produce lime from $CaCO_3$ mud. This mud is obtained when lime is added to the sodium sulfide, sodium carbonate solution from the recovery furnace. The kiln is operated at approximately 1370°K (2000°F). The lime kiln is shown with Warner-type, kiln mounted integral tube coolers. The coolers cool the product lime to 590-640°K (600-700°F) and preheat combustion air which is used to burn natural gas. Combustion gases leave the kiln at approximately 480°K (400°F).

Figure 6 shows a possible dryer scheme. Many different arrangements of dryers can be used. The dryer section consists of a number of hollow iron or steel cylinders over which the paper web passes in a serpentine fashion. The cylinders are rotated in synchronization. Heat is supplied by steam condensing inside the cylinders and usually the sheet is pressed tightly against the dryers by a heavy dryer felt. The prime purpose of the felt is to bring the sheet as close as possible to the dryer surface. The air film between sheet and dryer is reduced to a reasonable minimum so that maximum practical heat transfer to the sheet is

Figure 3. Paper energy intensive equipment diagram - multi-effect evaporation
[Rejected heat: Radiation - 170 kJ/kg (75 Btu/lb)
Water vapor - 2320 kJ/kg (1000 Btu/lb) at 330°K (130°F)
Foul condensate - 460 kJ/kg (200 Btu/lb) at 330°K (135°F)
Soap resins - 185 kJ/kg (80 Btu/lb) at 355°K (180°F)]



Sextuple-effect evaporation system

Figure 4. Paper energy intensive equipment diagram - direct heat evaporation and recovery furnace
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Stack gas - 6050 kJ/kg (2600 Btu/lb) at 420°K (300°F)]

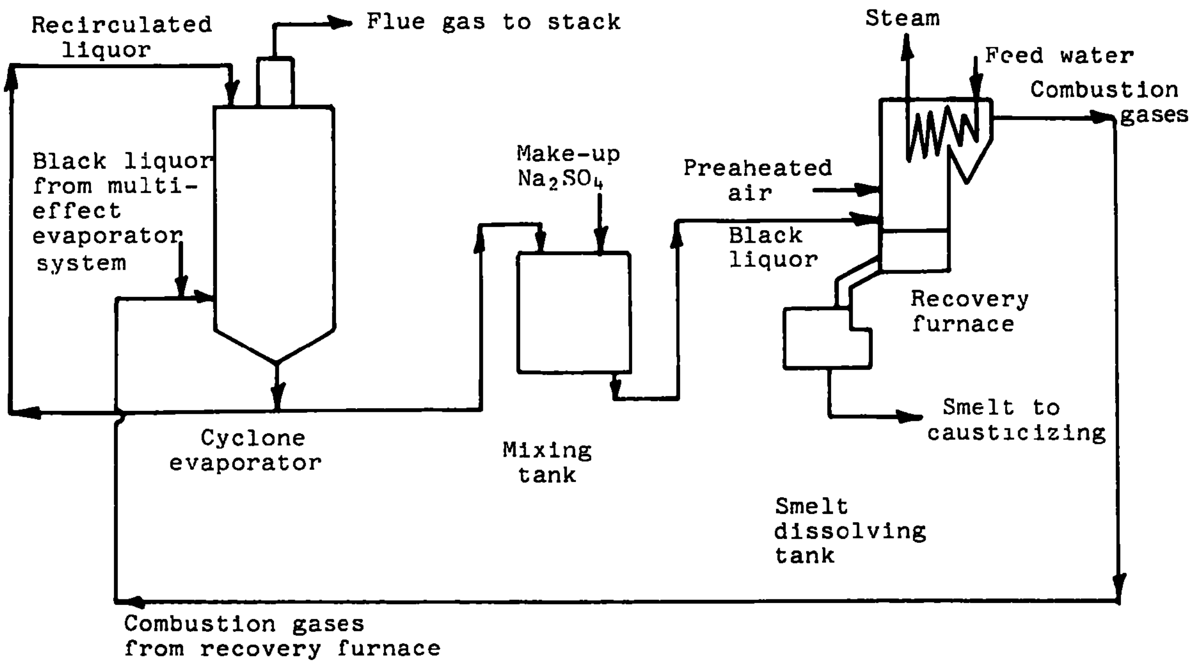
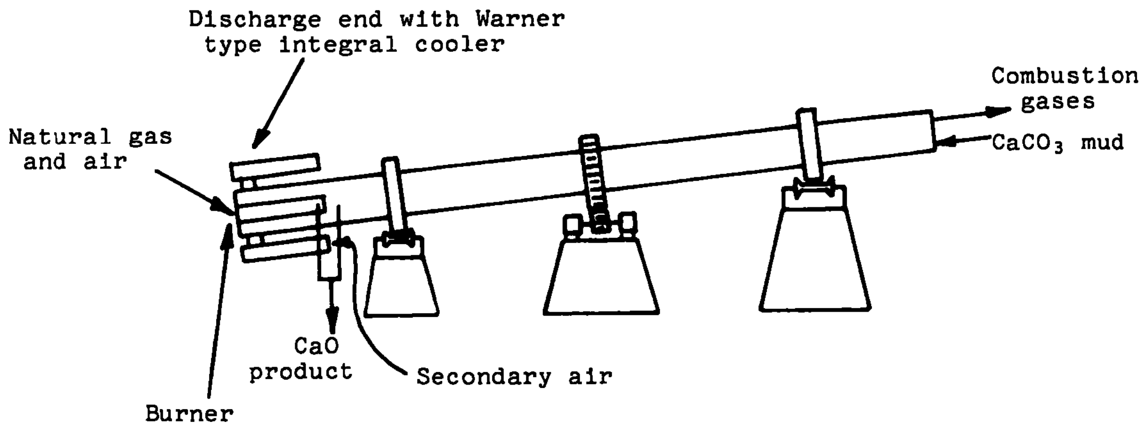
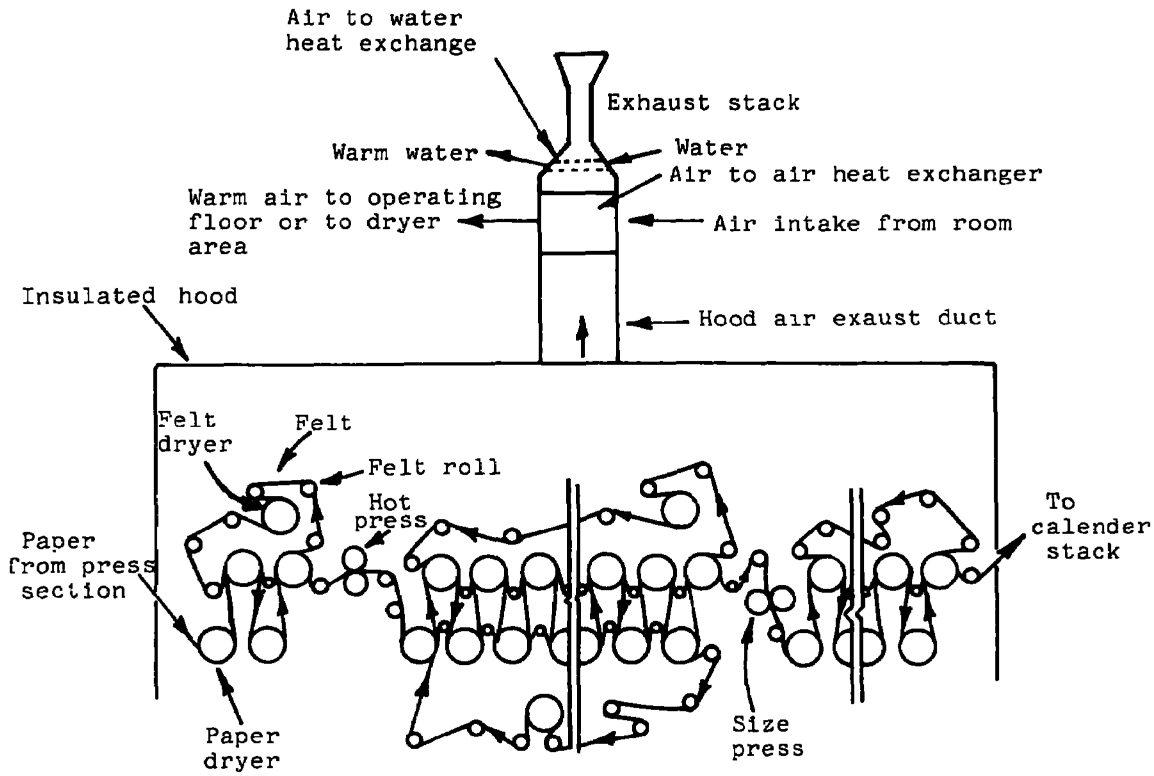


Figure 5. Paper energy intensive equipment diagram - calcining
[Rejected heat: Radiation - 280 kJ/kg (120 Btu/lb)
Combustion gases - 1020 kJ/kg (40 Btu/lb) at 480°K (400°F)
Hot product - 100 kJ/kg (40 Btu/lb) at 615°K (650°F)]



Lime kiln

Figure 6. Paper energy intensive equipment diagram - dryer
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Exhaust air plus water vapor - 4170 kJ/kg (1800 Btu/lb) at 365°K (200°F)]



Kraft dryer section

obtained. A reasonably large portion of the dryer is wrapped by the sheet, thus resulting in fairly good heat transfer while adequate ventilation is possible through fairly generous clear spaces throughout the dryer section. The paper entering the dryer can contain 1 to 3 kg water per kg paper.

Table 1 shows the causes of energy losses in the pulp and papermaking process. It also gives estimates of the size of the losses and some possible energy conservation approaches.

B. Cement by the Wet Process

The stone, clay, glass and concrete industrial category (SIC 32) consumed approximately 45000 MW (1350×10^{12} Btu) of energy in 1971. Processes for manufacturing cement and glass accounted for over 55 percent of this total. Because of their dominance of this category, processes for manufacturing these two materials are analyzed in this report.

Portland cement is the dominant product of industrial category 3241. In 1972 the energy consumption of this category was approximately 16000 MW (480×10^{12} Btu).* Energy consumed in portland cement manufacture accounted for over 95 percent of this quantity. Figure 7 shows the primary steps in the portland cement manufacturing process using the "wet process". In 1972 approximately 59 percent of the cement production in the United States came from this process. It consists of blending a calcareous (lime-bearing) material, an argillaceous (clayish) material and an iron containing material (iron ore) with water and grinding. The water content in the slurry is then reduced from 50 percent to 20-30 percent by letting the solids settle in a tank. The thickened slurry is then charged into a rotary kiln. As the slurry moves through the kiln, water is evaporated and then the endothermic reaction which releases CO_2 from the limestone occurs at 925°K (1200°F). Finally, at 1480°K (2200°F) complex silicates form in an exothermic reaction which raises the cement temperature to 1750-1810°K (2700-2800°F). The charge leaves the kiln in the form of "clinker", marble size particles produced by melting of portions of the charge. The clinker is aircooled by preheating combustion air, combined with gypsum (2-3 percent gypsum) and ground to a fine powder. Approximately 85-90 percent of the total energy required for this process is used in the kiln operation*. Natural gas, coal or oil can be used as the fuel.

Figure 8 shows the kiln operation. The energy usage in a cement kiln is dependent on a number of factors and can range

*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

Table 1. PAPER ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
1. Digestion of wood chips		
a. Radiation & convection	230 kJ/kg (100 Btu/lb)	Insulation Maintenance
b. Heat in terpenes stream	230 kJ/kg (100 Btu/lb)	Design modification (waste heat recovery)
c. Vaporization of water in washer	185 kJ/kg (80 Btu/lb)	-------------
2. Multi-effect evaporation		
a. Radiation & convection	170 kJ/kg (75 Btu/lb)	Insulation Maintenance
b. Heat in foul condensate	460 kJ/kg (200 Btu/lb)	Design modification (waste heat recovery)
c. Heat in water vapor leaving last evaporator	2320 kJ/kg (1000 Btu/lb)	Design modification (consider additional effect)
d. Heat in soap resins	185 kJ/kg (80 Btu/lb)	-------------
3. Direct heat evaporation & recovery furnace		
a. Radiation & convection	230 kJ/kg (100 Btu/lb)	Insulation Maintenance
b. Heat in flue gas	6050 kJ/kg (2600 Btu/lb)	Design modification (waste heat recovery)
4. Calcination		
a. Radiation & convection	280 kJ/kg (120 Btu/lb)	Insulation Design modification housing of kiln)
b. Heat in exiting combustion gases	1020 kJ/kg (440 Btu/lb)	Design modification (waste heat recovery) (reduce water content in kiln feed)
c. Heat in exiting product	100 kJ/kg (40 Btu/lb)	Design modification (waste heat recovery)

Table 1. (continued)

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
5. Paper drying		
a. Radiation & conduction through hood	230 kJ/kg (100 Btu/lb)	Insulation
b. Heat in hood exhaust gas	4170 kJ/kg (1800 Btu/lb)	Design modification (waste heat recovery)
6. Overall process		
a. Drying of pulp in some pulp mills	-------	Process integration (integrate pulp & paper production)
b. Unnecessary bleaching of pulp in some cases	-------	Market modification
c. High degree of wetness of paper leaving presses	4400 kJ/kg (1900 Btu/lb)	Research & development (improve drying efficiency of presses)
d. Low yield of paper from wood	-------	Research & development
e. Overdrying of paper	-------	Operation modification
f. Lack of paper recycling	10,000 kJ/kg (4000 Btu/lb)	Waste utilization
g. Inefficient evaporation of water in direct heat evaporator	460 kJ/kg (200 Btu/lb)	Design modification (replace direct heat evaporator with additional effect in multi-effect evaporation system)

Figure 7. Cement (wet process) energy consumption diagram
[1972 USA production: 73 x 10^9 kg (160 x 10^9 lb)]
[1972 USA energy consumption (natural gas, coal, oil, electricity): 16,000 MW (480 x 10^{12} Btu)]

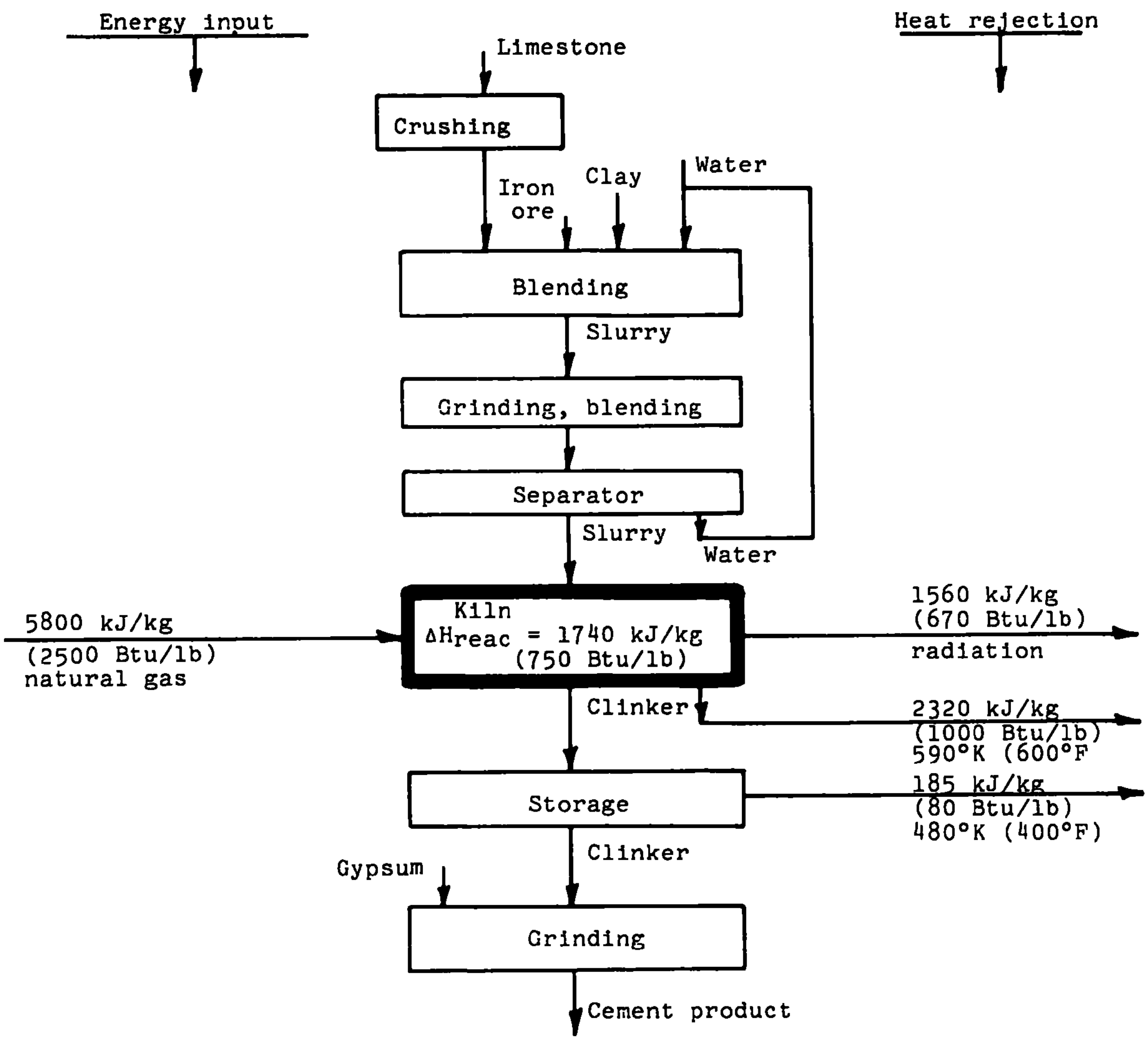
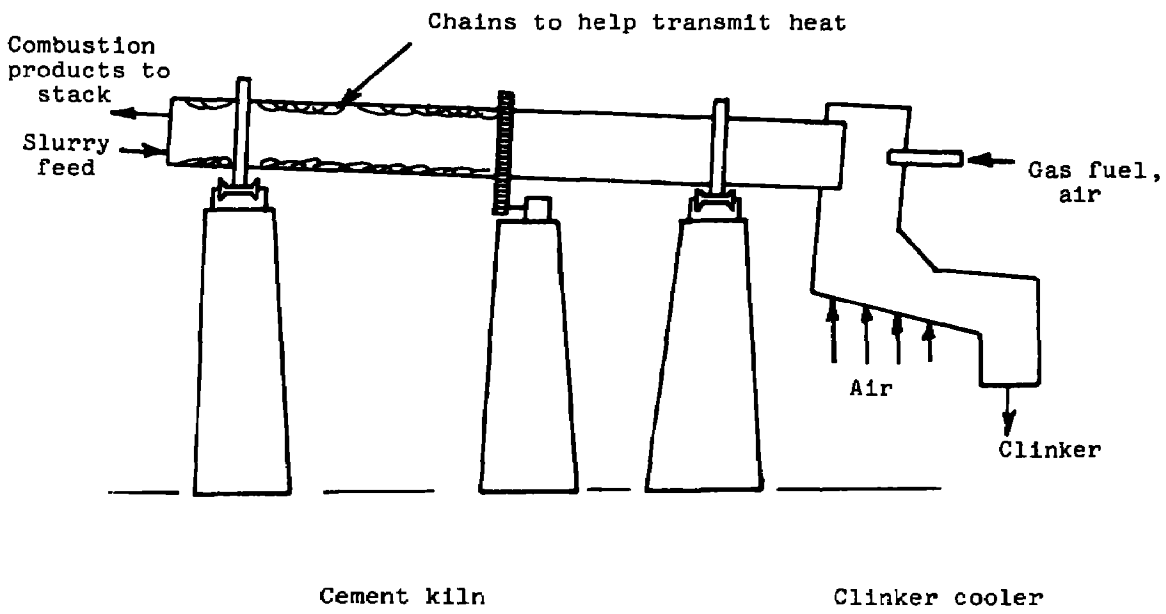


Figure 8. Cement (wet process) energy intensive equipment diagram - cement kiln
[Rejected heat: Radiation - 1560 kJ/kg (670 Btu/lb)
Exit gases - 2320 kJ/kg (1000 Btu/lb) at 590°K (600°F)
Clinker - 185 kJ/kg (80 Btu/lb) at 480°K (400°F)]



from 3250 to 11600 kJ/kg (1400 to 5000 Btu/lb). The value chosen for this report is an intermediate one of 5800 kJ/kg (2500 Btu/lb). Feed preheaters which use the heat available in exiting combustion gases are used on recently built cement kilns to decrease energy consumption.

Table 2 shows the causes of energy losses in the cement manufacturing process. It also gives estimates of the size of the losses and some possible energy conservation approaches.

C. Glass Manufacture

Three major glass industrial categories (3211 or flat glass, 3221 or glass containers, 3229 or pressed and blown glass and glassware) are large consumers of energy because each category includes glass melting as a part of the process. These three groups consumed 9200 MW (275 x 10^{12} Btu)* in 1971. Natural gas was the primary energy source.

Figure 9 shows the major steps in the glassmaking process. The primary energy consumption step whether the final product is a container, flat glass, or blown glass is the melting of the raw materials. Approximately 70-80 percent of the total energy consumed in the glass manufacturing process is expended in this operation.

Figure 10 shows a melting operation in a continuous glass tank. Usually these tanks are rectangular and are divided into two compartments, a large melting compartment and a smaller cooling or refining compartment. A crown above the tank walls provides a space for combustion. Regenerators economize fuel by recovering heat from the flue gas before it passes to the stack. The temperature in the melting compartment of the glass tank is 1770°K (2730°F).

Table 3 shows the causes of energy losses in the glass melting operation. It also lists the approximate magnitude of the losses and possible energy conservation approaches.

D. Food Processes

The analysis of energy consumption within the food industrial category (SIC 20) is not as quantitative as the analyses of the other industrial categories. One reason for this is the difficulty in covering such a diverse industry in a short time. Equally important is the lack of information on energy consumption by operation. This lack is probably due to the minor importance of energy costs in most food processes.

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*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

Table 2. CEMENT ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
1. Kiln		
a. Radiation & convection	1560 kJ/kg (670 Btu/lb)	Maintenance Insulation
b. Heat in exiting gases	2320 kJ/kg (1000 Btu/lb)	Design modification (Increase use of feed preheaters)
c. Heat in exiting product	185 kJ/kg (80 Btu/lb	Design modification (waste heat recovery)
2. Overall Process		
Evaporation of water in kiln	1160 kJ/kg (500 Btu/lb)	Process modification (substitute dry process for wet)

Figure 9. Glass energy consumption diagram
[1971 USA production: 16 x 10^9 kg (34 x 10^9 lb)]
[1971 USA energy consumption (primarily natural gas, electricity): 9200 MW (275 x 10^{12} Btu)]

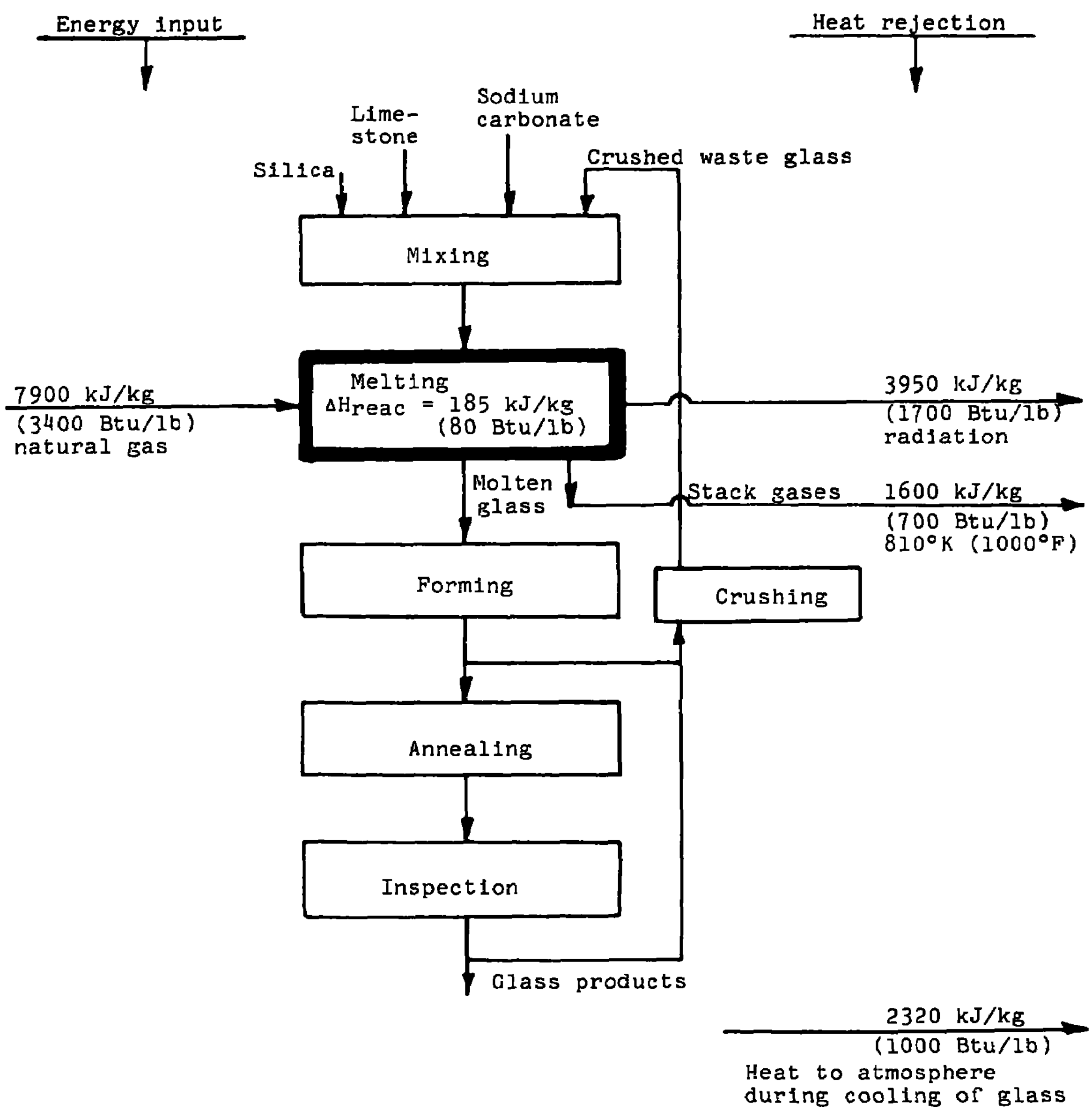


Figure 10. Glass energy intensive equipment diagram - melting furnace [Rejected heat: Radiation - 3950 kJ/kg (1700 Btu/lb) Stack gases - 1600 kJ/kg (700 Btu/lb) at 810°K (1000°F)]

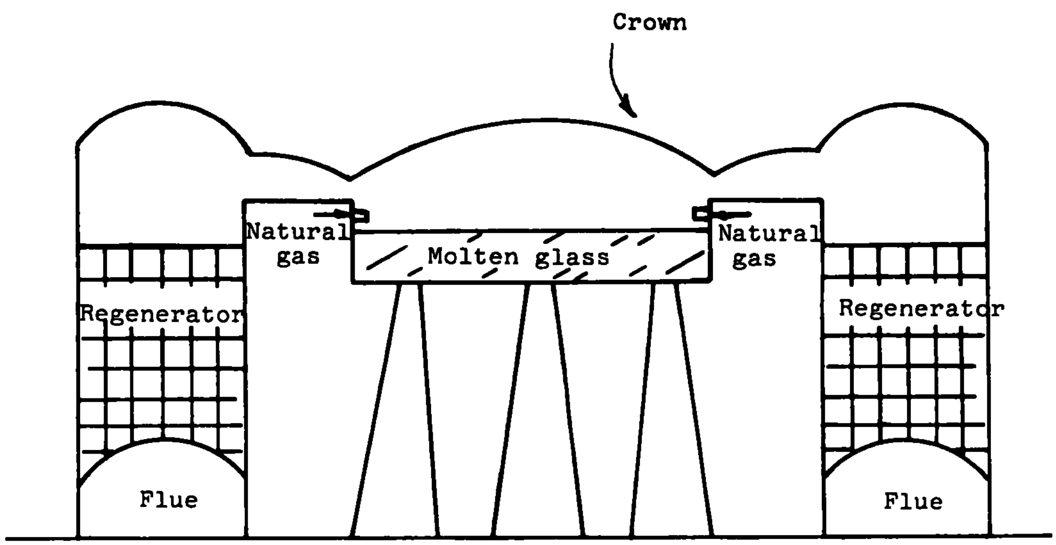


Table 3. GLASS ENERGY CONSERVATION APPROACHES

Causes of energy losses		Approximate magnitude of losses	Energy conservation approaches
1. Glass melting			
	a. Radiation & convection	3950 kJ/kg (1700 Btu/lb)	Maintenance Insulation Research & development (submerged combustion)
	b. Heat in stack gases	1600 kJ/kg (700 Btu/lb)	Design modification (waste heat recovery)
2. Overall Process			
	a. Sensible heat in inerts (N_2) contained in combustion air	690 kJ/kg (300 Btu/lb)	Process modification (oxygen enrichment of combustion air)
	b. Difficulty in melting raw materials	920 kJ/kg (400 Btu/lb)	Process modification (use agglomerated feed)
	c. Cooling of glass with no heat recovery	2320 kJ/kg (1000 Btu/lb)	------------

In 1971 the approximate energy consumption for the food category was 30,000 MW (900 x 10^{12} Btu)*. This report covers processes which account for approximately 50 percent of this total.

The meatpacking industrial category (SIC 2011) is the largest energy consumer within the food category. The total energy usage by this category in 1971 was approximately 2800 MW (85 x 10^{12} Btu)*. The primary sources of energy were natural gas and electricity. The energy usage can be conveniently split into three major groups:

- beef slaughter - approximately 840 MW (25 x 10^{12}Btu)*
- other slaughter - approximately 1000 MW (30 x 10^{12}Btu)*
- meat processing- approximately 1000 MW (30 x 10^{12}Btu)*

Figure 11 shows the major steps in a beef slaughter process. This process is not especially energy intensive and energy requirements vary widely depending on the extent of the by-product processing. The primary energy consumption steps in the process shown are refrigeration of products and rendering (converting into fats, oils, and proteinaceous solids) of by-products.

Figure 12 shows the major steps in pork processing. The total energy consumption shown for 1971 includes both pork processed under the 2011 industrial category (meatpacking) and the 2013 industrial category (sausages and other prepared meat products). The energy intensive steps include cooking/smoking and refrigeration of the products.

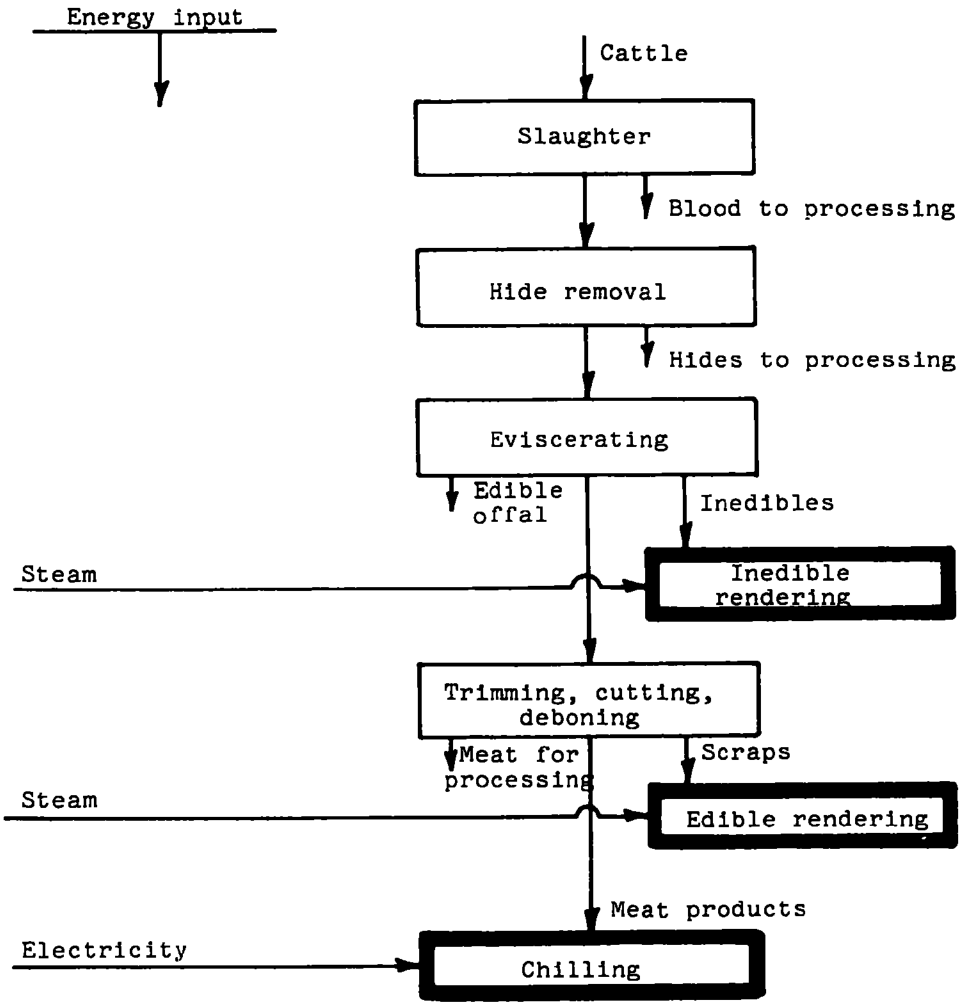
Table 4 lists causes of energy losses in beef slaughtering and pork processing. It also lists possible energy conservation approaches for these processes.

The fluid milk industrial category (SIC 2026) includes bulk fluid products, packaged fluid milk, cottage cheese, buttermilk, flavored milk drinks and a number of other minor products. The total energy usage by this category in 1971 was approximately 1900 MW (58 x 10^{12} Btu)*. Bulk and packaged fluid milk comprise by far the largest volume of production although the process for producing them is not energy intensive.

Figure 13 shows the major steps in the fluid milk process. This process accounts for approximately 20 percent of the total energy consumption in this industrial category. Milk and cream are usually separated in a centrifugal clarifier, pasteurized at a temperature of 336-345°K (145-162°F) [pasteurization at 345°K for 16 seconds is more efficient than at

*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

Figure 11. Meat packing (beef slaughter) energy consumption diagram [1971 USA production (beef): 8.2 x 10^9 kg (18.1 x 10^9 lb)] [1971 energy (primarily natural gas,* electricity): 840 MW (25 x 10^{12} Btu)]



* Natural gas is used for steam generation.

Figure 12. Meat (pork) processing energy consumption diagram
[1971 USA production: 1.9×10^9 kg (4.1×10^9 lb)]
[1971 energy consumption (primarily natural gas, electricity): 1100 MW (33×10^{12} Btu)]

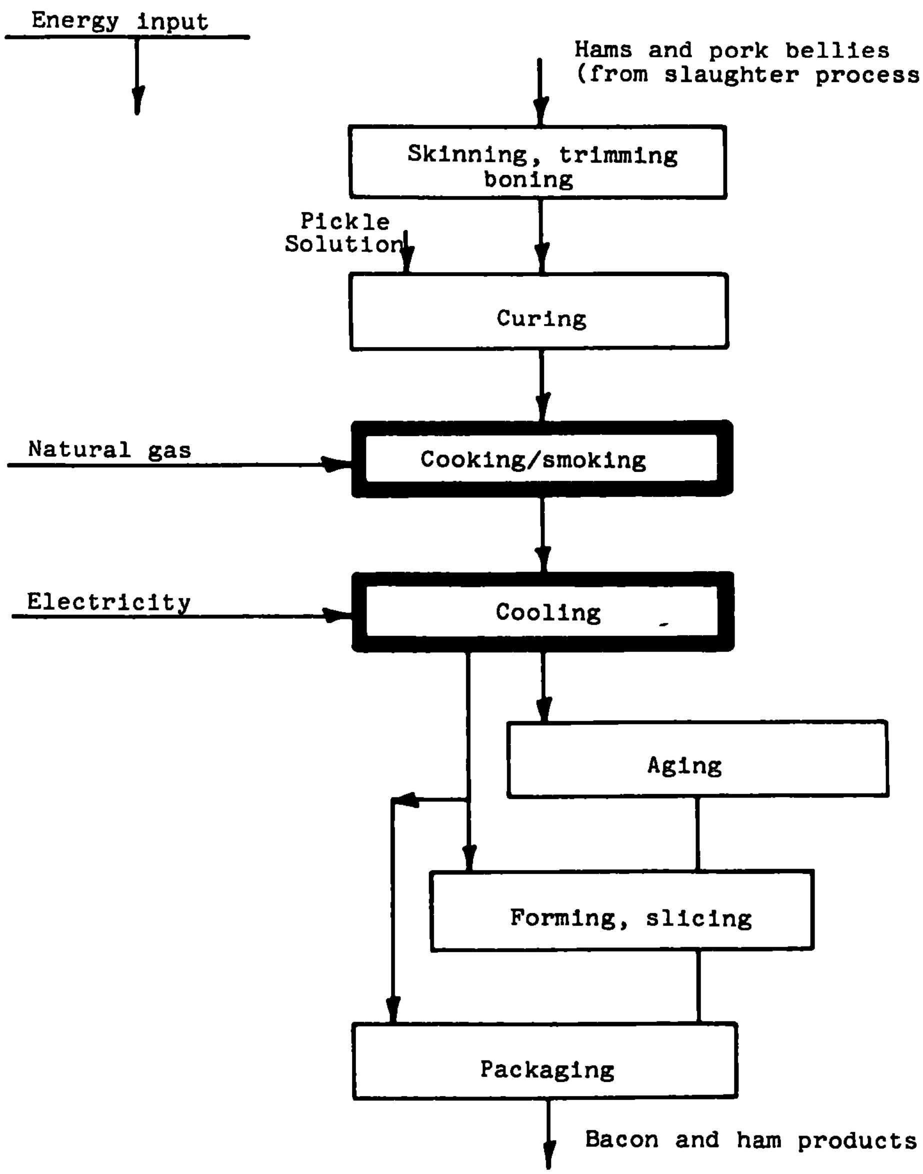
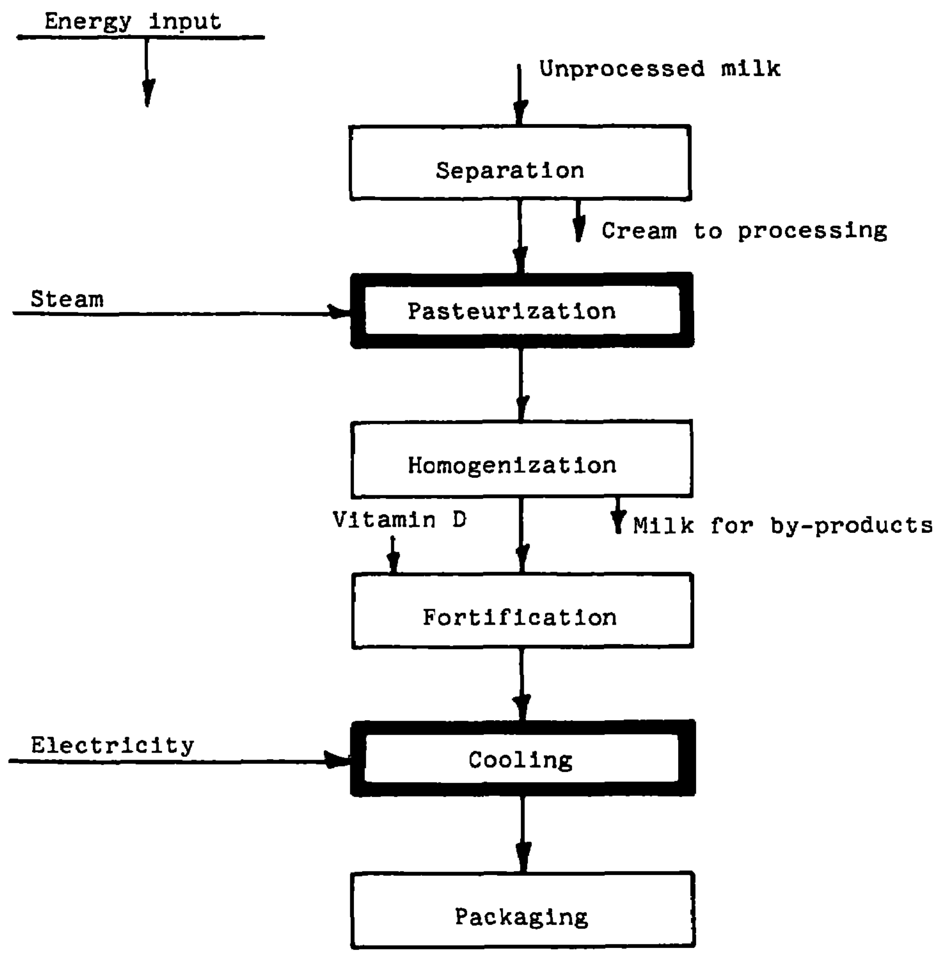


Table 4. BEEF SLAUGHTER AND PORK PROCESSING ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Cooling	
Conduction and convection	Insulation Maintenance
2. Rendering (cooking)	
Radiation and convection	Insulation Maintenance
3. Cooking/smoking	
a. Heat in exhaust gases	Design modification (waste heat recovery)
b. Radiation & convection	Maintenance Insulation
4. Overall Process	
Unnecessary purchase of electricity from utilities	Process integration (consider co-production of electricity and steam)

Figure 13. Fluid milk energy consumption diagram
[1971 USA production: 23 x 10^9 kg (51 x 10^9 lb)]
[1971 energy consumption (primarily natural gas,* electricity): 400 MW (12 x 10^{12} Btu)]



* Natural gas is used for steam generation.

336°K for 30 minutes], and homogenized by pumping through a small orifice at high pressure (14,000 to 17,000 kN/m^2 or 2000-2500 psi). The milk is then fortified by the addition of vitamin D, cooled and packaged. The primary energy consumption steps are refrigeration after processing and heating for pasteurization.

Table 5 lists the causes of energy losses in the fluid milk process. It also lists possible energy conservation approaches.

The canned fruits and vegetables industrial category (SIC 2033) includes plants primarily engaged in the canning of fruits, vegetables, fruit juices and vegetable juices. It also includes manufacturers of catsup, other tomato sauces, preserves, jams and jellies. The total energy usage by this category in 1971 was approximately 18,000 MW (53×10^{12} Btu)*.

Figure 14 shows the major steps in a generalized canning process. All products do not go through all of the operations shown. Green vegetables generally go through the blanching operation where air is expelled when the vegetables are immersed in hot water or steam. Tomato products generally require cooking. Exhausting of carbon dioxide and oxygen from the cans is accomplished by passing the open cans through a hot water or steam bath. Sterilizing is usually done with steam under pressure at a temperature of 375-390°K (212-240°F). These four heating operations are the primary energy consuming steps in the canning industry. Natural gas is the main source of energy to generate steam for these operations.

Table 6 lists the causes of energy losses in the canned fruits and vegetables process. It also lists possible energy conservation approaches.

The frozen fruits and vegetables industry (SIC 2037) includes plants primarily engaged in the freezing of fruits, fruit juices, vegetables and specialties. The total energy usage by this category in 1971 was approximately 1300 MW (39×10^{12} Btu)*.

Figure 15 shows the major steps in a frozen vegetable process. Vegetables accounted for over 40 percent of the production in this category in 1971 but only 15-20 percent of the energy consumption. The primary energy consumption operations are the freezing plus cold storage of the product along with the blanching of the raw vegetables. Natural gas and electricity are the primary energy sources.

Table 7 lists the causes of energy losses in the frozen vegetable process. It also lists energy conservation approaches.

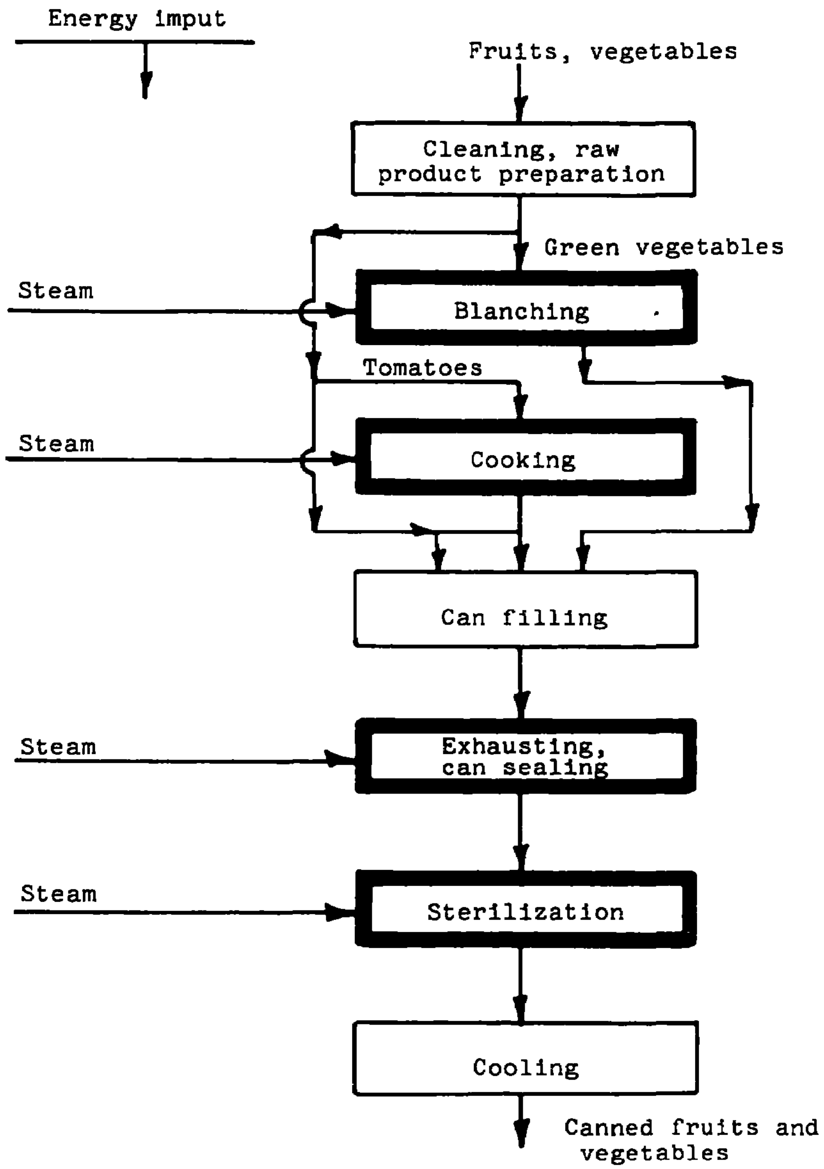
---

*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

Table 5. FLUID MILK ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Pasteurization	
Conduction & convection	Design modification (continue replacement of old type vat pasteurization equipment with high temperature-short time pasteurization equipment) Maintenance, Insulation
2. Cooling	
Conduction & convection	Insulation Maintenance
3. Overall process	
Unnecessary purchase of electricity from utilities	Process integration (consider co-production of electricity and steam)

Figure 14. Canned fruits and vegetables energy consumption diagram
[1971 USA production: 13.5 x 10^9 kg (30 x 10^9 lb)]*
[1971 energy consumption (primarily natural gas**): 1800 MW
(53 x 10^{12} Btu)*

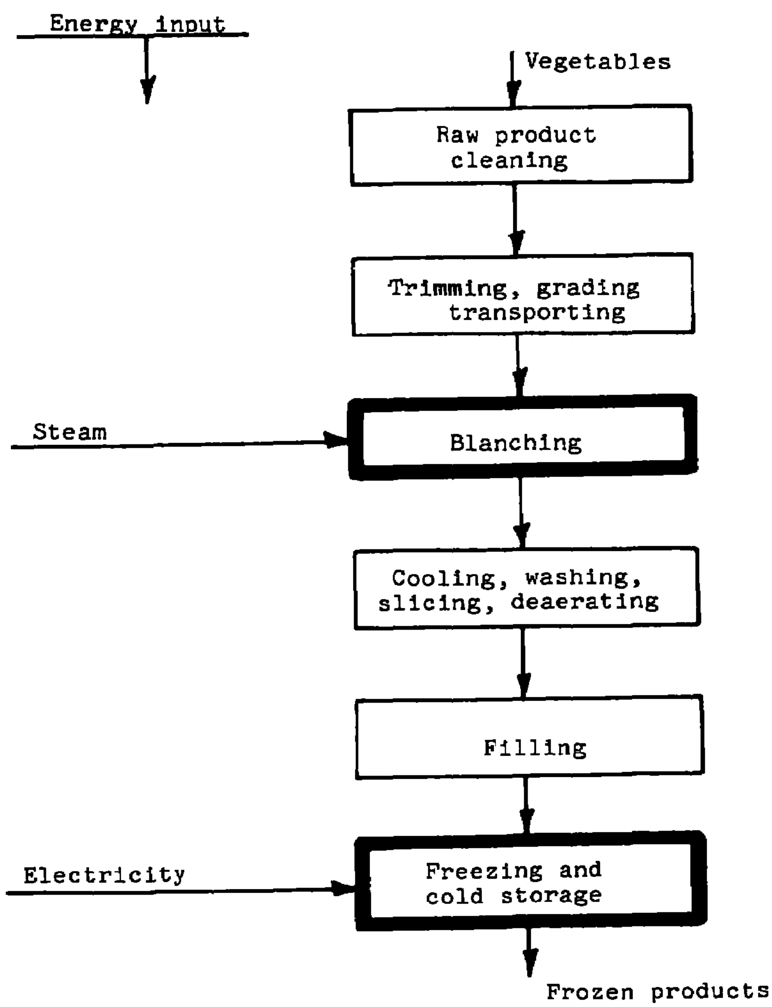


* This includes juices, preserves, jams, and jellies.
** Natural gas is used for steam generation.

Table 6. CANNED PRODUCTS ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Blanching, cooking exhausting, steril- ization	
a. Conduction & convection	Maintenance Insulation
b. Heat required to heat vessels	Design modification (replace batch operations with continuous operations)
c. Overdoing operations	Operation modification (closer control of temperatures and times of heating)
2. Overall Process	
Purchase of electricity from utilities	Process integration (consider co-production of steam and electricity)

Figure 15. Frozen foods (vegetables) energy consumption diagram
[1971 USA production: 2.2 x 10^9 kg (4.8 x 10^9 lb)]
[1971 energy consumption (primarily natural gas*, electricity): 2300 MW (7x 10^{12} Btu)]



* Natural gas is used for steam generation.

Table 7. FROZEN FOODS (VEGETABLES) ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Blanching	
Conduction & convection	Insulation Maintenance
2. Freezing	
a. Conduction & convection	Maintenance Insulation
b. Excess lowering of temperature	Operation modification (closer temperature control)
3. Overall Process	
Purchase of electricity from utilities	Process integration (consider co-production of steam and electricity)

The animal feeds category (SIC 2042) includes plants primarily engaged in manufacturing feeds for animals and fowls. The total energy consumption in 1971 for this category was approximately 2070 MW (62 x 10^{12} Btu)*. The energy usage can be conveniently split into three major groups:

formula feeds - approximately 1030 MW (31 x 10^{12} Btu)*
dehydrated feeds - approximately 670 MW (20 x 10^{12} Btu)*
other - approximately 370 MW (11 x 10^{12} Btu)*

Figure 16 shows the major steps in a typical formula feed process. The process is not excessively energy intensive. Approximately 60 percent of the total energy consumption is used to agglomerate or pelletize the feed, even though only 50 percent of the prepared formula feeds are pelletized. Natural gas is the primary energy source for this process.

Figure 17 shows the major steps in the dehydrated alfalfa process. The process is energy intensive due to the dehydrating operation.

Table 8 shows the causes of energy losses in the formula feed and dehydrated alfalfa processes. It also lists possible energy conservation approaches.

The bread, cake and related products industrial category (SIC 2051) consists of plants primarily engaged in manufacturing bread, cakes and other "perishable" baking products. This group's energy usage in 1971 was 1870 MW (56 x 10^{12} Btu)*.

The largest volume of output in this category is bread and bread rolls. Figure 18 shows the major steps in the breadmaking process using a continuous-mix process. The primary energy consumption operations are baking, space heating/ventilation and distribution of the products.

Table 9 shows the causes of energy losses in the breadmaking industry. It also lists possible energy conservation approaches.

The beet sugar industrial category's (SIC 2063) energy consumption in 1971 was 2700 MW (80 x 10^{12} Btu). Nearly all of this was fuel energy with the primary energy source being natural gas.

Figure 19 shows the major steps in the beet sugar process. The primary energy consumption occurs in the multi-effect evaporation of water from the sucrose solution and in the drying of beet pulp in a rotary dryer.

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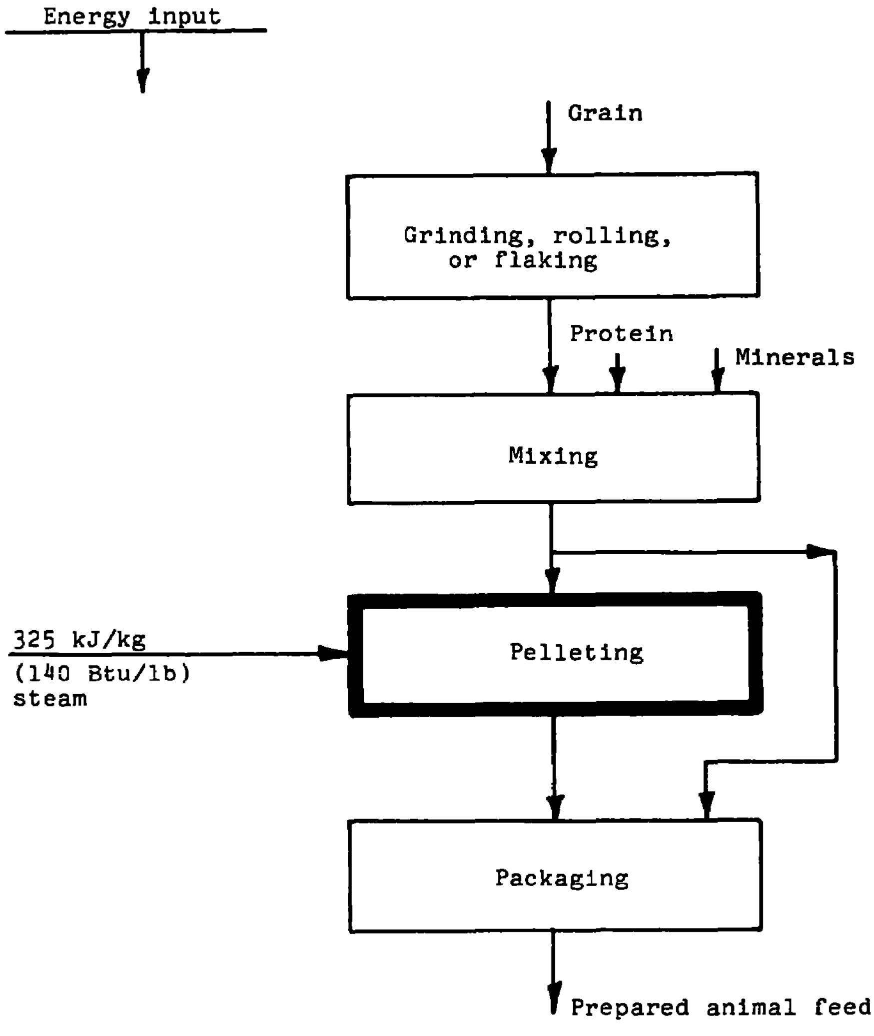
*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).

Figure 16. Animal feeds (formula feed) energy consumption diagram
[1971 USA production: 65 x 10^9 kg (142 x 10^9 lb)]
[1971 energy consumption (primarily natural gas*, electricity): 1030 MW (31 x 10^{12} Btu)]



* Natural gas is used for steam generation.

Figure 17. Animal feeds (dehydrated alfalfa) energy consumption diagram [1971 USA production: 1.4×10^9 kg (3.1×10^9 lb)] [1971 energy consumption (primarily natural gas, electricity): 670 MW (20×10^{12} Btu)]

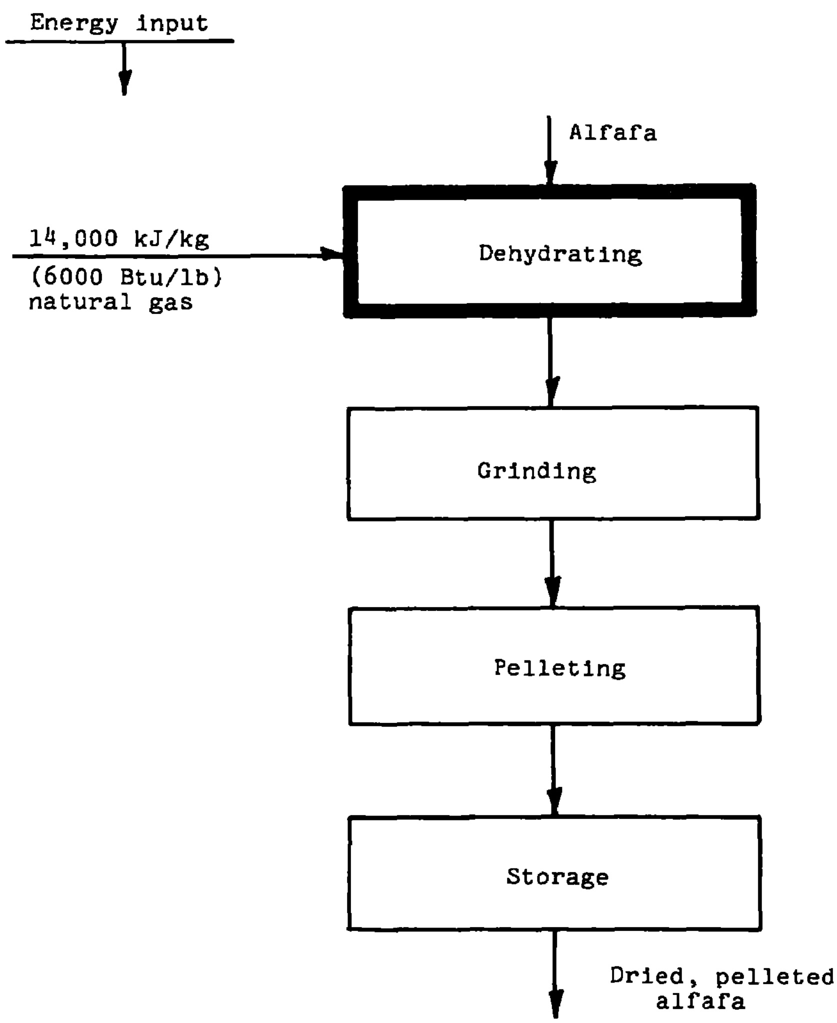


Table 8. ANIMAL FEEDS
(FORMULA FEED AND DEHYDRATED ALFALFA)
ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Pelleting (formula feed)	
a. Conduction & convection	Maintenance Insulation
b. Heat lost in pellets	
2. Dehydrating (alfalfa)	
a. Radiation, conduction & convection	Maintenance Insulation
b. Heat lost in exhaust gases	Design modification (waste heat rpcovery)
c. Heat lost in hot product	Design modification (waste heat recovery)
3. Overall process (formula feed)	
Purchase of electricity from utilities	Process integration (consider co-production of steam & electricity)

Figure 18. Bread and rolls energy consumption diagram
[1971 USA production: 7.1 x 10^9 kg (15.6 x 10^9 lb)]
[1971 energy consumption (primarily natural gas, petroleum, electricity): 1600 MW (48 x 10^{12} Btu)]

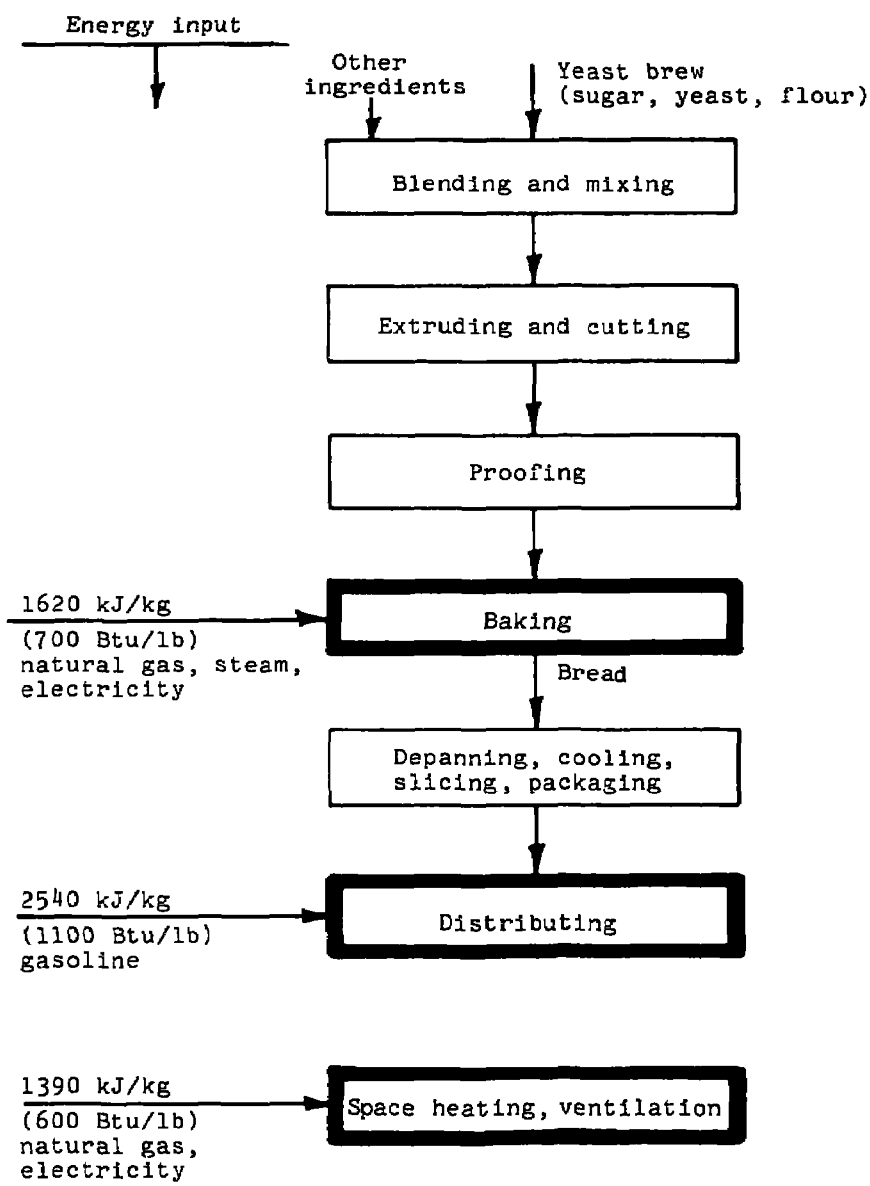


Table 9. BREAD AND ROLLS ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Baking	
a. Radiation, conduction, & convection	Maintenance Insulation
b. Heat in exhausted combustion gases	Design modification (continue conversion from still gas ovens to agitated ovens)
c. Heat in hot bread product	Design modification (preheat combustion air with bread)
2. Distribution	
Low efficiency operation of vehicles	Maintenance Operation modification
3. Space heating	
Conduction & convection	Maintenance Insulation

Figure 19. Beet sugar energy consumption diagram
[1971 USA production: 3.0 x 10^9 kg (6.8 x 10^9 lb)]
[1971 energy consumption (primarily natural gas): 2700 MW (80 x 10^{12} Btu)]

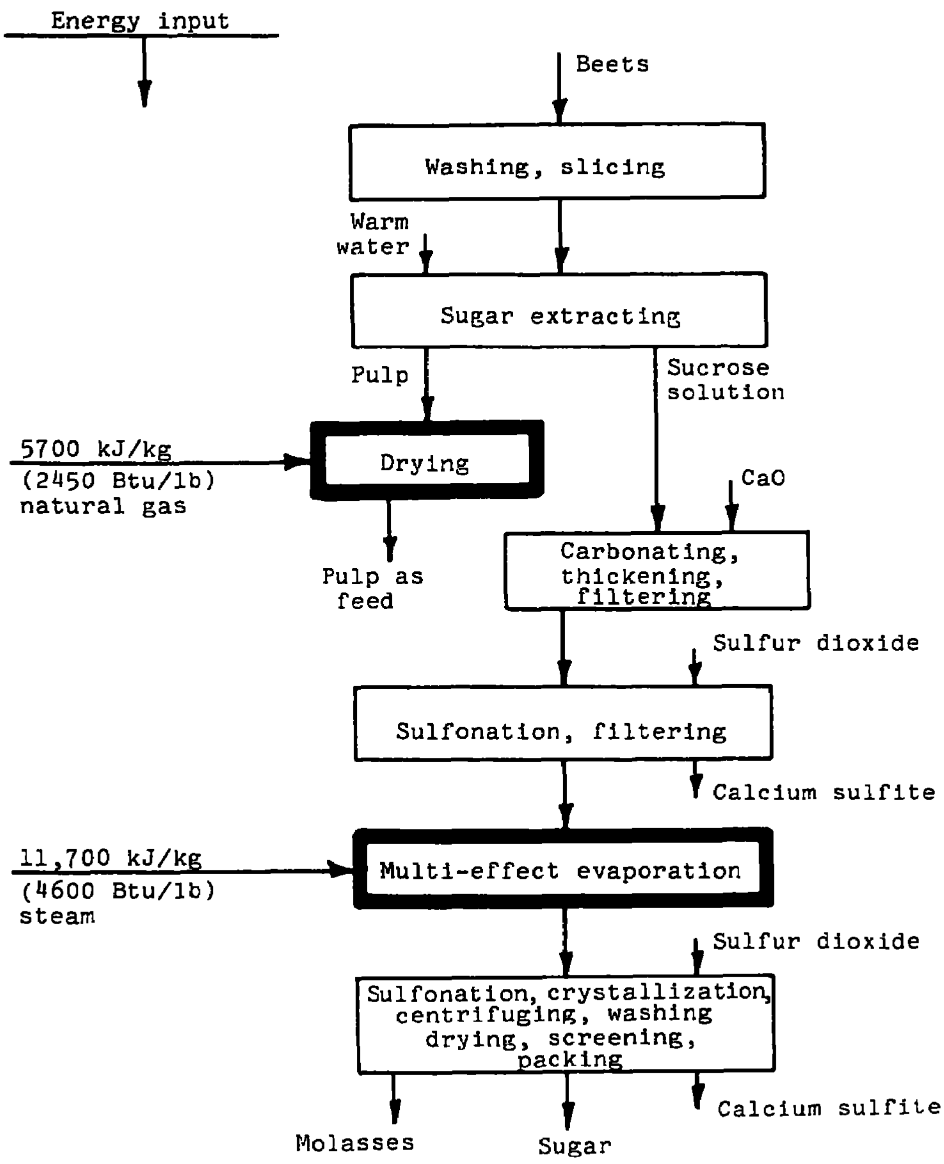


Table 10 shows the causes of energy losses in the beet sugar process. It also lists possible energy conservation approaches.

The malt beverage industrial category's (SIC 2082) energy consumption in 1971 was 1700 MW (51 x 10 Btu)*. The primary energy sources are natural gas and electricity.

Figure 20 shows the major steps in the brewing process. Major energy consumption occurs in the brewing, spent grain drying**, and cooling/aging operations.

Table 11 shows the causes of energy losses in the malt beverage process. It also lists possible energy conservation approaches.

E. Summary of Energy Losses and Recommended Conservation Approaches

Table 12 is a summary of energy losses and recommended conservation approaches for the paper, cement, glass and food industrial groups.

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*Purchased electricity is counted as 3600 kJ/kwh (3413 Btu/kwh).
**Only 40 percent of the spent grain is dried. Figure 20 shows a process in which all of the spent grain is dried.

Table 10. BEET SUGAR ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Pulp drying	
a. Radiation, conduction and convection	Maintenance Insulation
b. Heat in exhaust gases	Design modification (waste heat recovery)
c. Heat in dried pulp	Design modificaton (waste heat recovery)
2. Multi-effect evaporation	
a. Radiation, conduction and convection	Maintenance Insulation
b. Heat in water vapor out of last effect	Design modification (add additional effect to decrease quantity of vapor)
3. Overall Process	
Use of heat to dry pulp	Research and development (develop alternate method for water removal such as pressing)

Figure 20. Malt beverage energy consumption diagram
[1971 USA production: 16 x 10^9 kg (34 x 10^9 lb)]
[1971 energy consumption (primarily natural gas, electricity): 1700 MW (51 x 10^{12} Btu)]

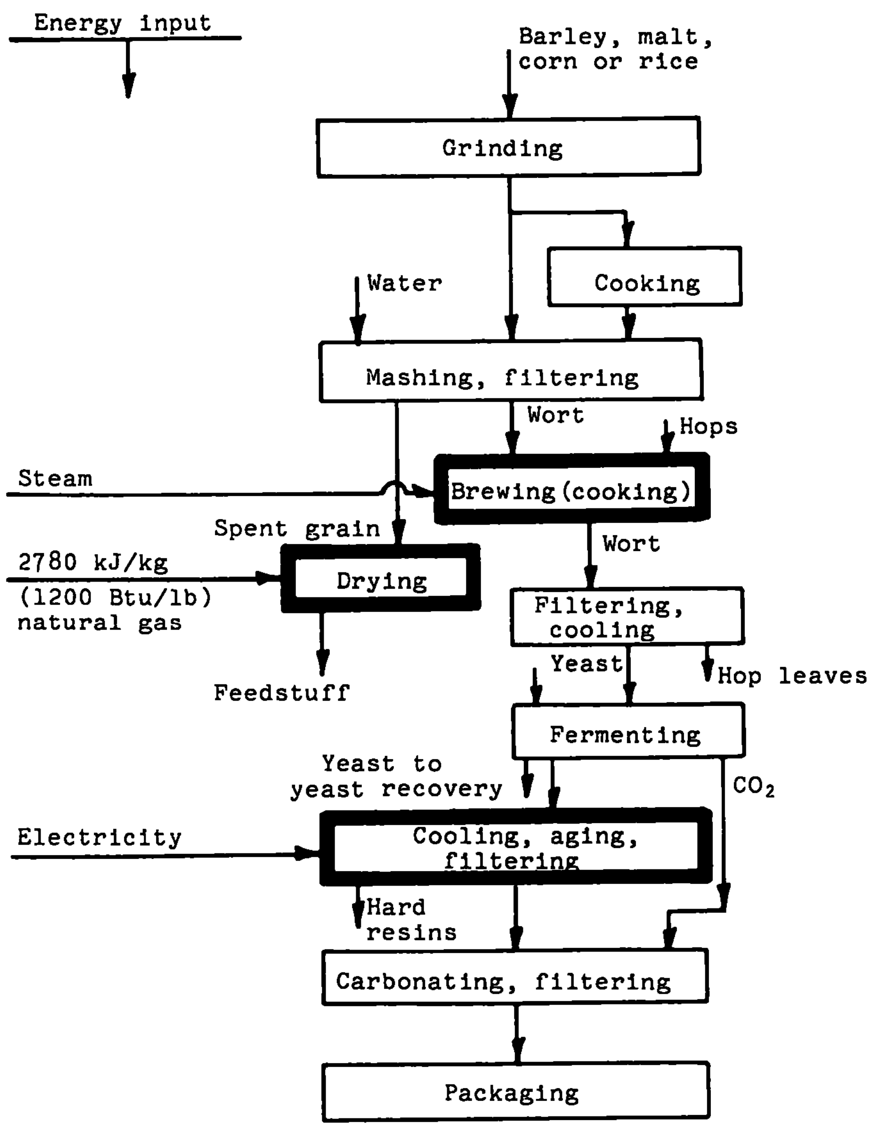

Table 11. MALT BEVERAGE ENERGY CONSERVATION APPROACHES

Causes of energy losses	Energy conservation approaches
1. Brewing	
a. Conduction and convection	Maintenance Insulation
b. Heat in brewing product	Design modification (waste heat recovery)
2. Grain drying	
a. Radiation, conduction and convection	Maintenance Insulation
b. Heat in exhaust gases	Design modification (waste heat recovery)
c. Heat in dried grain	Design modification (waste heat recovery)
3. Cooling, aging	
a. Conduction and convection	Maintenance Insulation
4. Overall Process	
a. Purchase of electricity from utilities	Process integration (consider co-production of steam and electricity) Market modification (intensify efforts to market wet grain)

Table 12. SUMMARY OF ENERGY LOSSES AND RECOMMENDED CONSERVATION APPROACHES

High energy consumption operations	Energy losses: Temperature level	Energy losses: Approx. magnitude	Energy conservation approaches
Paper Industry:			
Digestion	Radiation	230 kJ/kg (100 Btu/lb)	Insulation Maintenance
	350-400°K (170-260°F)	415 kJ/kg (180 Btu/lb)	Design modification
Multi-effect evaporation	Radiation	170 kJ/kg (75 Btu/lb)	Design modification
	320-350°K (115-170°F)	2780 kJ/kg (1200 Btu/lb)	Insulation Maintenance
	350-400°K (170-260°F)	185 kJ/kg (80 Btu/lb)	
Direct heat evaporation & recovery furnace	Radiation	230 kJ/kg (100 Btu/lb)	Design modification
	400-450°K (260-350°F	6050 kJ/kg (2600 Btu/lb)	Insulation Maintenance
Calcination	Radiation	280 kJ/kg (120 Btu/lb)	Design modification
	450-500°K (350-440°F)	1020 kJ/kg (440 Btu/lb)	Insulation Maintenance
	600-650°K (620-710°F)	100 kJ/kg (40 Btu/lb)	
Paper drying	Radiation	230 kJ/kg (100 Btu/lb)	Design modification
	350-400°K (170-260°F)	4170 kJ/kg (1800 Btu/lb)	Insulation
Overall process	- - - - -	- - - - -	Research and development Waste utilization Process integration Market modification Operation modification Design modification

Table 12 (continued)

High energy consumption operations	Energy losses: Temperature level	Energy losses: Approx. magnitude	Energy conservation approaches
Cement Industry:			
Kiln	Radiation	1560 kJ/kg (670 Btu/lb)	Design modification
	450-500°K (350-440°F)	185 kJ/kg (80 Btu/lb)	Insulation Maintenance
	550-600°K (530-620°F)	2320 kJ/kg (1000 Btu/lb)	
Overall process	- - - - -	- - - - -	Process modification
Glass Industry:			
Melting tank	Radiation	3950 kJ/kg (1700 Btu/lb)	Research and development
	800-850°K (980-1070°F)	1600 kJ/kg (700 Btu/lb)	Design modification Insulation Maintenance
Overall process	- - - - -	- - - - -	Process modification
Food Industry:			
- - - - -	- - - - -	- - - - -	Process integration Insulation Maintenance

SECTION V

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SECTION VI

GLOSSARY OF ABBREVIATIONS

Btu	British thermal unit
cond	condensate
CW	cooling water
hr	hour
kg	kilogram
kJ	kiloJoule
kN	kiloNewton
kW	kiloWatt
kwh	kilowatt hour
lb	pound
m	meter
psia	pounds per square inch absolute
MW	megawatt
stm	steam
yr	year

SECTION VII

APPENDIX

ENERGY CONSERVATION APPROACHES

Design modification - This term includes design changes in equipment or process.

Insulation - This term implies that a review of the economics of additional insulation is needed.

Maintenance - This term implies that the economics of additional maintenance effort needs review.

Process integration - This term relates to the best use of steam by using the same steam in more than one process or to the optimization of the steam-electricity production ratio. It also covers the combination of two or more processes within one plant.

Research and development - This term relates to the improvement of processes by future discoveries.

Operation modification - This term includes changes in operating procedures or practices that do not require a design change.

Market modification - This term relates to the substitution of a low energy consumption product for a high energy consumption product.

Process modification - This term relates to a change in a process due to a change in process feedstock, raw materials, or process route.

Waste utilization - This term relates to the use of fuel value of waste process streams or to the recycling of discarded materials.

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16. ABSTRACT The report gives results of a study of energy consumption in the paper, stone/clay/glass/concrete, and food industries. It analyzes energy-intensive steps or operations for commonly used manufacturing processes. Results of the analyses are in the form of energy consumption block diagrams, energy-intensive equipment schematic diagrams, and tables that indicate the causes of energy losses, as well as possible conservation approaches. (The analysis of energy consumption in the food industry is not as quantitative as in the others.) The most common energy-intensive operations in these industries are: (paper) -- pulp digestion (cooking), evaporation, furnace and kiln operations, and drying; (stone/clay/glass/concrete) -- kiln and furnace operations; and (food) -- cooking, drying, and refrigeration. Energy losses in these operations could be reduced by: design, market, and process modification; better insulation and maintenance; waste utilization; process integration; and research and development.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS			b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy	Food Industry	Cookery		06H
Consumption	Conservation	Refrigera-		
Rocks	Pulping	ting		08G 13H,07A
Clays	Evaporation	Drying		07D
Glass	Furnaces	Marketing		11B 13A, 05C
Concretes	Kilns	Insulation		13C
Paper Industry	Research	Wastes		11L

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