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ECONOMIC ANALYSIS OF WIND-POWERED REFRIGERATION COOLING/ WATER-HEATING SYSTEMS IN FOOD PROCESSING

Final Report
March 1980

W. S. Garling, M. R. Harper, L. Merchant-Geuder, and M. Welch

Tetra Tech, Inc.
Arlington, Virginia

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Final Report

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ABSTRACT

Potential applications of wind energy include not only large central turbines that can be utilized by utilities, but also dispersed systems for farms and other applications. The U.S. Departments of Energy (DOE) and Agriculture (USDA) currently are establishing the feasibility of wind energy use in applications where the energy can be used as available, or stored in a simple form. These applications include production of hot water for rural sanitation, heating and cooling of rural structures and products, drying agricultural products, and irrigation. This study, funded by USDA, analyzed the economic feasibility of wind power in refrigeration cooling and water heating systems in food processing plants. Types of plants included were meat and poultry, dairy, fruit and vegetable, and aquaculture.

The methodology for this study involved (1) making an inventory of food-processing plants by state; (2) describing equipment and processes, and describing or estimating energy requirements; (3) analyzing wind patterns, and comparing plant locations with available wind power; and (4) performing an economic analysis. The economic analysis determined breakeven costs of small wind energy conversion systems (SWECS) required to economically supplement or replace present energy sources, estimated payback periods, and compared breakeven costs with projected SWECS costs.

With the projected costs and energy prices assumed, SWECS (under 100 kilowatts) were found to be economically viable for some processing plants operating year-round, if wind power averaged at least 200 watts per square meter. Seasonal plants operating for less than 6 months annually probably could not install SWECS economically. Wind systems in most cases probably would be used as supplemental power sources, because of the intermittent nature of the wind and the high temperatures required in some processing operations. Payback periods estimated were fairly long--8 to 12 years--even if breakeven costs were met.

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EXECUTIVE SUMMARY

Food processing consumed over one million terajoules in 1977. In many food-processing plants, substantial energy is required for refrigeration and freezing, and for hot water and steam both in processing and for sanitation. Resistance heating and electricity for refrigeration are possible applications of wind energy in these plants, and wind power might be used to drive a heat pump. Low-cost thermal storage should be viable: an evaporator could chill an ice-builder to store cooling capacity for windless periods, and a condensor could heat incoming water to moderate temperatures to be used either directly or as a pre-heat where hot water is required,

The methodology for this study involved: (1) making an inventory of food-processing plants by state. Types of plants included were those requiring both water heating and refrigeration/cooling in their operations: meat and poultry (both slaughtering and processing), dairy (both farms and plants), fruit and vegetable, and aquaculture. (2) equipment and processes were described and energy requirements described or estimated. (3) wind patterns were analyzed on an annual and seasonal basis, at three different heights. (4) an economic analysis was performed to determine breakeven costs of small wind energy conversion systems (SWECS) required to economically supplement or replace present energy sources, estimate payback periods, and compare breakeven costs with projected SWECS costs.

Processing Plant Inventory

Estimates of numbers of food-processing plants were based primarily on listings of federally inspected plants, and on data from a directory of canning, freezing, and preserving industries. The inventory indicated that in the United States there are nearly 7,000 meat plants, over 240,000 dairy farms, nearly 3,000 dairy plants, around 1,300 fruit and vegetable processing establishments, and about 130 aquaculture plants. (These estimates are likely to be on the conservative side. Meat and dairy plants include federally inspected facilities only.) Slaughtering and processing facilities are concentrated in the Midwest, which has nearly one third of the total; the states of California, New York, and Pennsylvania also each contain over 700 meat plants. Wisconsin and Minnesota alone contain nearly one-third of the dairy farms and one-fifth of all dairy plants. Other states with large numbers of dairy farms and plants include California, Iowa, New York, Ohio, and Pennsylvania. Large numbers of fruit and vegetable plants are located in California, Florida, Michigan, New York, and Wisconsin; aquaculture plants are concentrated in the Pacific Northwest, Rocky Mountain states, and New England.

Equipment, Procedures, and Energy Use

Operations of interest in food-processing plants include the chilling of products before and during processing, refrigeration and freezing for storage, and cleaning and processing operations requiring hot water or steam. Among the latter are the removal of hair from hogs and feathers from chickens (scalding or singeing); cooking and canning of meat,

vegetable, fruit, and some dairy products; clarification, separation, and pasteurization of dairy products, and the washing, blanching, and peeling of fruits and vegetables. Temperature requirements for these operations vary substantially: freezing temperatures commonly are around -40°C , and temperatures for cold storage slightly above 0°C . The highest temperatures are required in cooking and canning; they can range up to over 200°C (about 400°F). Other processes generally require temperatures of under 80°C (175°F).

Fossil fuels are used most frequently for hot water and steam generation, while electricity is used for refrigeration, freezing, and ice-making equipment. Electricity also may be used to generate heat for hot water. Annual energy requirements were estimated for various sizes and types of processing plants and for certain selected processes, using data obtained from energy audits performed on individual plants. Some examples are:

- 2,400 cubic feet (ft^3) natural gas for the singeing operation in a slaughtering plant with kill rate of 300 hogs/year.
- $71\text{--}882 \times 10^3$ kWh to scald 15 million kilograms (kg) chickens; $1.3\text{--}1.8 \times 10^6$ kWh for process refrigeration in the same size plant.
- 6,000 kWh for milk cooling and hot water heating on a 20-cow dairy farm.
- Nearly 20 million cubic ft natural gas (154,000 gallons of fuel oil) and $97\text{--}279 \times 10^3$ kWh to satisfy all energy requirements of a one million kg/year cheese plant.
- Thermal energy requirements of about 4 million cubic ft natural gas (about 30,000 gallons of fuel oil) for a plant processing 1.7 million kg peas over 6 weeks.

Energy use in food processing varies considerably by establishment, according to parameters such as region and season of year, plant capacity utilized, and size plant.

Wind Pattern Analysis

To show the availability of wind power for food-processing applications, wind contour maps were prepared. These maps show areas with annual average wind power density of 100 watts per square meter (W/m^2) at 10, 20, and 50 meters (m) above ground. $100 \text{ W}/\text{m}^2$ was chosen as the cutoff point below which wind power would be unlikely to produce useful power economically.

Large food-processing plants may be able to install large WECS to take advantage of wind power at 50 m. Smaller plants in the Midwest and West should be able to utilize wind power at 20 m. In 21 states, wind power averages at least $100 \text{ W}/\text{m}^2$ at 50 m during every month. Over 40 percent of all meat plants, 62 percent of the dairy farms, about 56 percent of dairy-processing plants, and over 33 percent of the fruit and vegetable plants are located in these states. (Aquaculture plants are not well represented).

Wind power averages over 400 W/m^2 at 50 m during the winter and spring in any of the western states (including part of the Southwest) and some sites in New England, but during the rest of the year drops substantially below this level except in a few Rocky Mountain and southwestern states. Fruit/vegetable and aquaculture plants, many of which are located in the Southeast, are least likely to be able to tap the wind resource. A large number of broiler plants also are concentrated in the Southeast. In addition, many fruit/vegetable plants operate primarily or only during the summer and early fall, when winds are poor.

Economic Analysis

The objective of the economic analysis was to derive the maximum price a user should be willing to pay to purchase a SWECS for use in food-processing applications (breakeven cost) and to compare this price with currently projected prices of wind machines. Seasonal costs for several processing operations were derived, using the most recently available national energy prices. Electricity was assumed to cost 3.14¢ per kWh, the average industrial retail price as of September 1979. The natural gas price used was the average price to industrial users as of September 1979 (212.4¢ per thousand cubic ft), while the fuel oil No. 2 July wholesale price of 64.3¢ per gallon also was assumed. Although fuel oil No. 6 also is used in processing plants, separate calculations were not made using No. 6 prices. These prices are lower than No. 2 prices but higher than those of natural gas.

Present values of the annual or seasonal energy costs of food-processing operations (the present value of the benefits or savings if these conventional energy sources were to be replaced) were calculated over a period of 20 years (assumed SWECS lifetime), with a 10 percent discount rate. Fossil fuel costs were assumed to escalate at a rate of 35 percent for the first 2 years and at 8 percent annually thereafter; electricity costs were assumed to rise 20 percent annually for the first 2 years and at 4 percent per year thereafter. These rates of increase were suggested by USDA and DOE personnel, and are estimated to be the rate of increase of fuel and electricity costs above inflation.

From the resulting present values, the allowable investment cost or breakeven cost for the SWECS were calculated. Breakeven costs were assumed to be equal to the present value of the savings generated (the fossil fuel and electricity costs saved) minus the present value of the annual costs associated with the SWECS. Assumptions were that (1) operations and maintenance costs (including property taxes and other miscellaneous costs) are 5 percent of fixed costs, and (2) the SWECS have a salvage value of zero at the end of the 20-year lifetime. These assumptions also are being used in other wind energy studies being prepared for USDA.

A payback analysis was performed, presenting annual outlays required for SWECS operation and resulting savings in conventional energy costs (assuming SWECS could be purchased at the breakeven cost level). Interest rates of 9 and 10 percent and 20 and 50 percent equity were assumed on 10-year loans. Payback--the point at which total accrued savings equaled or exceeded total outlays--occurred between the eighth and twelfth years. There was little sensitivity to the changes in interest rate or percent equity.

Break even costs then were compared with wind system costs projected at the 10,000th unit. The SWECS selected for comparison were those tested at Rocky Flats, all of which were rated at 8.9 meters per second (20 miles per hour), and for which comparable power curves were available. These SWECS ranged from one to 40 kW rated. Mean power output was calculated using the Rayleigh distribution and the power curves supplied by Rocky Flats. Mean outputs were calculated for four average wind speeds at 20 and 50 m: 4.4, 5.6, 6.4, and 7.0 meters per second (100, 200, 300, and 400 W/m², respectively). Although large wind systems were not the focus of these studies, large food-processing facilities could take advantage of the greater wind power available at 50 m heights, whereas systems installed for farm applications probably would not. Projected SWECS costs at the 10,000th unit, obtained from Rocky Flats, were \$3,000, \$8,000, and \$20,000 for 2-kW, 8-kW, and 40-kW machines, respectively. These costs did not include site preparation, installation, or any storage costs.

The analysis indicated that use of SWECS could be economically viable for some food-processing plants operating year-round, if located in areas with winds of at least 200 W/m² (5.6 meters per second velocity at 20 or 50 m). Seasonal processing plants operating less than 6 months per year probably would not find wind systems viable in any wind regime.

Because electricity is more expensive than fossil fuels (on a heat- or kWh-equivalent basis), SWECS should be able to replace electricity more economically than fossil fuels. The assumption of higher escalation rates for fossil fuels than for electricity narrows these differentials, but electricity generated from oil or natural gas will continue to be significantly more expensive than the fuels themselves. Among the fuels, it currently would be most advantageous to replace the expensive fuel oil No. 2, and least advantageous to replace natural gas. The ratio of projected SWECS cost to breakeven cost would fall if a heat pump were used in conjunction with the wind turbine, to replace or supplement both heating and cooling supplied by conventional energy sources.

Conclusion

With the projected costs and energy prices assumed, the installation of wind turbines could be economically viable for some processing plants operating year-round with wind averaging 200 W/m² or above. For those plants with seasonal peaks in their operations, viability will depend in great part on wind availability during those seasons. Seasonal plants operating for less than 6 months of the year probably would not find wind systems viable.

Because of the intermittent nature of the wind, unless low-cost storage systems can be used, wind energy is most likely to be used as a supplemental power source in food processing. Further, it probably would not be economical to use wind energy alone in processing operations requiring high temperatures; SWECS in these cases could be used for intermediate temperatures or preheating.

Even if breakeven costs are achieved, payback periods are fairly long (8 to 12 years). The acceptability of this length of payback depends on the time horizons of farmers and processing plant operators.

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I. INTRODUCTION

The food-processing industry consumes substantial energy in the form of electricity, natural gas, and fuel oil. In 1977 over one million terajoules (980.5 trillion Btus) were consumed at a cost of \$2.6 billion. Preliminary analyses conducted by the U.S. Department of Agriculture have identified heating and cooling operations in processing plants as potential application of wind energy. The purpose of this report was to determine to what extent the energy required for these operations can be supplied economically by (small) wind systems. Plants have been restricted to those processing meat and poultry (including aquaculture plants), dairy products (including dairy farms), and fruits and vegetables. All these plants must use substantial amounts of warm water for cleaning, and most require hot water or steam for processing. Most of these products also must be chilled to slow the growth of bacteria before or during processing, and refrigerated or frozen for storage.

An inventory of processing plants, including estimates of numbers and sizes by state, is presented in section II. Section III describes the heating and cooling processes used in the various types of plants, emphasizing temperature, time, and water volume requirements. Current energy sources and requirements also are described, both on an aggregate level and, where data are available, for individual plants. In section IV wind contour maps are presented, along with data on plant location by state. The location of food-processing facilities thus can be compared directly with available wind power. Wind power is analyzed both on an annual and a seasonal basis. Section V presents an economic analysis of the feasibility of wind power use, including calculations of breakeven costs for several types and sizes of processing plants, estimates of energy output for some small wind systems, and comparisons of breakeven costs versus the projected costs of these wind systems. A payback period analysis is included. Summary and conclusions are contained in section VI.

Appendixes A through D present tables concerning plant types and sizes, seasonality of processing operations, energy consumption in food processing, and wind data, respectively. Appendix E contains sample payback period analyses, and a list of the small wind systems used for the analysis in section V are included in appendix F. Appendix G contains the Bibliography.

Measurements in this report - temperatures, energy units, weights, etc. - are given in metric units. For convenience, the commonly used U.S. equivalent units also are presented, in parentheses, in the text. Tables show metric measurements only. Exceptions are units of natural gas and fuel oil, which are listed in terms of cubic feet and barrels or gallons, respectively, since these fuels are priced and sold on this basis.

II. PROCESSING PLANT INVENTORY

The approximate numbers of meat, dairy, fruit and vegetable, and aquaculture plants in each state are given below, where possible by size and type. Figures for meat plants are given for slaughtering plants, processing plants, and combination slaughtering-processing plants separately. Figures also are given separately for dairy farms and milk-processing facilities. Plants that perform canning operations, canning and freezing, freezing only, and other specialized processing are itemized. Aquaculture plants are listed by type of fish. Following these data, information is presented on the seasonality of plant operations, which is most important in the fruit and vegetable industry.

A. Number and Location of Plants

Data on the number of different types of food-processing plants were obtained from a variety of sources. The numbers should be regarded as approximate, and in most cases somewhat understate the true number of plants. The reason for the understatement is that in the case of some plants--e.g., meat and dairy--only federally inspected plants are included. In some states all these plants are federally inspected, but in others a few establishments are state inspected only.* More details on the data sources are given below in the discussion of the different plant categories and in the accompanying tables.

The number of meat plants by state are shown in table 1. These plants, in the case of red meats, are classified by whether they are slaughtering plants only, processing plants only, or a combination of the two. Relatively few plants slaughter only, except in Pennsylvania. Over one-third of the plants in the country that slaughter only are in Pennsylvania. About 4,110 plants process only, while 1,312 both slaughter and process. By far the greatest concentrations of red meat slaughtering and processing plants are in the states of California, New York, and Pennsylvania (over 700 plants each). Illinois, Missouri, New Jersey, Tennessee, and Texas each have over 200 plants, and Colorado, Connecticut, Kentucky, Massachusetts, Minnesota, Montana, North Carolina, North Dakota, Oregon, and Washington each have over 100. In most states at least some plants process poultry as well as red meat. The largest number of combination meat/poultry plants are found in California, Minnesota, New Jersey, New York, and Pennsylvania (over 100 plants each). Plants processing only poultry are found in most states; California and Pennsylvania again are the leading states.

* Letters were sent to the Meat and Poultry Inspection Programs in all regions of the country. Responses were received from some of these regions. According to the responses, all meat and poultry plants in Oregon, Colorado, and California; 25 percent of plants in Idaho; all but 40 and 70 plants in Utah and Arizona, respectively; and 55 percent of all plants in Missouri are federally inspected.

Table 1. NUMBER OF MEAT-PLANTS, BY STATE

State	Number of Plants						Grand Total ^c
	Meat (Red) ^a			Total Meat	Poultry Only	Meat & Poultry ^b	
	Slaughter	Processing	Slaughtering & Processing				
Alabama	0	27	11	38	25	17	63
Arizona	0	19	6	25	0	13	25
Arkansas	0	16	11	27	38	18	65
California	16	631	64	711	61	282	772
Colorado	9	108	39	156	5	38	161
Connecticut ^d				131	7	41	138
Delaware	0	6	0	6	6	3	12
Florida	10	55	2	67	5	31	72
Georgia	5	49	11	65	41	32	106
Hawaii	0	1	1	2	0	2	2
Idaho	0	13	9	22	1	4	23
Illinois	9	240	16	265	16	80	281
Indiana	1	71	20	92	17	33	109
Iowa	11	44	38	93	7	24	100
Kansas	4	36	21	61	3	22	64
Kentucky	7	119	44	170	7	42	177
Louisiana	0	20	13	33	5	10	38
Maine ^d				18	7	8	25
Maryland	0	38	3	41	16	23	57
Massachusetts ^d				197	22	63	219
Michigan	1	63	23	87	6	19	93
Minnesota	4	113	60	177	22	104	199
Mississippi	2	11	6	19	18	11	37
Missouri	21	166	107	294	23	63	317
Montana	2	41	33	76	0	42	76
Nebraska	18	74	63	155	8	51	163
Nevada	1	18	6	25	2	18	27
New Hampshire ^d				31	3	12	34
New Jersey	4	264	24	292	16	109	308
New Mexico	1	11	10	22	0	10	22
New York	12	605	91	708	34	258	742
North Carolina	1	52	6	159	26	19	185
North Dakota	3	16	32	51	0	17	51
Ohio	4	108	29	141	13	35	154
Oklahoma	2	23	23	48	4	18	52
Oregon	0	75	40	115	8	23	123
Pennsylvania	110	404	190	704	56	258	760
Rhode Island ^d				32	4	8	36
South Carolina	1	9	5	15	8	11	23
South Dakota	1	5	10	16	3	4	19
Tennessee	6	121	80	207	15	69	222
Texas	11	176	84	271	28	96	299
Utah	1	15	13	29	7	7	36
Vermont ^d				11	0	5	11
Virginia	1	50	8	59	19	41	78

Table 1. NUMBER OF MEAT PLANTS, BY STATE (Cont'd)

State	Number of Plants						Grand Total ^c
	Meat (Red) ^a			Total Meat	Poultry Only	Meat & Poultry ^b	
	Slaughter	Processing	Slaughtering & Processing				
Washington	4	109	37	150	11	50	161
West Virginia	0	13	3	16	3	7	19
Wisconsin	3	75	18	96	15	37	111
Wyoming	1	1	3	5	0	3	5
Total	287	4,111	1,313	6,231	641	2,191	6,872

^aSome plants may include poultry processing.

^bIncluded under Meat (Red).

^cSum of columns 4 and 5, to avoid double counting. (Column 6 is included in column 4.)

^dBroken out by region rather than by state in the source *Meatfacts*. Calculations can be made of the number of plants in each category (slaughter, processing, and both) by referring to the USDA *Meat and Poultry Inspection Directory*, cited below.

Sources: American Meat Institute, *Meatfacts* (Washington, D.C., 1979), p. 11; U.S. Department of Agriculture, Food Safety and Quality Service, *Meat and Poultry Inspection Directory* (Washington, D.C., January 1979).

Number of dairy farms and milk-processing establishments are presented in table 2. Wisconsin leads in number of dairy farms, with over 48,000, and Minnesota is second with nearly 29,000. Other states with very large numbers of dairy farms include Iowa, New York, Ohio, and Pennsylvania. Wisconsin ranks first also in number of milk processing plants, with 455. California has 271 and Minnesota has 207 plants; New York, Ohio, and Pennsylvania each have over 100. Many of these plants, as indicated in table 2, do not actually do any processing, but apparently are holding and shipping points. The number of plants processing cheese, butter, and ice cream also, for the most part, produce other milk products. Most of the plants listed process fluid milk. Again, these are federally inspected plants.

In fruit and vegetable processing, as shown in table 3, California is by far the leading state, with 221 plants. New York, Michigan, Wisconsin, Florida, Washington, and Oregon rank next with 96, 91, 85, 73, 69 and 59 plants, respectively. Most of these plants involve canning operations, but some freeze all their production. Many both freeze and can, a few include drying operations as well as canning, and a few specialize only in processes such as dehydrating, evaporating, and freeze drying. The number of plants of these different types in each state are shown in appendix A.

It is more difficult to obtain any inventory of aquaculture plants than of the other kinds of plants included in this report, since they are not listed as such in any one place. The data in table 4 were chosen from the 1975 National Marine Fisheries Service list of fishery processors, based on the species of fish produced, and were verified or updated based on telephone conversations with aquaculture experts in various states.

Oyster processors were included in the case of New York, Connecticut, and the West Coast, where oyster farming/processing is well established, but excluded in other states. Aquaculture operations are more limited in other coastal states.

According to table 4, the southeastern and midwestern states, and a few Rocky Mountain states, are most important in terms of aquaculture operations. Catfish and, in Louisiana, crayfish are the main products in the southeastern states. The midwestern states produce some catfish, carp, and buffalofish, but mainly for live release (hatchery operations). In Idaho and Colorado trout are the main aquaculture product (some catfish also are farmed and processed in Idaho).

B. Plant Sizes

Most slaughtering plants in the country fall into the small size category. About half of the approximately 1,500 plants that slaughter cattle slaughter under 1,000 head per year. Another 25 percent slaughter between 1,000 and 10,000 head annually, with the remaining plants handling up to and over 50,000 head (one-eighth of the plants fall into the last two categories). The number of plants slaughtering calves, hogs, lambs, and poultry is skewed even more toward smaller sizes (many plants, of course, slaughter more than one type animal). Modern broiler-processing plants, however, can process 9,600 birds per hour, or 76,800 during an 8-hour

**Table 2. NUMBER OF DAIRY FARMS AND
MILK-PROCESSING PLANTS, BY STATE**

State	Number of Dairy Farms	Number of Plants ^a				Total
		No Pasteurizing	Butter	Cheese	Ice Cream	
Alabama	909	5	—	—	9	25
Alaska	25	—	—	—	—	2
Arizona	169	5	—	—	8	14
Arkansas	1,324	8	—	4	8	20
California	3,214	49	21	33	189	271
Colorado	1,097	14	3	—	28	34
Connecticut	805	1	—	9	27	41
Delaware	214	1	—	—	—	5
Florida	461	9	—	—	15	36
Georgia	1,053	17	—	—	9	38
Hawaii	33	—	—	—	—	5
Idaho	3,442	9	6	14	7	28
Illinois	6,300	37	6	24	40	92
Indiana	6,409	10	7	5	30	47
Iowa	13,927	52	12	16	21	99
Kansas	4,030	30	2	10	11	53
Kentucky	7,000	20	2	12	9	61
Louisiana	1,503	5	—	—	20	30
Maine	1,323	9	—	—	15	24
Maryland	2,231	2	—	—	15	19
Massachusetts	950	7	—	12	38	59
Michigan	9,619	44	12	15	41	82
Minnesota	28,897	66	47	31	11	207
Mississippi	1,533	11	—	4	9	30
Missouri	7,206	40	3	14	17	74
Montana	851	—	9	—	14	22
Nebraska	4,954	36	—	13	—	56
Nevada	77	4	—	—	3	11
New Hampshire	661	6	—	—	11	12
New Jersey	773	3	—	7	16	33
New Mexico	187	7	—	—	—	13
New York	17,540	133	24	49	73	192
North Carolina	2,117	3	—	—	20	26
North Dakota	4,505	7	11	13	12	43
Ohio	11,216	11	8	23	51	114
Oklahoma	1,781	11	3	—	14	25
Oregon	1,483	11	10	5	18	39
Pennsylvania	16,546	99	11	23	67	163
Rhode Island	118	1	—	—	13	17
South Carolina	469	1	—	—	6	12
South Dakota	5,866	11	10	17	4	32
Tennessee	5,678	11	4	10	15	39
Texas	2,921	37	—	4	31	85
Utah	1,323	7	6	10	12	23
Vermont	3,409	30	4	13	5	42
Virginia	3,390	13	—	—	9	38
Washington	2,115	17	12	8	19	50
West Virginia	936	1	—	—	7	11
Wisconsin	48,422	216	36	353	40	455
Wyoming	349	4	—	—	—	10
Other	—	—	30	27	25	—
Total	242,169	1,131	299	778	1,062	2,959

^aMost plants producing butter, cheese, ice cream also produce fluid milk/fluid milk products.

Sources: U.S. Department of Agriculture, Economics, Statistics and Cooperatives Service, Crop Reporting Board, *Dairy Products Annual Summary 1978*, June 1979; U.S. Department of Health Education and Welfare, Food and Drug Administration, *Sanitation Compliance and Enforcement Ratings of Interstate Milk Shippers*, July 1979; National Milk Producers Federation, *1979 Dairy Producer Highlights* (Washington, D.C., 1979).

Table 3. NUMBER OF FRUIT/VEGETABLE-PROCESSING PLANTS, BY STATE^a

State	# Plants	State	# Plants
Alabama	6	Montana	2
Arizona	6	Nebraska	5
Arkansas	18	Nevada	2
California	221	New Hampshire	2
Colorado	11	New Jersey	41
Connecticut	2	New York	96
Delaware	15	North Carolina	14
Florida	73	North Dakota	3
Georgia	19	Ohio	49
Hawaii	8	Oklahoma	8
Idaho	24	Oregon	59
Illinois	43	Pennsylvania	52
Indiana	46	Rhode Island	1
Iowa	13	South Carolina	5
Kansas	4	Tennessee	15
Kentucky	10	Texas	34
Louisiana	17	Utah	6
Maine	18	Virginia	23
Maryland	39	Washington	69
Massachusetts	15	West Virginia	4
Michigan	91	Wisconsin	85
Minnesota	29	Wyoming	1
Mississippi	3		
Missouri	12	Total	1,319

^aNo plants processing fruits and vegetables were listed in Alaska, New Mexico, South Dakota, or Vermont. Figures are from data presented in *The Directory of the Canning, Freezing, Preserving Industries* (Westminster, Md.: Edward E. Judge & Sons, 1978), and should be regarded as approximate. Plants that process primarily meats are excluded.

Table 4. AQUACULTURE PLANTS AND SPECIES, BY STATE

State	Species	# Plants
Alabama	Catfish	21
Arkansas	Catfish	2
California	Oysters ^b	3
Colorado	Trout ^a	1
Connecticut	Oysters ^b	1
Florida	Catfish ^c	4
Idaho	Trout ^a	6
Louisiana	Catfish ^c	1
	Crayfish	34
Mississippi	Catfish ^d	6
New York	Oysters ^b	1
Oregon	Oysters ^b	11
South Carolina	Catfish ^c	2
Tennessee	Catfish	1
Utah	Trout ^a	2
Washington	Oysters ^b	16
	Salmon ^e	17

^aPlants that raise these and other species for live distribution, which are common in the West and Midwest, are excluded.

^bIncludes plants that process oysters only; excludes those processing oysters in addition to other seafoods.

^cIncludes plants processing catfish and other fish.

^dAdditional plants on the Coast process both catfish and seafood.

^eIncludes plants processing salmon only, not salmon and other seafood. Many of these 17 plants may not be specifically aquaculture.

Source: U.S. Department of Commerce, National Marine Fisheries Service, *Processors of Fishery Products in U.S., 1975* (Washington, D.C., 1977); personal communications from aquaculture experts in the above states.

shift.¹ Nearly 24 million birds annually are processed in a plant this size, assuming a 6-day week and a constant process rate all year. One study of three broiler plants referred to the plant processing around 16 million kilograms (kg) (35 million pounds) annually as small, that processing 27 million kg/(59 million lbs) as medium-sized, and the one producing 40 million kg (88 million lbs) as large.² Table A-1 shows the size distribution of slaughtering plants.

Plants producing canned and frozen meats also are concentrated more heavily in the smaller size categories. Of the plants for which size data were available, nearly one-third produce under 100,000 cases annually, while only about 7 percent produce over 5 million cases annually. The size distribution of these plants is:

Under 100,000 cases:	29 percent
100,000-250,000 cases:	11 percent
250,000-500,000 cases:	14 percent
500,000-1,000,000 cases:	19 percent
1,000,000-2,000,000 cases:	14 percent
2,000,000-5,000,000 cases:	6 percent
over 5,000,000 cases:	7 percent

Because of the range in can sizes, it is difficult to obtain a range of production in terms of weight. The production of frozen meats, however, is listed in terms of weight. Plants producing frozen meats only range in size as indicated below:

Under 909,000 kilograms (kg):	26 percent
909,000-2,273,000 (kg):	26 percent
2,273,000-4,545,000 (kg):	14 percent
4,545,000-9,091,000 (kg):	10 percent
9,091,000-22,727,000 (kg):	16 percent
22,727,000-45,455,000 (kg):	7 percent

These size distributions should be regarded as approximate. A relatively small proportion of the meat processing plants in the country are represented in The Directory of the Canning, Freezing, Preserving Industries, where the above data were obtained.³ In addition, size information was not listed for many of the plants represented in the Directory. Average dairy farm sizes ranges from about 30 cows per farm to over 400 cows per farm (see table A-2). The largest farms tend to be in the West, the Southeast, and Hawaii. Many of those states that have extremely large numbers of farms, such as Wisconsin and Minnesota, have relatively small herds per farm -- only 37 cows per farm in Wisconsin and 29 cows per farm in Minnesota. During the last half century, dairy plants have handled the cream and/or milk from between a few up to thousands of farms. Recently the number of dairy plants as well as the number of farms has been decreasing, and those remaining have increased substantially in size. Daily volume can range from a few thousand to a few million kg of milk. For plants producing butter, average annual output is about 1.5 million kg (3.3 million lbs) and it stands at about 2.1 million kg (4.5 million lbs) for plants producing cheese. Average annual ice cream output is around 2.9 million liters (768,000 gallons). Cottage cheese and nonfat dry milk output

averages 1.3 million and 3.3 million kg (2.9 and 7.2 million lbs) per plant per year, respectively.

The size distribution of vegetable canning plants according to the Directory³ is:

Under 100,000 cases:	19 percent
100,000-250,000 cases:	24 percent
250,000-500,000 cases:	18 percent
500,000-1,000,000 cases:	16 percent
1,000,000-2,000,000 cases:	10 percent
2,000,000-5,000,000 cases:	9 percent
over 5,000,000 cases:	4 percent

Size data were available for 500 of the 1,047 plants listed. Again, can sizes vary among plants. The size distribution of frozen food plants (those plants producing frozen fruits and vegetables only--no canning operations) is:

Under 909,000 kilograms (kg):	23 percent
909,000-2,273,000 (kg):	20 percent
2,273,000-4,545,000 (kg):	15 percent
4,545,000-9,091,000 (kg):	12 percent
9,091,000-22,727,000 (kg):	14 percent
22,727,000-45,455,000 (kg):	11 percent
over 45,455,000 (kg):	5 percent

Frozen food plants of unknown size number 245; only 123 were classified as to size.

Although the smaller sizes of meat and fruit/vegetable plants are more prevalent according to the above data, the number of plants in the largest size categories probably is understated. The Directory³ gives size data only for companies; if a company has more than one plant, the size of the plants cannot be deduced. Thus, the very large food-processing companies with several factories--many of which may be quite large themselves--are not included in the above size distributions.

Aquaculture plants for which data were obtained process from around one million to possibly over 11 million kg (2 million to over 25 million pounds per year. Idaho, with its seven plants, produces 9.5 to 10 million kg (21 million to 22 million lbs) of trout per year, or an average of 1.4 million kg (3 million lbs) per plant. Two plants in Alabama process 0.9 million and 1.8 million kg (2 million and 4 million lbs) of catfish, respectively, per year, while 19 other plants process smaller amounts of catfish along with other fish. In Mississippi there are five plants capable of processing over 4,500 kg (10,000 or more lbs) of farm-raised catfish per day, with a maximum combined processing capacity of about 91,000 kg (200,000 lbs) daily. Construction is to begin soon on two new plants that will have the capability to process an additional (combined) 82,000 kg (180,000 lbs) of catfish daily.

C. Seasonality

Seasonality of plant operations is an important consideration in matching power requirements to wind energy availability. Broiler plants often process higher volumes in the summer, and dairy plants frequently operate at high capacity in spring and summer and at low capacity in fall. Some aquaculture plants also are seasonal. Crayfish in Louisiana are harvested beginning in November, with the most intensive harvesting beginning in March or early April. During this time, crayfish are supplied fresh to the public. Freezing of crayfish tails begins in May and June, so that supplies for restaurant demand may be met during the off-season (July to October). Plants processing trout, catfish, and other fish in the western and southeastern states generally operate year-round, as do oyster aquaculture operations. In fact, one of the advantages of aquaculture is the provision of a year-round supply of fish rather than reliance on seasonal fishing activity.

Seasonality is found to the greatest extent in fruit and vegetable processing; many of these plants operate for only a few months. Others smooth the peaks in their operations by processing a wide variety of products. They also may hold some products for further processing when the peak harvesting season is finished. Most of the plants inventoried seem to do both these things. Others include meats and other nonseasonal items in their operations. Those that process only a few items and thus are likely to operate for only a part of the year are listed, by state, in table A-3. They are listed by product, for the top ten products, in table A-4.

Some of the products listed in table A-4, such as pickles, sauerkraut, and vinegar can be produced all year. Potato processing plants probably operate all year, as potatoes are easily stored for long periods. Opening and closing processing dates for some fruits are as follows: most states process apples between 15 August and 15 September, although the earliest and latest dates are 1 August and 31 December, respectively. Berries are canned or frozen throughout the summer. Blackberries are processed during June and July and raspberries in July and August. Blueberry processing takes place from June through September, depending on the state: June through July is the season in the southern states, while late July and early August is the season in Michigan, and August through early October in Washington. Strawberry time is April through October in Arkansas, May and June in Oregon, and June and July in other states that grow this crop. Cherries are harvested and ready for processing in June and July in several states; in July and August in Michigan, Montana, and Ohio; May through July in California, and June through August in New York.

Processing times for most vegetables are similar to those of the fruits listed above. Corn is canned between July and October, with earlier dates in the South and a season of August-September in most states. The bean season varies with type of bean, and may be anywhere from April to December, usually between June and September. In June and July most peas are processed and August through October is the main tomato season, but both these seasons vary somewhat by state. Tables B-1 and B-2 show processing seasons for these and other products on a state basis.

III. EQUIPMENT, PROCEDURES, AND ENERGY USE

A. Meat Slaughtering and Processing

Proper procedures for cooling and heating in animal slaughtering and meat processing plants are essential to ensure a safe, high-quality product. Refrigeration requirements and processing operations involving heating and cooling procedures are described separately for slaughtering plants and for further processing of meats.

Slaughtering

In slaughtering plants refrigeration is necessary for chilling the carcasses after slaughter and dressing, to preserve the texture of the meat and reduce the growth rate of microorganisms. Beef carcass chilling usually is done overnight in chilling rooms. The beef then is shipped in refrigerated trucks or moved to holding rooms where the temperature is maintained at 1° to 2°C (34° to 36° F) to complete the process.

Refrigeration systems commonly used in chilling and holding rooms are operated with ammonia as the primary refrigerant. The most common types are dry coil systems, which include unit coolers equipped with coils, defrosting equipment, and fans for air-vapor circulation. After chilling, the carcass is broken into the main cuts, which are vacuum packed and readied for shipment. Temperatures must be held under 4°C (40° F) to prevent development of pathogenic organisms in beef, -3° to -2° C (26° to 28° F) for pork, and 0° to 1°C (32° to 33°F) for variety meats such as hearts, livers, and kidneys.

Hot water and steam are required during dressing operations for removing hair on hogs or feathers on poultry (scalding and singeing), and for constant cleaning of the plant and carcass washing. The scalding operation for hogs requires about 94,625 liters (25,000 gallons (gals) of water to fill the scalding tub and 265 liters/minute (70 gals/min) hot (58°C) make-up water, for a rate of 730 hogs per hour. In addition, 455 kg (1,000 lbs) of steam per hour are required in the scalding tub.

Modern poultry slaughtering practice on a continuous processing line involves automatic electrical stunning, bleeding for 90 to 120 seconds, and scalding or singeing for up to 2 minutes to loosen feathers. Though scalding usually is done in warm water (semiscalding, from 51° to 55°C; or subscalding, from 59° to 60°C), steam spray scalds are being developed for better sanitation. Semiscalding, which retains skin pigment, is used on broilers marketed in the chilled state, whereas subscalding is used on turkeys and mature chickens or broilers to be further processed and frozen.

Most evisceration and feather removal procedures now are being performed by mechanical means. The poultry must be thoroughly washed after evisceration and cooled to below 2°C (35°F) in less than 2 hours to retard microbial growth. The cooling is done with either tanks of crushed ice or, more frequently, big mechanical continuous immersion slush ice chills, which are fed by conveyor lines. After cooling, the poultry are cut into parts and packed in boxes for freezing, packed in ice whole and ready to cook, or frozen for distribution.

Hot water requirements for sanitation in slaughtering plants are substantial. For example, on a once-thorough basis alone, approximately 1,136 liters (300 gals)/min hot or tempered water go through a plant with a kill rate of 80 beef (330 hogs) per hour. Animal viscera are inspected on a moving pan or flight inspection table, and as the pans return they are washed and rinsed in a series of hot and cold water sprays. About 380 liters (100 gals)/min water are required for washing and rinsing the pans in this size plant, half of which is 82°C (180°F) water. Dressed carcasses are washed in a cabinet washer prior to inspection, using about 980 liters (260 gals)/min 43°C (110°F) water.

Freezing

Rapid freezing is important to the appearance and texture of many frozen meats, and is provided most frequently by blast freezers or tunnels. Blast chill temperatures vary, but usually range from -29° to -40°C (-20° to -40°F). Air velocities are high at over 8 feet per second. The time required for freezing depends on the shape and type of product, method of packing, and placement of loads in the freezer.

Other types of freezing include immersion in a refrigerated liquid or by a shower of liquified gas such as nitrogen, contact plate freezing, and slush freezing. Some of the refrigerated liquids in use for immersion freezing include nitrogen, carbon dioxide, and Refrigerant 12, a fluorinated hydrocarbon the temperature of which can be adjusted. Temperatures of these liquids are about -29°C (-20°F). The liquid nitrogen shower system has been introduced for freezing the outer shell of products to -73°C (-99°F) or below, after which the entire product may be equilibrated in a holding room to around -23°C (-9°F). Temperature in the freezer box where the liquid nitrogen is released may be as low as -157° C (-250° F). Individually Quick Frozen (IQF) food freezing with carbon dioxide also is used, particularly for freeze drying.

In the contact plate system, freezing coils are placed in a plate and the food placed between the plates. The temperature is usually about -34°C (-30°F), although many plants now freeze the products at or near -40° C (-40°F).

Once freezing has been accomplished, the products are maintained in storage freezers. Temperatures in storage freezers usually range from -18° to -26°C (0° to -15°F).

Processing

Processed meats include smoked, cured, canned, cooked, dehydrated, and intermediate-moisture products. The multitude of processed products today makes individual description impossible, but heating and cooling operations generally are similar.

Cooking

Much of the energy used for heating operations in the meat-processing industry is in the form of cooking. Meat cooking is of two basic types: dry heat and moist heat. Dryheat cooking, including broiling, roasting, frying, and braising, usually is reserved for the most tender meats or used in low-humidity smokehouses. Broiling is not frequently used, and frying is used only for thin cuts of meat. Roasting occurs at temperatures of 121° to 177°C (250° to 350°F), the required temperature depending on the cooking time desired. Higher temperatures--around 205°C (400°F) - may be used for the last 15 to 20 minutes of cooking.

Most meat cooking is of the moist-heat type, or a combination of dry- and moist-heat cooking. Moist-heat cooking uses hot liquid or steam, with water added during the procedure. Stewing, pot roasting, simmering, and swissing are common moist-heat procedures. Simmering is employed to cook certain cuts of beef and some sausages such as braunschweiger. The products are heated to temperatures below boiling (71° to 77° C). When closed systems are used, the build-up of pressure raises cooking temperatures. Pressure cooking is the extreme form of closed-system cooking. Live steam sometimes is injected into smokehouses to accelerate the rate of temperature rise during the final phases of cooking, after which the meat is removed from the smokehouse, and finished off with steam.

Cooking often is accomplished by methods that combine moistheat and dry-heat methods (e.g., with tough cuts such as shank meat, head of round, breast of lamb, chuck roasts of beef). Sausages, hams, and roasts for precooked and frozen meals often are cooked by combination methods to reduce shrinkage and improve flavor. Braising is one such method, and involves first heating the meat in fat, then simmering.

Canning

Canning of all processed foods is to provide safe products for consumption that preserve as much as possible their flavor, texture and appearance qualities. However, due to the low acidity of meat products the problems of spoilage from microorganisms and enzyme activity are compounded because extreme heat treatments (as in sterilization) can result in loss of texture and flavor of the product.

Commercial sterile canned meat products generally reach an internal temperature of 107°C (225°F), but this temperature may be as low as 102°C (215°F) depending on salt and nitrite content. The most important process in sterile canning operations is retorting, a process that subjects products to high temperatures for sufficient duration to destroy any organisms that could affect health. Retorts are steel tanks in which metal crates are placed for cooking and subsequent cooling, and may be nonagitating, continuous agitating, or hydrostatic. Most canned meat products manufactured in the United States are cooked in nonagitating retorts, enclosed pressure vessels that operate in excess of atmospheric pressure and use pure steam to superheat water. The steam is provided by an outside source, usually a steam boiler or generator, and the process usually is performed on a batch basis. Continuous agitating retorts agitate the cans inside, resulting in a shorter processing schedule with faster rate of heat penetration into the meat.

With hydrostatic retorts, the steam pressure is maintained by water pressure. These retorts are made up of water and steam chambers referred to as legs. The temperature of water in the water chamber varies from 16° to 107°C (60° to 260°F); that of steam in the steam chamber is controlled by pressure produced by the water chamber. Cans are conveyed through the machine by means of carriers connected to chains, and enter a water chamber where the temperature is about 82°C (180°F). As the cans move down the chamber they encounter increasingly hotter water. In the lower part of the chamber, the water temperature reaches 107° to 118°C (225° to 245°F). Near the water seal area next to the steam chamber the water temperature approaches that of steam, and in the steam chamber, cans are exposed to temperatures between 116° and 130°C (240° and 265°F) (depending on the product being sterilized). Some cookers make the cans complete two passes, one up and one down the steam chamber; other models are designed for up to six passes. After leaving the steam chamber a can goes through a water seal into water ranging in temperature between 107° and 118°C where the cooling cycle begins. The can moves through progressively cooler water to the top of the leg where water temperature is between 88° and 107°C, or in some models as low as 16°C. Can cooling then is completed.

A major advantage of the hydrostatic cooker is that the product is subjected to progressive temperature and pressure change, which does not weaken the can. Heat and water savings are also made through recirculation of the water. Heat from the sterilized cans is passed to the cans following, greatly decreasing steam requirements. Retention time at sterilization temperature can be reduced by about 10 percent as compared to still retorts.

Some meat products, such as canned and picnic hams, are not subject to sterilization but are instead pasteurized. Though canned, they are considered perishable products and must be refrigerated. The products are cooked in 69° to 77°C (155° to 170°F) water in open cooking tanks until internal temperature of the meat is 66° to 69°C. The length of cooking is determined by size of can but ranges between 120 and 400 minutes. The products then are cooled quickly to an inside temperature between 21° and 3° (70° and 100°F).

All sterile canned meats should be stored at or below 21°C, which will ensure a product of good quality for 4 to 5 years. Lower temperatures result in longer shelf life. Pasteurized canned products ideally should be stored in dry refrigerated rooms at temperatures not exceeding 4°C (40°F). Proper shelving at these temperatures will result in a shelf life of 2 years or more.

Aseptic canning is a method of sterilizing container and products separately, then assembling them in an aseptic atmosphere to obtain a sterile package that can be stored at room temperature. The product to be canned is heated, while flowing continuously, to a temperature of around 149°C (300°F), quickly achieving sterilization. All portions of the product are subject to optimum conditions of time and temperature, thus avoiding the possibility of overcooking and change in flavor or color. Nevertheless, aseptic canning techniques have not been readily accepted by meat canners, as the products must be homogeneous and able to flow readily--conditions which many meat products are unable to meet.

Another method of avoiding overcooking of meats is the "Flash-18" process, in which cans are filled in a sterilized room under 8.2 kg (18 lbs) of air pressure at a temperature of 107°C (225°F). The temperature is held constant to attain sterilization and the cans are closed under the same conditions, thus eliminating retorting. The closed cans then are cooled rapidly.

Energy Sources and Requirements

Meat-packing plants alone consume about 10 percent of all energy used in the "food and kindred products" sector in the United States, or about 103,000 TJ (98 trillion Btus) in 1977. Processing of sausages and other meats consume an additional 2 percent, and poultry dressing plants yet another 2 percent.

Fuel oil, natural gas, and electricity are the primary energy sources used in slaughtering plants and meat processing. In virtually every state in which slaughtering and meat processing are an important industry, natural gas and electricity consumption for these purposes are substantial. Fuel oil is used substantially in twelve states (primarily Illinois, Minnesota, Nebraska, and Pennsylvania), while natural gas is used in 31 (with California, Colorado, Illinois, Iowa, Minnesota, Nebraska, Texas, and Wisconsin the leading states), and electricity in 39 (particularly California, Georgia, Illinois, Iowa, Nebraska and Texas). Only a few states in the Midwest have plants that operate on coal.

Energy consumption is affected by the age, size, and location of plants, and by percent of plant capacity utilized and the technical design and efficiency of boilers and other equipment. Older plants tend to be less efficient than more modern ones, and larger plants usually are more efficient than smaller ones. Plants located in northern climates require more space heating, while those in southern states need more refrigeration. Season of year is also a factor in poultry plants, but is less important in most other meat plants. Consumption of different fuels and electricity by state is presented in tables C-1 and C-2. Table C-3 classifies energy consumption by different energy sources on a heat basis, for comparison purposes.

Fossil Fuel Consumption

Hot water/steam processes and refrigeration in slaughtering and meat-processing plants are highly energy intensive. The former require fossil fuels for heat generation and, because natural gas is the fossil fuel most commonly used, several studies have considered natural gas requirements in meat plants. A 1975 Federal Energy Administration study determined that boilers accounted for 95 percent of natural gas use by slaughter-houses, and 88 percent of that used by processing and combination slaughtering-processing plants. Hot water for hog singeing, sanitation, and other uses also most frequently is furnished by natural gas. Eight cubic feet of natural gas per hog slaughtered is estimated to be required for the singeing operation⁴. A small plant slaughtering only about 300 hogs per year thus would require 2,400 cf natural gas for the singeing operation alone (as indicated in table A-1, over 68 percent of plants slaughtering hogs have a kill rate of under 1,000 animals annually, averaging 278 hogs/yr). A large plant slaughtering 650,000 hogs annually (the largest 109 hog-slaughtering facilities kill 69.98 million hogs per year, as shown in table A-1) requires 5.2 million cf natural gas.

Energy demands in terms of flow rates and temperatures of hot water and steam for three selected meat plants were determined by Lund et al.⁵ A purpose of this study was to determine the total hot water flow required for all unit operations requiring hot water under 100°C (212°F). One plant both slaughtered and processed hogs and beef, with output of 680,000 kg (748 tons)/day; the second slaughtered hogs at the rate of 500,000 kg (550 tons)/day; and the third processed meat products at a rate of 64,000 kg (70 tons)/day. The flow rate of hot (82°C) water ranged from 185,000 to 340,000 kg/hr in the first plant; 7,000 to 53,000 kg/hr in the second plant; and 1,500 to 36,500 kg/hr in the third plant. Peaks and troughs varied regularly from week to week. Load requirements for water ranging from 11°C to 82°C were 1.8 billion kJ (1.7 billion Btus)/day, 330 million kJ (313 million Btus)/day, and 23 million kJ (22 million Btus)/day, respectively.

Based on a 6-day production week 52 weeks a year, annual production in these meat plants was about 212 million, 156 million, and 20 million kg (233,000 tons, 171,000 tons, and 22,000 tons) per year, respectively. Approximately 514.45 million, 94.72 million, and 6.66 million cubic feet of natural gas, respectively, were being consumed for hot water generation annually.

The primary use for fuel in broiler-processing plants is for heating water in boilers for scalding and washing operations. Other uses include space heating, singeing, and cooking if the poultry is further processed in the same plant. Rendering operations also are fuel-intensive. Modern broiler processing plants, processing at least 9,600 birds per hour, require from 2.64 to 6.33 TJ (2.5 billion to 6.0 billion Btus) 1 per month,¹ and between 31.68 and 75.96 TJ (30 to 72 billion Btus) annually.

Average annual fuel consumption for several southeastern broiler-processing plants studied by Jones and Lee in 1975 and 1976 was 1,545 kJ/kg (741 Btu/lb) of processed ready-to-cook weight. Small plants averaged slightly more, while large ones averaged less. Individual plant consumption rates ranged from 1,064 kJ/kg (510 Btu/lb) to a high of 2,161 kJ/kg (1,036 Btu/lb). Rendering plants were found to use about the same amount of fuel as processing plants.¹ Whitehead and Shupe found average fuel consumption rates in broiler plants to be considerably lower. In their survey of three southeastern broiler-processing plants, they found consumption rates of about 4,700, 1,500, and 1,300 kJ/bird. The plant with the highest rate included an on-site rendering plant. Assuming an average weight of 1.8 kg/bird,* these rates were about 2,600, 836, and 700 kJ/kg, respectively. The three plants processed about 27 million, 43 million, and 74 million kg annually.²

Broiler plant fuel consumption rates per kg tend to be lower during the summer because of the higher volume processed (total fuel consumption thus is highest during the summer) and higher temperatures. The differences in ambient temperatures create variations in space heating requirements, and greater load factors in boilers result from seasonal differences in water temperatures. Jones and Lee found consumption decreases of 7 to 9 percent with each 10

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According to agricultural statistics of various states, average broiler weights range from around 1.6 to 3.2 kg (3.6 to 7.0 lbs); most are around 1.8 kg (4 lbs).

degree rise in average ambient temperature. They found summer fuel consumption averaging 1,493 kJ/kg (716 Btu/lb) of poultry processed, with monthly averages as low as 1,251 kJ/kg (600 Btu/lb); winter consumption rates averaged 1,990 kJ/kg (954 Btu/lb).¹

Poultry plants with extremely large volumes tend to have lower fuel consumption rates (although higher total consumption) regardless of seasonal factors. Consumption declines of 6 to 6.5 percent occurred with each 455,000 kg (million pound) increase in monthly volume of poultry processed (Jones and Lee, 1977).¹ Seasonal differences in fuel consumption tend to decrease as the volume processed rises—temperature variation has a greater impact in the relatively low volume winter months. Seasonal fuel consumption also is closely related to the utilization of plant operating capacity; it takes smaller amounts of additional fuel to process added volumes of poultry at higher levels of plant capacity. Jones and Lee found consumption decreases of between 8 and 9 percent with each 10 percentage points increase in plant operating capacity.¹

As in other meat slaughtering and processing facilities, natural gas is the fossil fuel most commonly used in poultry plants. Natural gas accounts for 65 to 85 percent of all fuel purchased by poultry plants, with fuel oil the second choice.² Most of the plants in the South use natural gas with fuel oil a secondary source. In the Georgia-Alabama area, where large numbers of plants are located, modes of fuel consumption include (a) natural gas only, on a noninterruptible basis; (b) natural gas plus fuel oil, with gas on an interruptible schedule; and (c) fuel oil only where gas is not available. Propane gas occasionally is used, but is more expensive than the other fuels.¹ Table 5 shows the amount of fuel used annually for three sizes of poultry plants between 1974 and 1976. Table 6 shows fuel use in the three plants studied by Whitehead and Shupe in 1976-1977.²

Electricity Consumption.

Less information is available on the electricity demand than on fossil fuel requirements of meat-packing and processing plants. The demand is substantial, primarily because of refrigeration requirements; for instance, it has been estimated that about 7 percent of all energy used in slaughtering plants is used for refrigeration.⁴ Because of the lack of data, electricity requirements for poultry plants only are summarized below.

Electricity in broiler-processing plants is used for ventilating and cooling buildings; operating machinery and equipment on processing lines; cooling, refrigerating, and freezing the product; generating ice for packing and shipping; lighting and supplemental heat; and on-site waste disposal facilities. Particularly large quantities of electricity are consumed in the refrigerating, freezing, and ice-building applications. Jones and Lee found the average annual electrical consumption for plants to be around 145 kWh per thousand kg (66 kWh/000 lbs) in primary operations, with small plants consuming at a slightly higher rate and large plants at a lower rate. Plants with freezer facilities, waste disposal ponds, and shop and office units included as part of the processing plant operations had an average consumption rate of 253 kWh/000 kg (115 kWh/000 lbs) processed. Individual plant

Table 5. AVERAGE ANNUAL FUEL CONSUMPTION FOR THREE SIZES OF BROILER-PROCESSING PLANTS, 1974-76^a

Size Plant	Average Annual Volume (millions kgs) ^{b,c}	Type Fuel	Annual Fuel Use	
			kJ/kg	Total (GJ)
Small	16.36	NG + FO	1,950	28,663
Medium	26.86	NG + FO	1,694	40,881
Large	39.64	NG + FO	1,601	57,042

^aExcluding rendering plants, broiler hatcheries, and feed mills.

^bConverted to metric units from units given in the original source.

^cBased on ready-to-cook eviscerated weight.

Source: Harold B. Jones, Jr., and Steve K. Lee, *Energy Use and Costs in Broiler Processing Plants in the South*, University of Georgia Research Bulletin No. 205, 1977, p. 10.

**Table 6. FOSSIL FUEL USE FROM JULY 1976 THROUGH JUNE 1977 FOR
THREE POULTRY-PROCESSING PLANTS**

Size Plant	Average Annual Volume (millions birds) ^a	Annual Fuel Use				NG + FO	
		Natural Gas		Fuel Oil			
		kJ/bird	Total (GJ)	kJ/bird	Total (GJ)	kJ/bird	Total (GJ)
60,000 birds/day ^b	15	4,515	67,500	204	3,000	4,719	70,500
100,000 birds/day	24	1,055	25,400	452	11,000	1,507	36,400
200,000 birds/day	41	886	35,900	452	18,400	1,338	54,300

^aCalculated from kJ/bird and total fuel use figures given in the source.

^bIncludes on-site rendering plant.

Source: W. K. Whitehead and W. L. Shupe, *Energy Requirements for Processing Poultry*, ASAE Technical Paper No. 78-3039, June 1978.
Calculated from tables 4 and 5.

consumption rates were highly variable, ranging from a low of 101 kWh/000 kg (46 kWh/000 lbs) to 359 kWh/000 kg (163 kWh/000 lbs), depending on the specific facilities and functions included. Table 7 shows annual electricity consumption in the plants surveyed by Jones and Lee (plants were divided into three groups; figures are averages for these groups).¹

Total electricity usage in the three plants surveyed by Whitehead and Shupe ranged from 186 kWh/000 head to 257 kWh/000 head (about 103 kWh/000 kg and 143 kWh/000 kg, respectively). Electricity use for certain processes in these plants is shown in table 8. Refrigeration and other mechanical drives were found to account for more than 80 percent of the total calculated electrical use.²

Electricity consumption, along with fuel use, varies substantially by season in broiler-processing plants. Consumption rates are higher in the summer, when warmer temperatures cause greater power requirements for coolers and freezers, icemaking equipment, and air-conditioning needs. Plants processing large volumes generally have lower consumption rates regardless of seasonal differences. Electrical consumption rates can decline 7 to 8 percent with each 455,000 kg (one million lb) increase in monthly volume of poultry processed.¹ Due to technical efficiencies in utilizing a given power load for refrigeration, ice making, and other functions, smaller amounts of additional electricity are required to process the higher volumes of poultry. Jones and Lee found electrical consumption rate declines of 8 to 10 percent with each ten percentage points increase in plant operating capacity.¹

B. Dairy Processing

Maintaining and changing temperature precisely at various stages of production through heating and cooling processes are essential in providing dairy products of high quality and proper consistency. Refrigeration in the form of cooling tanks, freezers, and cold storage rooms preserves products both before and after processing. Refrigeration also furnishes chilled water for cooling products after pasteurization, and holds or lowers product temperatures during processing. Chilled water usually is refrigerated at a central source and recirculated by pumps through the various pieces of dairy equipment that require cooling. Such refrigeration may be by flash-cooling equipment or through an ice bank, with some plants using both systems. Pasteurization, a process whereby the product is subjected to heat treatment, is used to eliminate the transmission of diseases from either animals or organisms that might enter the milk after production.

Proper sanitation and cleaning of equipment and plant are essential to ensure the production of wholesome products. The processes and sanitation procedures on dairy farms and in fluid milk and other product processing that require heating and cooling applications are discussed below. Sanitation procedures for farms and plants are described in a separate section following processing requirements.

**Table 7. AVERAGE ANNUAL ELECTRICAL CONSUMPTION
FOR THREE SIZES OF BROILER-PROCESSING FIRMS
1974-1976**

Size Plant	Average Annual Volume	Annual Electricity Use	
	(millions kg) ^{a,b}	kWh/kg ^b	Total (000 kWh)
Small	16.73	0.189	3,162
Medium	26.77	0.145	3,882
Large	39.32	0.123	4,836

^aBased on ready-to-cook eviscerated weight.

^bConverted to metric units from units listed in source.

Source: Harold B. Jones, Jr., and Steve K. Lee. *Energy Use and Costs in Broiler Processing Plants in the South*, University of Georgia Research Bulletin No. 205, 1977, p. 28.

Table 8. ELECTRICAL USE IN SELECTED PROCESSES FOR THREE POULTRY-PROCESSING PLANTS, JULY 1976 THROUGH JUNE 1977

Process	Electrical Use					
	Plant 1 (15 mil. birds/yr) ^a		Plant 2 (24 mil. birds/yr) ^a		Plant 3 (41 mil. birds/yr) ^a	
	kWh/000 birds	Total kWh (000)	kWh/000 birds	Total kWh (000)	kWh/000 birds	Total kWh (000)
Slaughtering, scalding, defeathering	17.97	270	26.58	638	24.77	1,016
Scalders	4.76	71	12.14	291	6.01	246
Pickers	11.09	166	9.57	230	12.36	507
Conveyors	0.48	7	1.01	24	0.30	12
Mechanical drives	0.20	3	0.71	17	1.22	50
Fans	0.79	10	2.18	52	1.83	75
Heat, a.c.	—	—	—	—	0.26	11
Lights	0.65	10	0.97	23	2.79	114
Eviscerating, chilling	15.75	236	21.84	524	10.21	419
Chillers	1.89	28	2.04	49	3.04	125
Conveyors	2.44	37	3.05	73	0.25	10
Mechanical drives	1.65	25	7.02	168	2.87	118
Pumps	1.48	34	—	—	—	—
Fans	0.40	6	2.64	63	1.38	57
Heat, a.c.	1.25	19	1.96	47	0.52	21
Lights	6.64	100	5.13	123	2.15	88
Process refrigeration	119.08	1,786	88.33	2,120	96.06	3,938
Compressors, condensers	106.38	1,596	79.80	1,915	83.28	3,414
Ice handling	2.19	33	2.67	64	8.64	354
Pumps	8.83	132	4.93	118	3.34	137
Lights	1.68	25	0.93	22	0.80	33
Total, above processes	152.80	2,292	136.75	3,282	131.04	5,373
Total plant electrical use	252.05	3,781	256.67	6,160	186.47	7,645

^aFrom table 8.

Source: W. K. Whitehead and W. L. Shupe, *Energy Requirements for Processing Poultry*, ASAE Technical Paper No. 78-3039, June 1978.

Dairy Farms

Cooling milk at the dairy farm now is done mostly in bulk tanks, which hold the milk for truck pick-up. Tank capacity ranges from 760 to 11,360 liters (200 to 3,000 gals), with a few larger tanks. As the cows are milked mechanically, the milk flows through sanitary tubing to the insulated milk tank, which has an inside lining of stainless steel. An electric motor operates an agitator for stirring the milk, and mechanical refrigeration begins to cool it even during milking.

The tank must have sufficient refrigerated surface at the first milking to cool 50 percent of its capacity in an everyday pick-up tank (25 percent of its capacity in a tank for every-other-day pick-up) from 32° to 10°C (90° to 50°F) within the first hour, and from 10° to 4°C (50° to 40°F) within the next hour (U.S. Public Health Service Sanitary Standards).

During subsequent milkings there must be sufficient refrigerated capacity to prevent the temperature of the blended milk from rising above 7°C (45°F). Some of the larger farms use plate heat exchangers to cool the milk rapidly. Cooled milk then may be stored in a vertical cylinder, or silo tank. Milk from the tank then is pumped into the truck.

Fluid Milk Processing

At the dairy plant, the milk is held in insulated or refrigerated storage tanks for up to 72 hours between receipt and processing. Some silo-type storage tanks of up to 227,000 liters (60,000 gals) are currently in use. The tanks must maintain the milk at temperatures of 4°C (40°F) or less. Most plants store raw milk at between 1° and 3°C (34° and 38°F) to minimize psychrophilic bacterial growth.

Processing involves classification and separation, pasteurization, homogenization, and flavor treatment. Clarification in which a clarifier removes foreign particles from milk, takes place at temperatures of 10° to 35°C (50° to 95°F). The lower end of this range is preferred to avoid foaming of the milk. A separator extracts fat from the milk to provide the correct fat content. The milk is heated in this process to at least 32°C (90°F) and sometimes to 74°C (165°F), although some recently developed separators may be used on cold milk.

The pasteurizer heats the raw milk to destroy pathogenic or disease-producing organisms. Several temperature-time treatments currently are recognized by the U.S. Department of Public Health for pasteurization of milk in indirect heat exchanges:

63°C	for	30 minutes
72°C	for	15 seconds
88°C	for	1 second
90°C	for	0.5 second
94°C	for	0.1 second
96°C	for	0.05 second
100°C	for	0.01 second

At 88°C (191°F) and higher, the pasteurization standard is sufficiently high to ensure the inactivation of pathogenic organisms in all fluid milk products. For pasteurization of milk products with added sweeteners, or butterfat below 88°C, temperature and time requirements are 66°C (150°F) for 30 minutes or 75°C (166°F) for 15 seconds.

Processes requiring 30-minute hold time are called "batch" or "hold" pasteurization methods. All other pasteurization heat treatments are achieved by continuous process methods. The 15-second 72°C standard is referred to as high temperature short-time pasteurization (HTST), whereas temperature/time combinations of 88°C and up are called ultra-high temperature (UHT) or higher-heat shorter-time (HHST) pasteurization. Most processed milk today is pasteurized by HTST processes. Only a few low-volume products that are mixed or otherwise handled as a batch are still pasteurized by the hold method.

Homogenization, during which milk is forced through small openings under pressure to reduce the size of butterfat globules (and thus improve stability of the milk product), takes place either immediately after preheating for pasteurization, or directly after pasteurizing. Many plants then use a vacuum process in addition to pasteurization to remove taints, off-flavor, or odors possess by volatile or low-boiling components in the milk. In this process, milk passes through a direct steam injector or steam infusion chamber where it is heated with culionary steam to a temperature of 77° to 93°C (170° to 200°F). It is then sprayed immediately into a vacuum chamber where both moisture and volatiles are removed, and is cooled by evaporation to the pasteurizing temperature and pumped to the regeneration section of the pasteurizing unit.

After the above processes have been completed, the milk is cooled in the pasteurizer cooling section to 4°C (40°F) or below. Usually it is stored at this temperature until packaged for shipment.

Manufactured Dairy Products

The major manufactured dairy products are butter, cheese, concentrated and dried milk products, and frozen desserts. In general, the principles of receiving and storage are the same as for fluid milk, but plants may receive some partially processed products. Processing systems incorporating heat treatment, homogenization, and separation are designed and applied in similar manner for handling fluid milk, milk products, cottage cheese skins, cheese dressing, and cultured products. Many plants produce a combination of products to take advantage of complementary operations whereby a byproduct of one or more operations may be used for further processing. Examples of combination plants include:

- Butter and nonfat dried milk plants, where milk is received and separated into cream for production of butter and skim milk for drying.

- Fluid milk, cottage cheese, and ice cream plants where leftover cream from separating skim milk for cottage cheese is used as an ingredient in ice cream making.

- Cheese- and whey-processing plants in which whey processing is an extension of cheese-processing operations. Many combination plants such as fluid milk/cottage cheese/ice cream plants utilize a single HTST system for processing milk by products and ice cream mix. They also use batch blending systems or automatic batch weigh systems to assemble these products prior to pasteurization.

Butter

Though butter production has fallen in recent years as consumers have switched to margarine-type substitutes, it is still an important product of the dairy industry. Much of the butter production takes place in combination butter-powder plants which get the excess of milk production after market needs for other dairy products are met. As a result the seasonal variation in butter production is large, with spring being the period of highest volume and fall the lowest.

Butter may be defined as a spread containing 80 percent milkfat and up to 16 percent moisture. It was produced traditionally by churning in batches, but is produced now on a continuous basis. First milk is warmed to 32° to 43°C (90° to 110°F) to improve separation efficiency, and then it is processed in a separator to achieve a 25 percent to 40 percent fat concentration to facilitate churning. The cream is pumped into the pasteurizer. Batch pasteurizing is usually at 71° to 77°C (160° to 170°F) for about 30 minutes, where HTST continuous pasteurization is at 66° to 120°C (150° to 250°F) for 16 seconds or more. The cream is immediately cooled to 4° to 10°C (40° to 50°F) and held cold for several hours, to partially solidify the milk-fat to permit churning. The cream is tempered to 10° to 13°C and rotated in a batch churn (a cylindrical drum or other container) until butter granules of about 5 millimeters are formed. The buttermilk is drained off and the butter is spray washed (if it is too soft) with water between -18° and -12°C (0° and 10°F). Water then is added to the churn until the volume of both butter and cream is equal to the former volume of the cream, and the butter is worked (churned slowly) to obtain the correct body characteristics. Butter should be stored at between -29° and -18°C (long period storage) or between 0° and 4°C for short periods.

Concentrated and Dried Milk Products

Milk may be concentrated as a necessary step in the preparation of condensed or evaporated milk products or as an initial step in the manufacture of dry milk. There are five basic types of evaporators used in the initial reduction of milk. These may be divided further into two types, namely conventional units, which utilize large volumes of low-pressure steam, and thermo-compression types which require high-pressure steam. Continuous types of evaporators have single, double or more evaporating effects. The greater number of effects produces a greater efficiency in steam usage.

A typical evaporator system incorporates the separator and cream pasteurizer. Raw milk is regeneratively heated by hot cream and further heated in a second-effect interstage heater to a separating temperature of

38°C (100°F). Cream produced by the separator is HTST-pasteurized, cooled, and transferred to cream storage tanks for use in other products. The whole milk (if the separator is bypassed) continues to the milk HTST pasteurizer balance tank, and passes through a series of heaters and vacuum chambers to achieve concentration. Where three-effect (three vacuum) evaporators are used, the temperature of product entering is 74°, 68°, or 57°C (165°, 155°, or 135°F) respectively with concentration levels after the first two effects of 20 percent and 30 percent total solids. The concentrated product then is transferred to a spray dryer for final drying to achieve a final product of 3 percent to 4 percent moisture. The product is sprayed into a chamber of hot air and the moisture removed.

Cheeses

Cottage cheese is made from skim milk. The skim milk is pasteurized at about 72°C for 15 seconds, discharged from the HTST pasteurizer into cheese vats, cooled to a setting temperature of 30°C (86°F), and maintained until the curd is ready to cut. The curd is cooked in the vats at about 54°C (130°F). The whey is drained and the cheese washed by adding water at 32°C (90°F) to the vat, and again drained. A second wash is done at 16° to 21°C (60° to 70°F), after which a final wash at 4°C is given to firm the curd. The packaged product, after processing, is maintained at 4°C or below.

Cheddar cheese is the predominant form of cheese produced, utilizing 65 percent of all fluid milk used to make such products. Raw or pasteurized whole milk is brought to a starter temperature of 30° to 31°C (86° to 88°F). The temperature is raised to 39° to 40°C (102° to 104°F) in about 45 minutes and held there for a similar period until the curd is firm. The whey then is drained and the cheese is cured for 6 months in a curing room which is maintained at a temperature of 7° to 16°C (45° to 60°F).

The general process involved in the manufacturing of most cheeses involves coagulation of the milk, cutting the curd, removing the whey and forming the curd, achieving desired acid content, salting and curing. Different cheese varieties are made by changing starter organisms, and making variations in the general processing procedures mentioned above.

Ice Cream

A typical ice cream mix is composed of milk fat (12.5 percent), serum solids (10.5 percent), sugar (15.0 percent) and stabilizer (0.3 percent). The general procedure for ice cream products is to pasteurize the mixture at 66°C (150°F) for 30 minutes if batch processed, or to utilize HTST procedures where continuous pasteurization methods (usually in large plants) are used. Homogenization also takes place. The mixture then is cooled and placed in a freezer. Freezing must be rapid to provide small ice crystals and incorporate enough air into the frozen product to give it the desired body. The ice cream is drawn from a continuous freezer at -6°C (22°F) with about 50 percent of the water frozen. In smaller plants, where batch processing is more often used, the batch freezer discharges the product at -4°C (25°F) with 35 percent to 40 percent of the water frozen.

After freezing and packaging, the ice cream is transferred to the hardening room to complete the freezing operation. The hardening room is maintained at -23° to -34°C (-10° to -30°F).

Sanitation

Procedures for cleaning dairy plant equipment vary considerably, but the major portion is cleaned by some sort of clean-in-place technique. Since the normal period of use of the equipment is less than one day, all tanks, vats, pipes, pumps and valves, heat exchangers, and packaging equipment are cleaned at least once every 24 hours. The processing and storage vessels often are spray cleaned, with water at temperatures of 54° to 57°C (130° to 150°F). For cylindrical and rectangular tanks, water is sprayed at a rate of 4.2 to 12.1 liters/square meter (0.1 to 0.3 gals/min/square foot) of internal surface; for vertical silo-type tanks flow rates are 31.0 to 37.1 liters/min/meter (2.5 to 3.0 gals/min/linear foot) of circumference. Vessels used for heating and cooling dairy products, which are more heavily soiled than those utilized only for storage or transportation, require hotter water for cleaning. Detergent solutions may be circulated for 45 to 60 minutes at 79° to 82°C (175° to 180°F).

Steam, hot water, or chemicals may be used to sanitize assembled equipment after cleaning. Steam sanitation is accomplished by maintaining steam in contact with the product contact surfaces for accepted time periods. Fifteen minute exposures are required when the condensate leaving the equipment is at 77°C (170°F), and only 5 minutes if the condensate temperature is 93°C (200°F). Hot water sanitation involves pumping hot water through to bring product contact surfaces into contact with the water, which should be maintained at the equipment outlet at 77°C for 5 minutes. Alternatively, a chemical sanitizer can be pumped through the assembly for at least one minute.

Energy Sources and Requirements

Dairy Farms

The primary consumption on dairy farms is electricity. Nearly 50 percent of the electrical energy consumed is for cooling milk for short-term storage and heating water for washing and sanitizing milk-handling equipment. Electrical energy for these two operations is estimated to average 300 kWh per cow per year.⁶ Also it has been estimated that the hot water electrical requirement is approximately 150 kWh/yr for each milking cow, assuming one gallon of 69°C (155°F) water per cow per day and original water temperature of 13°C (55°F). Thus about 150 kWh/yr per cow also is consumed in cooling the milk. A small dairy farm with 20 cows then requires a total of 6,000 kWh annually for both these applications; a large 400-cow farm requires about 120,000 kWh (see table A-2 for average sizes of dairy farms by state).

Dairy Plants

Dairy plants, like meat plants, consume substantial amounts of electricity and natural gas or fuel oil. Relatively few plants use fuel oil; plants in the states of New York, Minnesota, Wisconsin, and Pennsylvania use more than twice as much as the plants in any other state. In general, the midwestern

1 eastern states are highest in fuel oil use. California, Illinois, Minnesota, and Wisconsin use the largest amount of natural gas for dairy applications, but 27 other states also consume substantial amounts. The highest electricity use is in California, New York, Ohio, and Wisconsin. All the above states are states with relatively large numbers of dairy farms and plants. Tables C-1, C-2, and C-4 present data on fuel use by state for the dairy industry.

For the combined requirements of thermal and electrical energy used in receiving, processing, packaging, and storing products in a fluid milk plant, 626 kJ/kg (300 Btu/lb) is a figure commonly cited.⁸ Energy requirements vary with plant size, type, number of products, location, specific equipment used and equipment efficiencies, and other factors. Some such plants have reported using no more than 459 kJ/kg (220 Btu/lb) of product handled.⁸ However, other fluid milk plants surveyed have used much higher levels of energy; Goel et al. reported an average of 2,094 kJ/kg for two fluid milk plants in New York.⁹ Of the latter total, 319 kJ/kg (153 Btu/lb) was thermal energy, 755 kJ/kg (362 Btu/lb) electricity, and 1,020 kJ/kg (489 Btu/lb) energy used in packaging. Goel, Jordan, and Rao found direct energy requirements in a plant producing evaporated and condensed milk to be 2,127 kJ/kg (1,020 Btu/lb); requirements in a plant producing condensed and evaporated milk were reported at 2,278 kJ/kg (1,092 Btu/lb).¹⁰

Fossil Fuel Consumption

The annual energy demand for hot water usage in three fluid milk plants is shown in table 9. Besides fluid milk, the small and medium-sized plant produced some ice cream, while the large plant produced cottage cheese.

Thermal energy was the major component of the direct energy requirements found in concentrated and powdered milk manufacture, accounting for about 82 percent of the direct energy consumed. The two plants studied by Goel et al. used natural gas and fuel oil No. 6 in boilers. The steam generated was used for concentration or dehydration, space heating during winter, and hot water for cleaning; in one plant it also was used for sterilizing evaporated milk.¹⁰ Table 10 shows thermal energy use in these plants.

Fuel oils No. 2 and No. 6 were the sources of thermal energy in a cheese plant studied by Goel et al. during 1976, with fuel oil accounting for about 83 percent of the total.¹¹ Thermal energy was used for pasteurization of milk, hot water, condensing whey, and cleaning operations. Consumption of thermal energy averaged 1,711 kJ/kg (763 Btu/lb) milk and 21,692 kJ/kg (9,343 Btu/lb) cheese produced. The plant consumed approximately 64 million kg milk during the year, producing 3.90 million kg cheddar and 1.24 million kg mozzarella cheese and 0.45 million kg cream (average annual output for plants producing cheese, as indicated in section II, is about 2 million kg (4.5 million lbs)). It operated at high capacity from April through August, and at low capacity during October and November. Annual thermal energy consumption, based on the above statistics, was around 113 TJ (107 billion Btus).

**Table 9. ANNUAL DAIRY PLANT ENERGY DEMAND
FOR HOT WATER**

Size Plant (m kg rec'd/yr)	Average Water Temp. (°C)	Processing Days/Week	Annual Energy Demand (MJ)
2.953	66	3	66,820
9.845	66	5	374,700
78.756	79	6	2,170,000

Sources: S. M. Thomas, F. W. Bakker-Arkema, and A. L. Rippen, *Feasibility of Solar Water Heating in Milk Processing Plants in the Midwestern United States*, ASAE Paper No. 77-6519, December 1977, p. 7; A.L. Rippen, personal communication, November 1979.

**Table 10. ANNUAL THERMAL ENERGY USE IN
TWO FLUID MILK PLANTS PRODUCING
CONCENTRATED AND POWDERED MILK**

	Plant A	Plant B
Milk processed (m kg)	98.34	88.93
Skim condensed milk processed (m kg)	—	3.31
Products (m kg)		
Evaporated milk	14.61	—
Condensed milk	14.46	5.64
Powdered milk	—	3.62
Butter	4.18	2.02
Cream	—	1.54
Thermal energy consumed (GJ)	170,350	171,650
per kg milk (kJ)	1,734	1,930
per kg solids (kJ)	13,861	15,691

Source: V. K. Goel, W. K. Jordan, and M. A. Rao, "Energy Use Profile in Concentrated and Powdered Milk Manufacture," *Journal of Dairy Science* 62, No. 6 (June 1979):877.

Electricity Consumption

Detailed data on electricity consumption are given by Goel et al. for plants producing concentrated and powdered milk, and cheese plants.^{10,11} Annual electricity consumption was 38.65 TJ (36.64 billion Btus) and 31.07 TJ (29.45 billion Btus) for plants A and B, respectively (see table 10 for production characteristics of these plants). Plant A consumed 394 kJ per kg (170 Btu/lb) milk and 3,145 kJ per kg (1,355 Btu/lb) of solids; plant B consumed 348 kJ per kg (150 Btu/lb) milk and 2,839 kJ per kg (1,223 Btu/lb) solids. An efficiency of 29.4 percent was assumed, taking into account energy losses during generation and transmission. Annual electricity requirements for each plant in kWh, then, were about 3.16 million and 2.54 million, respectively.

Consumption of electricity in the cheese plant averaged 281 kJ/kg (121 Btu/lb) of milk processed and 3,417 kJ/kg (1,472 Btu/lb) of cheese produced. Because electrical consumption data for cheese cold storage facilities outside the plant were not available, actual consumption was higher than these figures indicate. A previous study, however, indicated much lower levels of electricity consumption: only 1,185 kJ/kg (511 Btu/lb) of cheese.¹¹

C. Fruit and Vegetable Processing

Operations in fruit and vegetable processing that involve extensive heating and cooling include storage; washing, peeling, and other preparation; canning; freezing; and dehydration and concentration. These operations and their temperature requirements are described below.

Storage

Fruits and vegetables may be stored from a few days to a month or more, depending on the particular crop and plant handling capabilities. Types of cooling systems used include hydrocooling, forced air, and vacuum. Hydrocooling may proceed by flooding, spraying, or immersion. Flooding involves showering the crop from overhead perforated flood pans with cold water as the product is conveyed through a cooling tunnel. Spray cooling is similar, except cold water is sprayed from overhead nozzles. For immersion cooling the product is submerged in agitated cold water. Some systems combine both flooding and immersion cooling. Floor-type hydrocoolers are used to cool produce in bulk bins and unitized pallet loads (pallets are portable platforms used for handling and storing packaged products). These systems have replaced use of block ice and sometimes are placed on trailers to perform cooling at the place of harvest, to remove field heat from the product and quickly lower internal product temperatures from as high as 43°C to 4°C (110°F to 40°F). Combination units are able to circulate up to 189,000 liters (about 50,000 gals) of 1°C (34°F) water per minute over the produce, with temperatures being controlled depending on the product being cooled. Fruits are most frequently hydrocooled. Vegetables are more frequently vacuum cooled, although very small fruit sometimes is cooled in this manner also. Berries usually are cooled by forcing air through filled packages.

Once cooled, fruits and vegetables are stored in controlled atmosphere rooms or warehouses. Storage temperatures range from -1°C to 13°C (30°F to

55°F) depending on the product. Apples generally are kept at about 0°C but the temperature may be elevated to 4°C if the atmosphere is adjusted. Root crops (beets, carrots, radishes and turnips) are stored at 0°C, as are leafy vegetables. Other vegetables are stored at higher temperatures: snap beans, okra, sweet peppers, and tomatoes at 7°C (45°F); potatoes at 3°C (38°F); pumpkins at 10°C (50°F); and sweet potatoes at 13°C (55°F).

Preparation

Preparation includes rinsing and washing, peeling, trimming, shucking and dicing, and blanching or scalding. The washing, peeling, and blanching operations require substantial amounts of hot water.

Peeling methods include boiling water or steam peeling, lye peeling, and scalding and Freeze peeling. Boiling water or steam peeling is used for fruits such as peaches, and sometimes for potatoes and other root vegetables. In the case of peaches, the fruit is passed through a steam box equipped with a series of spray heads through which steam is sprayed directly on unpeeled peach halves. A 30-second treatment usually loosens the peel to where it can be removed in one piece with cold water and soft brushes.

Lye peeling is used on peaches, pears, nectarines, and other fruits, and on tomatoes, potatoes, sweet potatoes, and carrots. Although the process requires large amounts of water, it is fast--a single lye peeler may handle up to 30 bushels per minute. For peeling peaches for canning, a boiling lye solution is used for 60 seconds, after which the fruit is washed. If the produce is to be frozen or dried the maximum temperature of the solution is 63°C (145°F), so that no cooking occurs.

Freeze peeling utilizes equipment similar to that used in steam peeling. Produce is frozen very quickly to a depth slightly below the skin, then thawed rapidly. This system of peeling has become more popular since the development of cryogenic freezing equipment, and because it is a clean method of processing. High pressure steam peelers have been developed during the 1970s with regulated pressure controls that avoid certain problems associated with conventional steam peelers. These systems effectively separate peels from a variety of fruits and vegetables, due to the increased internal pressure created within the produce.

Blanching of vegetables may be accomplished in several ways. The usual process for turnip greens, spinach, collards, okra, and snap beans is to heat them with steam or immerse them in hot water (88°C), after which the water is discarded. Other vegetables are pre-shrunk and blanched in the peeling process, then shelled and dried and put into cans (whole potatoes, cut sweet potatoes, pumpkins, squash, dried carrots, and beets). In canning operations the blanched product is packed without cooling and much of the heat of blanching is used in the sterilization process. Vegetables that are to be frozen are cooled quickly and thoroughly.

Canning

The principles of canning are basically the same for the various fruits and vegetables, although required temperatures and times differ with the particular product. In conventional canning operations the food is placed inside the containers, air is removed by vacuum, and the cans are hermetically sealed. The cans then are placed in containers to be sterilized with steam or boiling water. Because the main spoilage agents in fruits are non-heat-resistant micro-organisms, exposure of prepared fruit products to temperatures at or near 93°C (200°F) generally is adequate for sterilization. One-pound containers of fruit products can be sterilized satisfactorily by a 20 minute treatment. Acid vegetables can be processed at 100°C in steam or water cookers, but nonacid products require higher temperatures for sterilization (for control of botulism), and are processed in retort-type or continuous pressure cookers.

Improved means of heat processing, including continuous agitating and hydrostatic cookers, aseptic canning, and flame sterilization, are being used extensively in the fruit and vegetable canning industry. Continuous agitating and hydrostatic cookers and aseptic canning procedures were described in the above section on meat processing. The Dole aseptic canning system carries out simultaneous canning operations in a closed, interconnected system, with sterilization taking place at between 135° and 149°C (275° and 300°F). Aseptic drum processing is used for pumpable fruit and vegetable products such as purees, concentrates, and pastes. The product first is sterilized with pressurized steam at up to 149°C, then is cooled under 51 to 66 cm (20 to 26 inches) of vacuum, filled under vacuum, and sealed aseptically. Sterilization is achieved in a heat exchanger as the product flows, and occurs within the 100° to 149°C range depending on pH, viscosity, and sensitivity of the product.

Flame sterilization techniques, in which the sealed cans are exposed to direct flames while rotating for long enough to ensure sterilization, have been developed. Flame sterilization is an HTST process that effectively processes canned foods that heat by convection (e.g., peas, green beans, carrots, mushrooms, and whole tomatoes). After processing, the cans must be cooled quickly to prevent overcooking. Cooling is done with water in the cooker under air pressure or by conveying the container from the cooker to a rotary cooler with a cold water spray.

Freezing

The production of frozen fruits has more than tripled since the 1950s, and growth in frozen vegetable production has been even more spectacular. The same methods are used in freezing these products as those described for freezing meats, and required temperatures are similar. Blast freezing and contact plate freezing (for packaged vegetables in cartons) are common. Plate freezing of packaged vegetables at around -40°C takes 30 to 90 minutes.

Slush freezing is popular for freezing juices because it permits freezing in containers of all sizes. A rotator slushfreezing unit is widely used for single-strength and concentrated juices. A thin stream of juice is forced

into the space between the center shaft and heat transfer tube. The rotator freezes the juice rapidly by passing a thin layer of it over a large refrigerated surface, and special blades remove the frozen product. Ammonia is the usual refrigerant in this equipment. For single-strength orange juice an outlet temperature above -2°C (28°F) is recommended because a cooler product cannot be handled by an automatic filler. By contrast, orange juice concentrates are commonly chilled at -7°C (20°F) as they are still quite fluid at this temperature. After the orange juice slush is frozen, it is packed into cans and frozen hard by passage through a low-temperature blast tunnel at -29° to -34°C (-20° to -30°F).

Storage of the frozen foods is best achieved at temperatures of -18°C (0°F) or less, and preferably in the -21° to -23°C (-5° to -10°F) range. If kept at even lower temperatures, some frozen vegetables can be kept up to 5 years while still maintaining product quality.

Concentrated and Dried Products

Fruit and vegetable concentrate production utilizes both low-temperature and high-temperature evaporators for juice concentration. Low-temperature evaporators, now used in multistage units, produce superior quality concentrates of vegetables and fruits, and their usage is increasing. The temperature range is between 18° and 29°C (65° to 85°F). HTST evaporators are in general use; the plate evaporator, a typical unit, has seven stages and a vacuum flash cooler arranged to produce four effects. Temperature in the various stages ranges from 41 to 96°C (105° to 205°F). Vacuum operation is used to remove water and to reduce the temperature of the concentrate. The heat of the concentrate is used to boil off liquid, thereby reducing its temperatures to a point corresponding to boiling at the pressure in the final step. Seven-stage four-effect evaporators that can process about 18,000 kg (40,000 lbs) per hour are used in many orange juice concentrating plants. Citrus juices initially must be heated to 91°C (195°F) for concentration.

Another method of concentrating fruit/vegetable juices is freeze concentration. Freeze concentration has three fundamental elements: a crystallizer or freezer that produces a slurry of ice crystals; a separation device where the crystals are separated from the mother liquid, which can be a centrifuge, water column or filter press; and a refrigeration unit to cool the liquid. Though this method produces a superior quality product, it is rarely used due to the high cost of processing.

Fruit drying is one of the oldest methods of preserving fruit. It is also one of the newest, in that new techniques during the last 3 decades have made commercial fruit drying a fast process whereby large quantities of high-quality product can be produced. Sun drying is still a major method of dehydration. For purposes of this study, however, only those processing techniques utilizing artificial heat are of primary relevance.

Most artificially dried fruit products are subject to dehydration processing—the use of mechanical equipment and heating methods under carefully controlled temperature, humidity and air flow. Several types of drying equipment are in use whereby heated air is passed over the food to be

dried, or the food is passed through heated air. The simplest and oldest type of equipment is the kiln dryer, in which heated air dries fruit as the air rises from the heat source. Kiln dryers generally are of two stories, with the heat source (usually natural gas) occupying the lower floor. The fruit material is spread out on the slotted floor about 25 cm (10 inches) in depth, and periodically turned and dried to about 14 percent to 24 percent moisture content in 6 to 8 hours. Apart from the slow drying disadvantage, this method is wasteful in the use of heat, although modifications have reduced the waste. This system is used primarily to dry apple slices.

The tower or "stack" dryer is basically a furnace with heating pipes and cabinets in which trays of fruit are dried. This system usually accommodates a maximum of 12 trays. Again, heated air rises through the fruit. The lower trays dry first and are removed. The entire stack then is moved down and new trays of fruit are added at the top. Cabinet tray dryers operate in a similar fashion to stack dryers except heat is provided by steam coils located between the trays. Though better temperature control is achieved, only small fixed quantities may be processed as in the previous two methods. All three systems are basically for small-scale batch operations, and take between 6 and 12 hours to complete the processing.

Tunnel dryers, the most efficient systems in use, are widely used for fruit drying. Though the equipment is similar to the tray dryer, it allows continuous processing of the product. It consists of a rectangular tunnel through which loaded trays are moved, with a current of heated air introduced at one end. This system provides rapid and uniform drying with little injury to the fruit. Size of tunnels vary considerably but may be up to 9.1 meters (30 feet) long in the form of two to three single-stage tunnels, and 1.9 meters wide by 2.1 meters high (6.25 by 7 feet). Air is usually directed in a counterflow direction, reaching 82° to 93°C (180° to 200°F). Air velocity is between 183 and 366 meters (600 and 1200 feet) per minute and can dry apple slices down to 2.5 percent moisture content in 2 to 3 hours, at a rate of 455 kg (1,000 lbs) per hour.

Other types of drying processes for fruit and fruit sections include conveyor drying and explosion puffing. The conveyor dryer is a variation on the tunnel dryer, except the fruit is conveyed through hot air system on a moving belt, which allows for completely continuous operations. Explosion puffing is a process whereby partially dehydrated pieces of fruit are heated in a closed vessel called a "gun", which has a quick-opening lid. When the water in the fruit is heated above its atmospheric boiling point and pressure has been developed in the chambers, the pieces are instantly discharged to atmospheric pressure. The flashing water vapor within each piece of fruit creates a porous structure that permits faster dehydration of the product prior to consumption or further processing. The fruit pieces then are dried to 4 percent to 5 percent content by conventional means.

Other techniques are used to dehydrate liquid or pureed materials and to prepare fruit powders. These include foam mat drying, spray drying, drum drying, microwave heating, vacuum drying, and freeze drying. The latter four are not in wide use because of their expense or, in the case of drum drying,

because of their expense or, in the case of drum drying, because of high temperatures that may accidentally cook the product. Foam-mat drying is a process in which liquid is converted to foam by means of gas, and spread on perforated trays that are dried by hot air, after which the product is made into powder. Drying takes 15 minutes in 71°C (160°F) air to achieve 2 percent moisture content. Processing is cheaper than vacuum or freeze drying and quality of product is high. Spray drying involves dispersion of liquid in a stream of heated air, the product being delivered as a fine powder. Spray drying is widely used to dehydrate fruit juices.

The number of products dehydrated is much smaller for vegetables than for fruits. There are three broad processing groups of vegetables in the United States: onions and garlic in California; potato flakes, granules and dices mainly in Idaho, Oregon, and Washington; and other dehydrated products, mainly processed in California. Forced-air drying is used extensively for most dried vegetable products, and drum drying is still used for products such as potato flakes and tomato concentrates. Spray drying is used for dehydration of liquid food products such as tomato puree. Drying equipment and temperatures are the same as those outlined above.

Energy Sources and Requirements

Fuel oil, natural gas and electricity are consumed in fruit and vegetable-processing plants (some coal is used in Indiana). Natural gas and electricity use are highest in California, Florida, Idaho, and Washington, which are the top fruit/vegetable-processing states. Fuel oil use is highest in Florida, New Jersey, New York, and Pennsylvania, and occurs also in other midwestern states. Tables C-1, C-2, and C-5 show fuel and electricity requirements for fruit and vegetable processing by state.

Fruit and vegetable processing consumes about 10 percent of all energy used for food processing. Canning and freezing operations are quite energy intensive, as is the case in other kinds of food processing. The blanching and sterilization procedures particularly have high energy requirements. Large amounts of thermal energy are required for the hot water processes, while electricity is required to run the processing and refrigeration/freezer equipment.

Data on thermal energy and electricity requirements in vegetable and fruit processing are available from Vergara et al. (1978),¹² Chhinan et al. (1978),¹³ and Mayou and Singh (1978).¹⁴ Additional information on fossil fuel use was obtained from Lund et al.⁵ and Cervinka et al.¹⁵ Vergara et al. estimated the amount of direct energy utilization in four vegetable canneries in western New York. The plants processed primarily low-acid vegetables (beans, beets, carrots, corn, peas, potatoes), but also sauerkraut and applesauce. Their total production in 1974 was about 85,000 metric tons (gross weight of final product). Peak production occurred during August to October and none occurred between March and May. Although the processing periods of the different commodities overlapped, the peak processing periods did not.

Total energy requirements for the four plants in 1974 was 538.74 TJ (10.72 billion Btus), and ranged from 74.41 TJ (70.54 billion Btus) in the smallest plant to 202.18 TJ (191.66 billion Btus) in the largest. Average kJ/kg requirements for the plants were about 6,338 (2,731 Btu/lb).

Chhinman et al. conducted an energy accounting study on spinach canning. The spinach processing season in the plant studied was 15 days long, with 73 metric tons of raw spinach processed during an 8-hour shift (nearly 2,200 metric tons for the season, assuming two shifts per day).¹³ Mayou and Singh analyzed energy consumption in California citrus packing plants. Seventeen plants were surveyed, accounting for 24 per cent of the total production in California during the 1976-77 crop year.¹⁴ The amount of 1976-77 production surveyed is shown in table 11.

Fossil Fuel Consumption

The major thermal energy source used in the four New York vegetable plants was fuel oil No. 6 (65 percent of all energy consumption). Fuel oil was used for steam generation, natural gas for space heating, and gasoline and propane for truck transport of solid waste and fuel for forklift trucks, respectively (see table 12). Theoretical energy requirements were calculated for blanching and sterilization, since these operations require considerable energy. These requirements, which do not incorporate the low efficiency of sterilizers and blanchers or surface and venting losses, are presented in table 13. Blanching and sterilization accounted for about 9 percent of total direct energy expenditures, and steam generation loss for about 23 percent. Lighting and electric motors were estimated to account for 21 percent, vehicle movement for 4 percent, and other activities for 22 percent of direct energy use. Average kJ/kg requirements for these plants were 571 for blanching and sterilization, 1,458 for steam generation loss, and 1,332 for losses to the environment (246, 628, and 574 Btu/lb, respectively).¹²

Chhinman et al. computed the thermal energy associated with the blancher, exhaust box, and retort. In the blancher, the product temperature was raised from 15°C (59°F) to 96°C (205°F) and held for 3 minutes. For 73 metric tons, the theoretical energy required during an 8-hour shift was 23.34 GJ (22.03 million Btus); whereas the blanchers actually required 75.50 GJ (71.57 million Btus); 69 percent of the heat was lost through mechanisms such as incomplete steam condensation in water, hot water discharged in drain, and equipment surface losses due to lack of insulation.¹³

The purpose of exhausting was to remove air from the product to assure an adequate thermal process during retorting. In the exhaust boxes, the cans containing blanched spinach were filled with heated water, and product temperature rose up to 77°C (171°F). For 73 metric tons, 107.50 GJ (101.91 million Btus) were used, indicating that only 12 percent of supplied energy was utilized. Retorting, conducted in all retorts, required 34.17 GJ (32.39 million Btus).¹³

**Table 11. CALIFORNIA CITRUS PRODUCTION
SURVEYED FOR ENERGY STUDY, 1976-77**

Area	Surveyed Production	% of Total Production
District 1 ^a		
Oranges, lemons	1.788×10^9 kg	21
District 2 ^b		
Oranges, grapefruits	1.988×10^9 kg	25
Lemons	2.141×10^9 kg	40
District 3 ^c		
Oranges, grapefruits lemons	0.408×10^9 kg	8
Total	6.321×10^9 kg	24

^aCentral California (Madera, Fresno, Tulare, Kern Counties)

^bSouthern California (Santa Barbara, Ventura, Los Angeles, Orange, San Diego, San Bernardino, Western Riverside Counties)

^cArizona—California Desert Valleys (Maricopa and Yuma Counties, Ariz.; eastern Riverside County and Imperial County, Calif.)

Source: L. P. Mayou and R. Paul Singh, *Energy Use Profiles in Citrus Packing Plants*, ASAE Paper No. 78-6539, December 1978.

**Table 12. FOSSIL FUEL DIRECT ENERGY CONSUMED IN FOUR
NEW YORK VEGETABLE-PROCESSING PLANTS, 1974**

Plant	Energy Source (TJ)				Total Fossil Fuels
	Fuel Oil #6	Fuel Oil #2	Natural Gas	Gasoline Kerosene Propane	
1	158.37 (78%)	0.55 (0.3%)	3.89 (2%)	5.87 (4%)	168.68
2	85.44 (76%)	0.13 (0.1%)	—	4.19 (4%)	89.76
3	97.17 (65%)	—	6.15 (4%)	9.38 (6%)	112.70
4	54.01 (73%)	0.25 (0.3%)	—	3.19 (4%)	57.45

Source: W. Vergara, M. A. Rao, and W. K. Jordan, "Analysis of Direct Energy Usage in Vegetable Canners," *Transactions of the American Society of Agricultural Engineers*, 1978, p. 1247. Converted from kcal to TJ.

**Table 13. THERMAL ENERGY USE FOR SELECTED FUNCTIONS IN
4 NEW YORK VEGETABLE-PROCESSING PLANTS, 1974**

Function	Thermal Energy Use (TJ)			
	Plant 1	Plant 2	Plant 3	Plant 4
Total energy consumption	202.19	113.03	149.03	74.51
Energy requirements for blanching and sterilization ^a	10.89	10.72	20.14	5.65
Loss during steam generation ^b	50.65	25.53	29.31	16.33
Energy losses to the environment ^c				
Buildings	13.89	9.25	11.89	6.24
Equipment	2.47	1.38	1.30	1.04
Pipes	8.25	0.59	2.72	2.38
Hot water	17.00	12.85	9.83	7.32

^aIncludes only the theoretical requirements. Energy losses due to ventings were not taken into account.

^bAssuming 0.7 as the efficiency of boilers

^cFrom a previous study.

Source: W. Vergara, M. A. Rao, and W. K. Jordan, "Analysis of Direct Energy Usage in Vegetable Canneries," *Transactions of the American Society of Agricultural Engineers*, 1978, p. 1247. Converted from kcal to TJ.

Thermal energy in the spinach plant was derived from natural gas and fuel oil, and amounted to 6.50 MJ/kg (2,800 Btu/lb) of raw spinach.

total seasonal requirements for 2,200 metric tons would be approximately 14.3 TJ (13.6 billion Btus). Thermal energy accounted for about 89 percent of total energy use.¹³

Of the citrus-packing plants surveyed by Mayou and Singh, all but one used natural gas for heating air and water. Only low grade heat was required, since water and air temperatures do not exceed 40°C (104°F) and 70°C (158°F), respectively. Hot water was used to wash the fruit; warm air to dry it. Natural gas consumption was higher in the central valleys than in southern California, since navel oranges harvested during November-June require more heat for surface moisture removal on foggy winter days in the central valley. Table 14 shows average natural gas requirements for the different fruits by area.¹⁴

Lund et al. studied the thermal energy requirements of a midwestern canning plant producing peas and corn. Particular unit operations that they considered were blancher makeup water (88°C), water flume (71°C), topper water (71°C), cleanup water (60°C), and boiler feed water (100°C). In the plant studied, the pea pack started 19 June and ended 6 August (about 7 weeks), and the corn pack started 7 August and ended 25 September (also 7 weeks). The production rate for canned peas was 40,000 kg/day (88,000 lbs/day) and for corn 58,000 kg/day (127,600 lbs/day). Per week, production rates were 241,000 kg (530,000 lbs) and 346,000 kg. (761,200 lbs) for peas and corn, respectively. Based on a 7-week season for both peas and corn, the total seasonal output for this plant was 1.687 million kg (3.711 million lbs) peas and 2.422 million kg (5.328 million lbs) corn. Table 15 shows the loads required for the operations identified above, both on a weekly and a seasonal basis. Eighty percent boiler efficiency and 15 percent line loss were assumed.⁵

Natural gas requirements to process other fruits and vegetables have been calculated by Cervinka et al.¹⁵ These estimates, made for processing in California, are shown in table 16.

Electricity Consumption

In the New York vegetable-processing plants studied by Vergara et al., electricity was required for lighting and to operate process equipment, and accounted for at least 17 percent of the direct energy consumed. Table 17 shows electricity consumption in each of the four plants. The efficiency of generation and transmission of electricity was taken into account, and the electrical energy consumed is expressed in terms of kJ of fossil fuels depleted. Conversion factor assumed was 1 kWh = 12,240 kJ (11,604 Btus).¹²

In the spinach plant studied by Chhinnan et al., electric energy was used for lighting and to operate pumps, conveyors, and other processing equipment. The average electrical energy intensity calculated was 0.072 kWh/kg (0.033 kWh/lb) of raw spinach. Using a conversion factor for fossil fuel equivalence for electricity of 11,077 kJ/kWh (10,500 /kWh), the electrical energy intensity was 800 kJ/kg (345 Btu/lb), or

**Table 14. NATURAL GAS REQUIREMENTS
FOR CITRUS PACKING**

Area	Natural Gas Consumption (kJ/kg)
District 1 ^a	
Oranges-grapefruit	159.8
District 2 ^b	
Oranges-grapefruit	53.9
Lemon	133.9
Oranges-grapefruit-lemon	135.9
District 3 ^c	
Oranges-grapefruit-lemon	107.2

^aCentral California (Madera, Fresno, Tulare, Kern Counties)

^bSouthern California (Santa Barbara, Ventura, Los Angeles, Orange, San Diego, San Bernardino, western Riverside Counties).

^cArizona-California Desert Valleys (Maricopa and Yuma Counties, Ariz.; eastern Riverside County and Imperial County, Calif.)

Source: L. P. Mayou and R. Paul Singh, *Energy Use Profiles in Citrus Packing Plants*, ASAE Paper No. 78-6539, December 1978, p.8.

**Table 15. THERMAL ENERGY REQUIREMENTS
FOR PEA AND CORN CANNING**

Operational	Loads (GJ)	
	Weekly	Seasonal
Peas		
Boiler feed water	212	1,484
Topper water	145	1,015
Flume water	110	770
Blancher make-up water	120	840
Clean-up water	49	343
Total	636	4,452
Corn		
Boiler feed water	275	1,925
Topper water	143	1,001
Flume water	118	826
Clean-up water	51	357
Total	587	4,109

Source: D. B. Lund, et al., *Feasibility of Using Solar Energy in a Canning Plant and Meat Processing Plant*, ASAE Paper No. 77-6518, December 1977.

**Table 16. NATURAL GAS REQUIREMENTS
FOR FRUIT AND VEGETABLE PROCESSING
IN CALIFORNIA**

Product	Process	Natural Gas Requirements (kJ/kg)
Apples	Canned	3,038
	Frozen	1,229
	Crushed	1,927
Apricots	Canned	4,341
	Frozen	2,438
Grapes	Canned	1,892
	Crushed	2,750
	Dehydrated	3,482
Grapefruit	Processed	2,546
Lemons	Processed	2,546
Oranges	Processed	2,546
Peaches	Canned	3,900
	Frozen	2,438
Pears	Canned	2,529
Prunes	Dehydrated	10,446
Asparagus	Canned	7,681
	Frozen	3,340
Beans	Canned	4,642
	Frozen	2,892
Broccoli	Frozen	2,817
Carrots	Canned	2,947
	Frozen	3,726
Onions	Dehydrated	2,855
Potatoes	Chips	2,852
	Frozen	3,250
	Canned	2,902
Tomatoes	Canned	3,363

**Table 17. ELECTRICAL ENERGY CONSUMED IN FOUR
NEW YORK VEGETABLE-PROCESSING PLANTS, 1974**

Plant	Electricity (TJ)	Consumption (000 kWh)	% Direct Energy Consumed
A	33.46	2,734	16.6
B	23.32	1,905	20.6
C	36.35	2,970	24.4
D	16.96	1,386	22.8

Source: W. Vergara, M.A. Rao, and W. K. Jordan, "Analysis of Direct Energy Usage in Vegetable Canneries," *Transactions of the American Society of Agricultural Engineers—1978*, p. 1247.

about 11 percent of total energy use.¹³ Electricity consumption for the season's production, assuming 73 metric tons of raw spinach processed per shift and 15 two-shift days of operation, would be about 1.76 TJ (1.66 billion Btus), or about 158,400 kWh.

The electrical power intensities in citrus-packing plants surveyed by Mayou and Singh ranged from 163.3 kJ/kg (70.4 Btu/lb) to 583.8 kJ/kg (251.6 Btu/lb). The same conversion factor as that used by Chhinnan was used here. Electrical consumption in citrus packing varies with the amount of precooling and length of refrigerated holding required, and ambient air temperatures. Electrical energy requirements for lemon packing are higher than those for orange packing, since lemon packing requires storage for up to 4 months, in comparison to a holding period of 2 to 3 weeks for orange packing. Table 18 shows these requirements.

D. Aquaculture

Nearly all aquaculture products are sold fresh (usually packed in ice) or frozen. Oysters are shucked, then sold fresh (raw). Trout usually are frozen; in Idaho, where most commercial trout farming and processing is done, the bulk of trout go out as 227- to 284-gram (8- to 10-ounce) boned and frozen fillets. Other freshwater fish such as buffalofish, catfish and carp may be frozen but frequently are not, and also may be smoked. Crayfish tails are cooked briefly for peeling and either packed in ice or frozen; freezing of tails usually is done in late May and June. Only salmon are canned in addition to being sold frozen, cured, or smoked. Canning has been decreasing, however, because of its cost.

Aquaculture plants usually freeze fish using the traditional sharp (slow) freezing or blast freezers. In sharp freezing, the fish are frozen to -20°C (-4°F). Blast freezers for fishery products are small rooms or tunnels where cold air is circulated by one or more fans over an evaporator and around the product to be frozen. Air velocities between 2.4 and 4.9 meters (8 and 16 feet) per second give the most economical freezing. Conveyor-type blast freezers, where fish are moved continuously through the blast room or tunnel, are widely used to freeze products prior to packaging. Trout and salmon in the western states are frozen in blast freezers. In the southern states, many plants still use the sharp freezing method. In Mississippi two plants use cryogenic freezers for their individually quick frozen catfish.

Crayfish are boiled for 2.5 to 3.0 minutes for peeling before freezing. Usually they are cooked in batches of about 91 kg (200 lbs) in large water boilers. Steam heaters are being developed and used in some plants. Cold storage facilities for fresh fish should be maintained at about 2°C (36°F), with over 90 percent relative humidity. Frozen fish must be kept at -23°C (-10°F) or lower to assure adequate shelf life. Storage above this temperature, even for short periods of time, results in rapid quality loss.

Energy Sources and Requirements

Because most aquaculture products are sold fresh and raw or frozen, the primary energy requirement is electricity to maintain cold storage facilities and to power freezing and ice-making equipment. Gas is used to heat crayfish boilers. More specific information on energy requirements in aquaculture plants was not available.

**Table 18. AVERAGE ELECTRICAL ENERGY INTENSITIES
FOR CITRUS PACKING IN CALIFORNIA**

Area	Electricity Consumed	
	(kJ/kg)	(kWh/kg)
District 1 ^a		
Oranges-grapefruit	480.9	0.043
District 2 ^b		
Oranges-grapefruit	163.3	0.015
Lemon	515.6	0.047
Oranges-grapefruit-lemon	583.8	0.053
District 3 ^c		
Oranges-grapefruit-lemon	297.6	0.027

^aCentral California (Madera, Fresno, Tulare, Kern Counties)

^bSouthern California (Santa Barbara, Ventura, Los Angeles, Orange, San Diego, San Bernardino, and western Riverside Counties)

^cArizona-California Desert Valleys (Maricopa and Yuma Counties, Arizona; eastern Riverside County and Imperial County, California).

Source: L. P. Mayou and R. Paul Singh, *Energy Use Profiles in Citrus Packing Plants*, ASAE Paper No. 78-6539, December 1978, p. 8.

IV. WIND PATTERNS AND LOCATION OF PROCESSING FACILITIES

To show the availability of wind power for food processing applications wind contour maps were prepared. These maps are shown in figures 1 through 9, with figure 1 showing the country as a whole and the rest of the figures showing particular regions. Hawaii is shown in figure 9. Alaska has not been included since, aside from a few dairy plants, the only food processing there is of fishery products. Figures 2 through 9 also show the number of processing plants of various kinds located in the states. These comparisons of wind patterns and processing plant locations are based on mean annual wind power. A discussion of seasonal wind patterns follows.

A. Wind Patterns

The contour maps were generated using annual average wind power data reported in J.W. Reed's Wind Power Climatology of the United States: Supplement.¹⁷ The adjusted values of annual wind power (using standard sea level air density) at 10-, 20-, and 50-meters (m) heights above ground were used. Of the total number of observing stations reported, those stations where no anemometer height estimates could be made were eliminated from the study, with 630 stations remaining.*

The number of stations used from each state are given in appendix D. An annual average wind power density of 100 watts per square meter (W/m^2) at the measured heights was chosen as the cut-off point below which wind power would be insufficient to power a turbine.² (The value 100 W/m^2 refers to total power in the wind, and roughly corresponds to an average wind speed of 10 miles per hour). In reading the maps, it should be noted that all areas in which wind power is sufficient (over 100 W/m^2) at 10 m will also have sufficient winds at 20 and 50 m. Similarly, those areas which have sufficient wind power at 20 m also will have sufficient power at 50 m.

These wind energy classification maps should be regarded as approximate; it was assumed in drawing the contour lines that physical wind phenomena were homogeneously transitional between data points. In other words, between a station with sufficient wind power at 10 m and above and one with sufficient wind power only at 50 m there was assumed to be a transitional zone with wind power of 100 W/m^2 at 20 m and above. Federally funded and university research that is currently proceeding will yield more detailed and accurate wind energy classification maps (e.g., the Battelle Northwest Study).

Figure 10 has been included to show specific average annual wind power estimates at 50 m. This map is more detailed than the preceding figures in that the latter show only zones where wind power is at least 100 W/m^2 . However, figure 10 does not show wind powers at the lower heights. Ranges of average annual and peak average wind speeds measured below 20 meters are listed by state in appendix D.

*

It should be noted that these 630 stations are mostly at airports, which are not necessarily representative in terms of wind power availability.

Figure 1. CONTOURED MEAN ANNUAL WIND POWER (W/m^2) ESTIMATES OF THE UNITED STATES

Figure 2. CONTOURED MEAN ANNUAL WIND POWER (W/m^2) ESTIMATES OF THE NORTHWEST REGION

**NORTHWEST: NUMBERS OF PLANTS BY
WIND-POWER REGION**

	10m	20m	50m	None	Total
Washington					
Meat	11	90	30	30	161
Dairy (farms)	317	635	740	423	2,115
Dairy (plants)	8	15	17	10	50
Fruit/vegetables	10	21	24	14	69
Aquaculture	1	13	13	6	33
Oregon					
Meat	10	62	20	31	123
Dairy (farms)	222	445	297	519	1,483
Dairy (plants)	6	12	8	13	39
Fruit/vegetables	9	18	12	20	59
Aquaculture	5	6	—	—	11
Idaho					
Meat	8	13	2	—	23
Dairy (farms)	1,721	1,205	482	34	3,442
Dairy (plants)	14	10	4	—	28
Fruit/vegetables	12	9	3	—	24
Aquaculture	6	—	—	—	6
Montana					
Meat	40	20	16	—	76
Dairy (farms)	596	170	85	—	851
Dairy (plants)	15	5	2	—	22
Fruit/vegetables	2	—	—	—	2
Wyoming					
Meat	3	1	1	—	5
Dairy (farms)	227	70	52	—	349
Dairy (plants)	7	2	1	—	10
Fruit/vegetables	1	—	—	—	1

Figure 3. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF THE SOUTHWEST REGION

SOUTHWEST: NUMBERS OF PLANTS BY WIND-POWER REGION

	10m	20m	50m	None	Total
California	91	39	184	458	772
Dairy (farms)	804	964	803	643	3,214
Dairy (plants)	68	81	68	54	271
Fruit/vegetables	55	67	55	44	221
Aquaculture	—	—	2	—	2
Nevada					
Meat	9	1	13	4	27
Dairy (farms)	27	27	15	8	77
Dairy (plants)	4	4	2	1	11
Fruit/vegetables	1	1	—	—	2
Utah					
Meat	5	21	10	—	36
Dairy (farms)	198	464	463	198	1,323
Dairy (plants)	3	9	8	3	23
Fruit/vegetables	1	2	2	1	6
Aquaculture	—	—	2	—	2
Arizona					
Meat	—	1	—	24	25
Dairy (farms)	42	59	59	9	169
Dairy (plants)	3	5	5	1	14
Fruit/vegetables	2	2	2	—	6
Colorado					
Meat	143	3	8	7	161
Dairy (farms)	603	165	219	110	1,097
Dairy (plants)	19	5	7	3	34
Fruit/vegetables	6	2	2	1	11
Aquaculture	1	—	—	—	1
New Mexico					
Meat	15	5	2	—	22
Dairy (farms)	131	37	19	—	187
Dairy (plants)	9	3	1	—	13
Fruit/vegetables	—	—	—	—	—

Figure 4. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF THE NORTHERN MIDWEST

**NORTHERN MIDWEST: NUMBERS OF PLANTS BY
WIND-POWER REGION**

	10m	20m	50m	None	Total
North Dakota					
Meat	48	5	—	—	51
Dairy (farms)	3,829	676	—	—	4,505
Dairy (plants)	37	6	—	—	43
Fruit/vegetables	3	—	—	—	3
South Dakota					
Meat	19	—	—	—	19
Dairy (farms)	5,866	—	—	—	5,866
Dairy (plants)	32	—	—	—	32
Fruit/vegetables	—	—	—	—	—
Nebraska					
Meat	163	—	—	—	163
Dairy (farms)	4,954	—	—	—	4,954
Dairy (plants)	56	—	—	—	56
Fruit/vegetables	5	—	—	—	5
Minnesota					
Meat	159	28	10	2	199
Dairy (farms)	23,118	4,045	1,445	289	28,897
Dairy (plants)	166	29	10	2	207
Fruit/vegetables	23	4	2	—	29
Iowa					
Meat	100	—	—	—	100
Dairy (farms)	13,927	—	—	—	13,927
Dairy (plants)	99	—	—	—	99
Fruit/vegetables	13	—	—	—	13
Wisconsin					
Meat	103	8	—	—	111
Dairy (farms)	29,053	19,369	—	—	48,422
Dairy (plants)	273	182	—	—	455
Fruit/vegetables	51	34	—	—	85
Michigan					
Meat	78	13	2	—	93
Dairy (farms)	7,695	1,443	481	—	9,619
Dairy (plants)	66	12	4	—	82
Fruit/vegetable	73	14	4	—	91

Figure 5. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF THE SOUTHERN MIDWEST

**SOUTHERN MIDWEST: NUMBERS OF PLANTS BY
WIND-POWER REGION**

	10m	20m	50m	None	Total
Kansas					
Meat	58	4	2	—	64
Dairy (farms)	3,748	201	81	—	4,030
Dairy (plants)	49	3	1	—	53
Fruit/vegetables	4	—	—	—	4
Oklahoma					
Meat	47	5	—	—	52
Dairy (farms)	1,603	178	—	—	1,781
Dairy (plants)	22	3	—	—	25
Fruit/vegetables	7	1	—	—	8
Texas					
Meat	230	62	7	—	299
Dairy (farms)	1,899	876	146	—	2,921
Dairy (plants)	55	26	4	—	85
Fruit/vegetables	22	10	2	—	34
Missouri					
Meat	237	59	21	—	317
Dairy (farms)	5,044	1,441	721	—	7,206
Dairy (plants)	52	15	7	—	74
Fruit/vegetables	9	2	1	—	12
Arkansas					
Meat	16	21	28	—	65
Dairy (farms)	27	556	741	—	1,324
Dairy (plants)	1	8	11	—	20
Fruit/vegetables	—	8	10	—	18
Aquaculture	—	—	2	—	2
Louisiana					
Meat	7	16	9	6	38
Dairy (farms)	301	150	376	676	1,503
Dairy (plants)	6	3	8	13	30
Fruit/vegetables	3	2	4	8	17
Aquaculture	—	—	—	34	34

Figure 6. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF THE EASTERN MIDWEST AND MIDDLE ATLANTIC

**EASTERN MIDWEST, MIDDLE ATLANTIC: NUMBERS OF
PLANTS BY WIND-POWER REGION**

	10m	20m	50m	None	Total		10m	20m	50m	None	Total
Illinois						West Virginia					
Meat	234	30	17	—	281	Meat	—	4	10	5	19
Dairy (farms)	5,355	630	315	—	6,300	Dairy (farms)	—	140	515	218	936
Dairy (plants)	78	9	5	—	92	Dairy (plants)	—	2	6	3	11
Fruit/vegetables	37	4	2	—	43	Fruit/vegetables	—	1	2	1	4
Indiana						Virginia					
Meat	83	17	7	2	109	Meat	16	30	6	26	78
Dairy (farms)	3,845	1,282	961	321	6,409	Dairy (farms)	169	1,187	678	1,356	3,390
Dairy (plants)	28	10	7	2	47	Dairy (plants)	2	13	8	15	38
Fruit/vegetables	28	9	7	2	46	Fruit/vegetables	1	8	5	9	23
Ohio						Maryland					
Meat	74	54	23	3	154	Meat	43	2	12	—	57
Dairy (farms)	5,384	3,926	1,682	224	11,216	Dairy (farms)	669	1,004	446	112	2,231
Dairy (plants)	55	40	17	2	114	Dairy (plants)	6	8	4	1	19
Fruit/vegetables	24	17	7	1	49	Fruit/vegetables	12	17	8	2	39
Kentucky						Delaware					
Meat	—	87	28	62	177	Meat	7	5	—	—	12
Dairy (farms)	—	3,904	1,952	1,952	7,808	Dairy (farms)	128	86	—	—	214
Dairy (plants)	—	31	15	15	61	Dairy (plants)	3	2	—	—	5
Fruit/vegetables	—	5	3	2	10	Fruit/vegetables	9	6	—	—	15

Figure 7. CONTOURED MEAN ANNUAL WIND POWER (W/m^2) ESTIMATES OF THE NEW ENGLAND AND UPPER MIDDLE ATLANTIC

**NORTHEAST: NUMBERS OF PLANTS BY
WIND-POWER REGION**

	10m	20m	50m	None	Total		10m	20m	50m	None	Total
Maine						Connecticut					
Meat	2	23	—	—	25	Meat	30	64	44	—	138
Dairy (farms)	132	1,191	—	—	1,323	Dairy (farms)	282	402	121	—	805
Dairy (plants)	2	22	—	—	24	Dairy (plants)	14	21	6	—	41
Fruit/vegetables	2	16	—	—	18	Fruit/vegetables	1	1	—	—	2
						Aquaculture	1	—	—	—	1
New Hampshire						Pennsylvania					
Meat	—	13	21	—	34	Meat	210	373	127	50	760
Dairy (farms)	—	463	132	66	661	Dairy (farms)	4,964	6,618	3,309	1,655	16,546
Dairy (plants)	—	8	3	1	12	Dairy (plants)	49	65	33	16	163
Fruit/vegetables	—	2	—	—	2	Fruit/vegetables	16	21	10	5	52
Vermont						Rhode Island					
Meat	—	7	3	1	11	Meat	32	4	—	—	36
Dairy (farms)	—	1,875	1,023	511	3,409	Dairy (farms)	106	12	—	—	118
Dairy (plants)	—	23	13	6	42	Dairy (plants)	15	2	—	—	17
Fruit/vegetables	—	—	—	—	—	Fruit/vegetables	1	—	—	—	1
Massachusetts						New Jersey					
Meat	152	48	15	4	219	Meat	87	213	6	2	308
Dairy (farms)	570	190	142	48	950	Dairy (farms)	309	410	39	15	773
Dairy (plants)	35	12	9	3	59	Dairy (plants)	13	17	2	1	33
Fruit/vegetables	9	3	2	1	15	Fruit/vegetables	16	22	2	1	41
New York											
Meat	223	445	37	37	742						
Dairy (farms)	5,262	10,524	877	877	17,540						
Dairy (plants)	57	115	10	10	192						
Fruit/vegetables	29	57	5	5	96						
Aquaculture	1	—	—	—	1

Figure 8. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF THE SOUTHEAST

SOUTHEAST: NUMBERS OF PLANTS BY WIND-POWER REGION

	10m	20m	50m	None	Total		10m	20m	50m	None	Total
Tennessee						Alabama					
Meat	—	30	155	37	222	Meat	1	11	28	23	63
Dairy (farms)	—	568	3,975	1,135	5,678	Dairy (farms)	45	91	364	409	909
Dairy (plants)	—	4	27	8	39	Dairy (plants)	1	3	10	11	25
Fruit/vegetables	—	2	10	3	15	Fruit/vegetables	—	1	2	3	6
Aquaculture	—	—	1	—	1	Aquaculture	—	—	21	—	21
North Carolina						Mississippi					
Meat	7	23	110	45	185	Meat	—	1	27	9	37
Dairy (farms)	106	317	1,376	318	2,117	Dairy (farms)	—	15	1,135	383	1,533
Dairy (plants)	1	4	17	4	26	Dairy (plants)	—	—	22	8	30
Fruit/vegetables	1	2	9	2	14	Fruit/vegetables	—	—	2	1	3
						Aquaculture	—	—	6	—	6
South Carolina						Florida					
Meat	—	6	14	4	23	Meat	—	37	32	3	72
Dairy (farms)	—	117	282	70	469	Dairy (farms)	32	221	139	69	461
Dairy (plants)	—	3	7	2	12	Dairy (plants)	3	17	11	5	36
Fruit/vegetables	—	1	3	1	5	Fruit/vegetables	5	35	22	11	73
Aquaculture	—	2	—	—	2	Aquaculture	—	4	—	—	4
Georgia											
Meat	—	43	40	23	106						
Dairy (farms)	—	105	474	474	1,053						
Dairy (plants)	—	4	17	17	38						
Fruit/vegetables	—	2	9	8	19

Figure 9. CONTOURED MEAN ANNUAL WIND POWER (W/m²) ESTIMATES OF HAWAII

HAWAII: NUMBERS OF PLANTS BY WIND-POWER REGION

	10m	20m	50m	None	Total
Hawaii					
Meat	2	1	—	—	3
Dairy (farms)	5	12	16	—	33
Dairy (plants)	1	1	3	—	5
Fruit/vegetables	7	—	1	—	8

Note: Over mountainous regions (shaded areas) the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Dennis L. Elliott, "Synthesis of National Wind Energy Assessments," BNWL-2220 (Richland, WA: Battelle Pacific Northwest Laboratories, July 1977).

Figure 10. MEAN ANNUAL WIND POWER (W/m^2) ESTIMATED AT 50 m ABOVE EXPOSED AREAS

B. Location of Processing Facilities versus Wind Power

Figures 1 through 10 indicate that the states that are generally best in terms of wind power availability are the midwestern and western states. The states with the least available wind power are the southeastern states. So that the wind availability of the various states can be matched with the number of processing plants in those states, the latter are listed on the pages facing each of the regional maps. The plants have been divided according to which wind power region of the state they are in.*

The size distribution of processing plants is important for the purpose of estimating approximate energy requirements and anticipating the size of wind turbine required, if plants were to utilize wind energy as a power source. Size should be considered in matching plant locations to available wind power; a small plant requiring only a small turbine might not be able to take advantage of winds at greater heights, which a larger turbine (turbine with an increased hub height) would utilize. On the other hand, lower-velocity winds could supply a relatively greater portion of the energy requirements of small as opposed to large plants.

The states best suited for the use of wind power in food processing are those having a large number of plants located in areas where wind power is at least 100 W/m^2 at 10 or 20 meters. If wind power is sufficient only at 50 m, a large facility would be required to tap this resource (either a large turbine or at least a tall platform). Further, wind power sufficient at 10 m indicates even greater potential at the higher levels.

All states have at least some plants located in areas where the wind power is sufficient at 10 or 20 meters. However, as stated in the previous section, plants in the southeastern and northwestern regions are the least likely to be able to utilize wind power, while those in the Midwest are best suited for dependence on the wind. The following section analyzes wind availability more closely, including seasonal occurrence.

*

In many cases these plants were actually located on an atlas, since data were available on cities and towns in which meat, fruit and vegetable, and most dairy plants were situated. However, because of the large volume of plants in the study, in some cases a uniform distribution of plants was assumed for the state. The percentage of the state with wind power sufficient at 10, 0, and 50 meters, respectively, then was applied to the total number of plants in the state to obtain approximate numbers of plants in these different areas. A spot check indicated that this assumption was not an unreasonable one. Location on a plant-by-plant basis was pursued for states with few plants, and for plants in areas where deserts or mountains would make the uniform distribution assumption obviously untenable. The percentages used are listed in appendix D.

C. Seasonal Wind Availability for Food Processing

An analysis of the areas in which mean annual wind power is greater than 100 W/m^2 is not sufficient to determine whether this wind power can be harnessed for food processing. Typically, wind power is greatest during the winter and spring seasons, and least during summer and early fall. Because of this seasonal variation many plants may be able to utilize wind power for only a part of the year. Those fruit and vegetable plants that operate primarily or only during the summer and early fall may be unable to tap this energy source at all. Seasonal wind patterns in the different regions of the country are considered below, at both 50 m and 20 m. A height of 10 m is too low for many wind systems applications. Fifty meters may be too high for most of the small wind energy conversion systems (SWECS) addressed in this report, but is a reasonable height for larger systems that might be installed for large plants.

The way in which wind power varies by season at 50 m is shown in figures 11 through 14. In 21 states, wind power averages at least 100 W/m^2 at 50 m during every month. These states are listed in table 19. Over 40 percent of all meat plants, two-thirds of the dairy farms, about 56 percent of dairy-processing plants, and over one-third of the fruit and vegetable plants are located in these states. Only aquaculture plants are not well represented (7 percent). These plants are the most likely candidates for wind energy use, during any or all seasons.

During the winter and spring months all states have average wind powers of at least 100 W/m^2 (50 m). All areas except the Southeast and California's central valleys have wind powers averaging above 200 W/m^2 , while at 300 W/m^2 much of the Southwest is excluded. Winds average above 400 W/m^2 in winter and spring in much of New England; the area encompassing the Texas Panhandle, most of Oklahoma, and Kansas; and most of the western states. During the summer months, the southeastern states have wind powers averaging under 100 W/m^2 , while parts of New England, the mid-Atlantic states, and some western states have average wind power of under 200 W/m^2 . Only in some coastal areas; the Texas-Oklahoma-Kansas region; and parts of Wyoming, Colorado, and Montana, is wind power greater than 300 W/m^2 in the summer. A few coastal and mountain areas in California and Oregon, and the Texas-Oklahoma-Kansas region, enjoy wind power averaging over 400 W/m^2 . Wind power is slightly higher in most states in the fall, but again much of the Southeast has wind power under 200 W/m^2 . Primarily the western states have wind power greater than 300 W/m^2 , with only some coastal areas, the Panhandle region, and a few parts of western states having wind power greater than 400 W/m^2 .

The wind power available at 20 m is significantly less than that available at 50 m, although the patterns of seasonal variation are the same. At 20 m, wind powers of up to and greater than 300 W/m^2 were analyzed, since very few stations record wind powers of 400 W/m^2 at this height. Table 20 shows states where some stations record wind power of at least 300 W/m^2 at 20 m, throughout each season. Additional stations record winds this high for one or 2 months out of the seasons listed.

Note: Over mountainous regions (shaded areas) the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Dennis L. Elliott, "Synthesis of National Wind Energy Assessments," BNWL-2220 (Richland, WA: Battelle, Pacific Northwest Laboratories, July 1977).

Figure 11. WINTER—AVERAGE WIND POWER (W/m^2) ESTIMATED AT 50 m ABOVE EXPOSED AREAS

Note: Over mountainous regions (shaded areas) the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Dennis L. Elliott, "Synthesis of National Wind Energy Assessments," BNWL-2220 (Richland, WA: Battelle, Pacific Northwest Laboratories, July 1977).

Figure 12 SPRING—AVERAGE WIND POWER (W/m^2) ESTIMATED AT 50 m ABOVE EXPOSED AREAS

Note: Over mountainous regions (shaded areas) the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Dennis L. Elliott, "Synthesis of National Wind Energy Assessments," BNWL-2220 (Richland, WA: Battelle, Pacific Northwest Laboratories, July 1977).

Figure 13. SUMMER—AVERAGE WIND POWER (W/m^2) ESTIMATED AT 50 m ABOVE EXPOSED AREAS

Note: Over mountainous regions (shaded areas) the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Dennis L. Elliott, "Synthesis of National Wind Energy Assessments," BNWL-222 (Richland, WA: Battelle, Pacific Northwest Laboratories, July 1977).

Figure 14. FALL—AVERAGE WIND POWER (W/m^2) ESTIMATED AT 50 m ABOVE EXPOSED AREAS

**Table 19. STATES WHERE WIND POWER IS AT LEAST 100 W/m²
AT 50 m AT 50% OR MORE OF THE STATIONS, ALL YEAR^a**

Colorado	Montana
Connecticut	Nebraska
Delaware	New Mexico
Idaho	New York
Illinois	North Dakota
Iowa	Oklahoma
Kansas	Rhode Island
Michigan	South Dakota
Minnesota	Texas
Missouri	Wisconsin
	Wyoming

^aFrom data in Reed.¹⁷

**Table 20. STATES (NO. STATIONS) WHERE WIND POWER AVERAGES
≥ 300 W/m² THROUGHOUT EACH SEASON**

Winter (Dec-Feb)	Spring (Mar-May)	Summer (Jun-Aug)	Fall (Sep-Nov)
California (3)	*California (9)	California (6)	Delaware (1)
Colorado (1)	Colorado (3)	Hawaii (2)	Kansas (2)
Delaware (1)	Delaware (1)	Kansas (2)	Michigan (1)
Idaho (1)	Hawaii (2)	Massachusetts (1)	Montana (1)
Illinois (3)	Idaho (2)	Montana (1)	New Mexico (1)
Indiana (2)	Illinois (2)	New Mexico (1)	North Dakota (1)
Iowa (2)	Iowa (3)	North Dakota (1)	Oklahoma (1)
Kansas (3)	Kansas (6)	Oklahoma (1)	South Dakota (1)
Massachusetts (4)	Massachusetts (3)	Texas (3)	Texas (3)
Michigan (2)	Minnesota (2)	Wyoming (1)	Wyoming (2)
Montana (5)	Missouri (1)		
Nebraska (1)	Montana (2)		
New Mexico (1)	Nebraska (10)		
New York (7)	Nevada (1)		
North Dakota (5)	New Mexico (8)		
Ohio (1)	New York (2)		
Oklahoma (1)	North Dakota (4)		
Pennsylvania (4)	Oklahoma (6)		
Texas (1)	Pennsylvania (1)		
Wyoming (6)	South Dakota (4)		
	Texas (11)		
	Wisconsin (1)		
	Wyoming (5)		

V. ECONOMIC ANALYSIS

The objective of the economic analysis was to derive the maximum price a user should be willing to pay to purchase a SWECS for use in food-processing applications (breakeven cost), and to compare this price with currently projected prices of commercially available wind machines. Below, the assumptions and methodology employed to determine breakeven costs, the size and number of SWECS required for various heating and cooling operations, and the feasibility of installing SWECS given their projected costs are described. Energy requirements for various types of food processing are estimated from data presented in section III, and these estimates along with the expected output of different sizes of SWECS in various wind regimes are inputs to the economic analysis. Emphasis is on the use of small wind systems.

A. Energy Requirements and Costs

Tables 21 through 31 show the annual (or seasonal) costs of conventional energy used in various sizes and kinds of food-processing plants. The estimated conventional energy requirements of these plants are also presented. Comprehensive data on energy requirements were not available for all types of plants; these data are based on the information presented in section III (tables 5 through 18). Some estimates of fossil fuel requirements and costs could be made for hog slaughtering plants but not for other animal slaughtering or processing facilities. Although overall fossil fuel and electricity use estimates have been made for dairy plants and citrus-packing plants, the amount of energy used in water heat/ refrigeration functions specifically could not be determined. Electricity requirements and costs for specific poultry plant operations are presented, as are fossil fuel requirements and costs for certain water-heating operations in vegetable plants. Estimates were made for the amount and cost of electricity for cooling milk and heating water on dairy farms.

For most of the plant types, energy requirement and cost data have been calculated for a range of plant sizes. The plant sizes chosen are based on information in sections II and III, and appendix A. According to these data, over two-thirds of hog slaughtering plants handle under 1,000 animals per year, averaging about 300. Using a conversion rate of 105 kg (230 lbs) per hog,* the number of head slaughtered annually in the plant studied by Lund et al. was nearly 1.5 million.⁵ Tables 21 and 22 provide data for these two sizes of establishments as well as for two intermediate sizes. The sizes of broiler processing facilities listed in tables 23 and 24 are based on the sizes of plants studied by Jones and Lee¹, and by Whitehead and Shupe.²

Estimates of energy requirements and costs are provided in table 25 for four different sizes of dairy farms. These sizes were selected based on data presented in table A-2, which indicate average numbers of cows per farm by state. North Dakota has the smallest average size dairy farm

*

From state agricultural statistics yearbooks.

Table 21. ESTIMATED ANNUAL NATURAL GAS REQUIREMENTS AND COSTS FOR HOG SINGEING

Size Plant (hogs/yr)	Natural Gas	
	Requirements ^a (000 cf)	Costs (\$)
300	2.4	5
10,000	80	170
100,000	800	1,699
1,500,000	12,000	25,490

^aBased on 8 cf per hog.⁴

Table 22. ESTIMATED ANNUAL FOSSIL FUEL REQUIREMENTS AND COSTS FOR WATER HEATING IN HOG-SLAUGHTERING PLANTS^a

Size Plant (hogs/yr)	Fossil Fuel Requirements ^b		Costs (\$)	
	Natural Gas (000 cf)	Fuel Oil #2 (gal)	Natural Gas	Fuel Oil #
300	19	146	40	94
10,000	638	4,913	1,355	3,159
100,000	6,345	49,088	13,541	31,563
1,500,000	95,625	736,313	203,108	473,449

^aAssuming either natural gas or fuel oil used for all water heating requirements.

^bBased on loads calculated by Lund, et al.⁴ 63.75 cf/hog assumed, with average hog weighing 105 kg (230 lbs).

**Table 23. ESTIMATED ANNUAL ENERGY REQUIREMENTS AND COSTS
IN POULTRY-PROCESSING PLANTS**

Size Plant (m kg)	Energy Requirements ^a			Costs (\$000)		
	Natural Gas ^b (mcf)	Fuel Oil #2 ^b (000 gal)	Electricity ^c (000 kWh)	Natural Gas	Fuel Oil #2	Electricity
15	10.25- 29.81	79- 230	1,515- 5,385	22- 63	51-148	48-169
30	20.50- 59.61	158- 459	3,030-10,770	44-127	102-295	95-338
40	27.33- 79.48	210- 612	4,040-14,360	58-169	135-394	127-451
75	51.24-149.03	395-1,148	7,575-26,925	109-317	254-738	238-845

^aAssuming all thermal energy requirements are filled by either natural gas or fuel oil.

^bRange of kJ/kg used: 743 (lowest estimate from Whitehead and Shupe²) to 2,161 (highest estimate from Jones and Lee¹). See section III.

^cRange of kWh/kg used: 101 to 359. This is the range found by Jones and Lee.¹ Plants studied by Whitehead and Shupe² were toward the lower end of this range.

Table 24. ESTIMATED ANNUAL ELECTRICAL REQUIREMENTS AND COSTS IN POULTRY-PROCESSING PLANTS: SELECTED WATER-HEATING/REFRIGERATION PROCESSES

Plant Size (m kg)	Process	Electricity Requirements ^a (000 kWh)	Costs (\$000)
15	Scalders	71- 182	2.2- 5.7
	Chillers	28- 46	0.9- 1.4
	Process refrigeration ^b	1,325-1,786	41.6- 56.1
	Compressors, condensers	1,197-1,596	37.6- 50.1
	Ice handling	33- 130	1.0- 4.1
30	Scalders	143- 364	4.5- 11.4
	Chillers	57- 91	1.8- 2.9
	Process refrigeration ^b	2,650-3,572	83.2-112.2
	Compressors, condensers	2,394-3,191	75.2-100.2
	Ice handling	66- 259	2.1- 8.1
40	Scalders	190- 486	6.0- 15.3
	Chillers	76- 122	2.4- 3.8
	Process refrigeration ^b	3,533-4,763	110.9-149.6
	Compressors, condensers	3,192-4,255	100.2-133.6
	Ice handling	88- 346	2.8- 10.9
75	Scalders	357- 911	11.2- 28.6
	Chillers	142- 228	4.5- 7.2
	Process refrigeration ^b	6,625-8,931	208.0-280.4
	Compressors, condensers	5,985-7,978	187.9-250.5
	Ice handling	164- 648	5.2- 20.4

^aFrom table 8. The range shown is based on the lowest and highest kWh per unit, for each process, as shown in table 8.

^bProcess refrigeration total includes pumps and lights also.

Table 25. ESTIMATED ANNUAL ELECTRICITY REQUIREMENTS AND COSTS FOR MILK COOLING AND HOT WATER ON DAIRY FARMS

Size Farm (# Cows)	Electricity Requirements (kWh) ^a		Costs (\$)	
	Cooling	Hot Water	Cooling	Hot Water
20	3,000	3,000	94	94
50	7,500	7,500	238	236
100	15,000	15,000	471	471
500	75,000	75,000	2,355	2,355

^aBased on 150 kWh/cow/yr.

Table 26. ESTIMATED ANNUAL ENERGY REQUIREMENTS AND COSTS FOR FLUID MILK PLANTS

Size Plant (m kg rec'd)	Energy Requirements ^a			Costs (\$)		
	Natural Gas ^b (mcf)	Fuel Oil #2 ^b (000 gal)	Electricity ^c (000 kWh)	Natural Gas	Fuel Oil #2	Electricity
3	0.88	7	186	1,869	4,501	5,840
10	2.93	23	620	6,223	14,789	19,468
80	23.47	181	4,960	49,850	116,383	155,744

^aAssuming all thermal energy requirements are filled by either natural gas or fuel oil.

^bAssuming a kJ/kg requirement of 319, from Goel et al.⁹ (see section III).

^cAssuming a kJ/kg requirement of 755 (0.062 kWh/kg assuming 29.4% efficiency) from Goel et al.⁹ (see section III).

**Table 27. ESTIMATED ANNUAL ENERGY REQUIREMENTS AND COSTS
FOR FLUID MILK PLANTS PRODUCING SOLIDS^a**

Size Plant (m kg milk rec'd)	Energy Requirements ^b			Costs (\$000)		
	Natural Gas ^c (mcf)	Fuel Oil #2 ^c (000 gal)	Electricity ^d (000 kWh)	Natural Gas	Fuel Oil #2	Electricity
3	4.78- 5.32	37- 41	90	10- 11	24- 26	3
10	15.94- 17.75	123- 137	300	34- 38	79- 68	9
80	127.66-141.97	982-1,093	2,400	271-302	631-703	75

^aIncluding evaporated, condensed, powdered milk; butter.

^bAssuming all thermal energy requirements are filled by either natural gas or fuel oil.

^cBased on range of kJ/kg or 1,734 to 1,930, from Goel et al.¹⁰ (see section III).

^dBased on kWh/kg of about 0.030, from Goel et al.¹⁰ (see section III). Lower than the estimate given in table 26, because less refrigeration required for these products.

**Table 28. ESTIMATED ANNUAL ENERGY REQUIREMENTS AND COSTS
FOR CHEESE PLANTS**

Size Plant (m kg cheese)	Energy Requirements ^a			Costs (\$000)		
	Natural Gas ^b (mcf)	Fuel Oil #2 ^b (000 gal)	Electricity ^c (000 kWh)	Natural Gas	Fuel Oil #2	Electricity
1	19.95	154	97- 279	42	99	3- 9
3	59.84	401	291- 007	127	296	9-26
5	99.73	768	485-1,395	212	494	15-44

^aAssuming all thermal energy requirements are filled by either natural gas or fuel oil.

^bBased on estimate of kJ/kg cheese of 21,692 from Goel et al.¹¹ (see section III).

^cBased on estimates of kWh/kg cheese of 0.097 to 0.279, from Goel et al.¹¹ (see section III).

**Table 29. ESTIMATED ANNUAL FOSSIL FUEL REQUIREMENTS AND COSTS
FOR VEGETABLE-PROCESSING PLANTS, SELECTED USES**

Type Plant	Size (m kg)	Use	Fossil Fuel Requirements ^a		Costs (\$)	
			Natural Gas (mcf)	Fuel Oil #2 (000 gal)	Natural Gas	Fuel Oil #2
Vegetable ^b	21	Blanching, sterilization	11.03	85	23,428	54,655
Spinach ^c	2.2	Blanching	2.09	16	4,439	10,288
		Exhaust box	2.98	23	6,330	14,789
		Retorting	0.95	7	2,018	4,501
Peas ^d	1.7	Boiler feed water	1.38	11	2,931	7,073
		Topper water	0.94	7	1,997	4,501
		Flume water	0.71	5	1,508	3,215
		Blanching	0.78	6	1,657	3,858
		Cleaning	0.32	2	680	1,286
Corn ^d	2.4	Boiler feed water	1.75	13	3,717	8,359
		Topper water	0.91	7	1,933	4,501
		Flume water	0.75	6	1,593	3,858
		Cleaning	0.32	2	680	1,286

^aAssuming all thermal energy requirements are filled by either natural gas or fuel oil.

^bFrom Vergara et al.¹² Size is the average size of 4 plants, in gross weight produced. Average kJ/kg for blanching: 571.

^cFrom Chhinnan et al.¹³ Size is in terms of raw spinach processed. Blanchers used an average of 1,034 kJ/kg, exhaust boxes an average of 1,473 kJ/kg, and retorts an average of 468 kJ/kg.

^dFrom Lund et al.⁵ Size in terms of peas and corn processed. Same plant processed both products, during different seasons. Average kJ/kg assumed for the different uses were: (for peas) boiler water—880; topper water—602; flume water—456; blanching—498; cleaning—203; (for corn) boiler water—795; topper water—413; flume water—341; cleaning—147.

**Table 30. ESTIMATED ANNUAL ELECTRICITY
REQUIREMENTS AND COSTS FOR
VEGETABLE-PROCESSING PLANTS**

Type Plant	Size (m kg)	Electricity Requirements (000 kWh)	Costs (\$)
Vegetable ^a	21	2,226	69,896
Spinach ^b	2.2	158	4,961

^aFrom Vergara et al.¹² Size is the average of 4 plants, in gross weight produced. Average kWh/kg were 0.106.

^bFrom Chhinnan et al.¹³ Size is in terms of raw spinach processed. Average kWh/kg was 0.072.

**Table 31. ESTIMATED ANNUAL ENERGY REQUIREMENTS AND COSTS
IN CITRUS-PACKING PLANTS**

Size Plant (m kg)	Energy Requirements ^a			Costs (\$000)		
	Natural Gas ^b (mcf)	Fuel Oil #2 ^b (000 gal)	Electricity ^c (000 kWh)	Natural Gas	Fuel Oil #2	Electricity
20	0.99-2.94	8-23	300-1,060	2- 6	5-15	9-33
30	1.49-4.41	11-34	450-1,590	3- 9	7-22	14-50
40	1.98-5.88	15-45	600-2,120	4-12	10-29	19-67

^aAssumes all thermal energy requirements filled by either natural gas or fuel oil.

^bRange of kJ/kg of 53.9 to 159.8 assumed, from Mayou and Singh.¹⁴

^cRange of kWh/kg of 0.015 to 0.053 assumed, from Mayou and Singh.¹⁴

(22 cows), while Florida has the largest (419 cows). Fluid milk plant sizes used were based on information supplied by Rippen.* Sample sizes of cheese plants were chosen based on data in section II (the average size cheese plant produces about 2 million kg (4.5 million lbs) cheese), and in Goel et al., who studied a plant producing about 5 million kg (11 million lbs) cheese.¹¹

Size of vegetable plants were taken directly from the studies of Lund et al.,⁵ Vergara et al.,¹² and Chhinnan et al.¹³ Size information was not given for the individual vegetable-processing plants in New York by Vergara et al., but these four plants averaged 21 million kg (46.2 million lbs) gross weight production annually. Plant sizes in the other vegetable plants refer to amount of raw produce received. The energy requirements and costs estimated for the plants studied by Vergara et al. are not comparable with the other data in tables 29 and 30, since Vergara et al. calculated theoretical requirements, and equipment efficiencies were not incorporated. Actual energy use was calculated in the other studies of vegetable plants.

The sample sizes of citrus-packing plants were based primarily on Mayou and Singh.¹⁴ Total thermal energy requirements and costs can be estimated for other types of fruit and vegetable plants using data presented in table 16 (section III). Both Mayou and Singh¹⁴ and table 16 provide data specific to California.

The energy parameters provided in tables 21 through 31 should be regarded as very general. Energy use varies widely among plants processing the same products, because of differences in plant size and configuration, efficiencies of equipment, percent of capacity at which the plants are operated, climate and season, etc. The wide range possible can be noted in tables 23 and 24, which show thermal energy and electricity requirements, respectively, in poultry plants. Because this report is of a general survey nature, these energy parameters are used as the basis for the economic analysis. However, plant operators interested in the feasibility of wind systems for their operations must make these calculations for their individual plants.

The energy prices assumed for the cost calculations were:

Electricity:	3.14¢/kWh
Natural Gas:	212.40¢/000 cf
Fuel Oil No. 2:	64.30¢/gal

The electricity price is the average industrial retail price as of September 1979.¹⁸ The natural gas price is the average price to industrial users reported by major interstate pipeline companies as of September 1979,¹⁸ and the fuel oil No. 2 price is the July 1979 wholesale price.¹⁹ Although fuel oil No. 6 also is used in processing plants, separate calculations were not made using No. 6 prices. Since these prices are lower than No. 2 prices but higher than those of natural gas, the range of potential fossil fuel costs was obtained using only natural gas and No. 2 data.

*

Personal communication. Rippen supplied size information for the fluid milk plants studied by Thomas et al.¹⁶

Because these prices are national averages, the prices paid by individual plants may be substantially higher or lower. Fuel and electricity prices vary by region, type of use, and season. Because of price controls instituted on natural gas in the early 1960s, prices of natural gas committed to interstate sales generally have been lower than those of natural gas sold intrastate. Federal regulations have not applied to intrastate sales, although state public utility commissions regulate retail prices for distributors. Although federal deregulation of natural gas is proceeding, variations in price by region still exist. In general, natural gas is cheapest in the southwestern, midwestern, and south Atlantic states. Fuel oil also is affected by federal regulations, as well as by the frequent price increases of the oil-exporting nations. Fuel oil is cheapest in the east- and west-south-central states.

Electricity rates vary by region because of differing sources of power or fuel and differences in regulations. The transmission facilities of individual utilities and customer densities in their distribution areas also are factors. Rates tend to be low in areas such as the Pacific Northwest, where hydroelectric power is used. They are also lower than the national average in the south-central and southeastern states, particularly in the Tennessee Valley Authority's area. Higher than average rates are paid in the mid-Atlantic and northeastern states. Utilities are regulated at the state level (in some states, municipal governments regulate within city boundaries), and the Federal Energy Regulatory Authority regulates the wholesale rates of all companies operating in interstate commerce (95 percent of all electric utilities).

Customer differentials in prices of fuel and electricity are based on type of use such as industrial, residential, and commercial. (Industrial rates, which generally are lower than the others, were used for this analysis.) In the case of natural gas, rates also are based on whether service is interruptible or noninterruptible. Processing plants frequently are classed as industrial interruptible customers, with lower rates than industrial customers who have noninterruptible service. Noninterruptible service customers also are sometimes charged peak rates during winter, when gas is drawn from liquefied storage facilities.

B. Breakeven Costs

The first step in the determination of breakeven costs was to calculate the present value of the potential savings of electricity and fossil fuel costs, assuming that these conventional energy sources were to be replaced by electricity generated by WECS. Present values were calculated over a period of 20 years (the assumed lifetime of the WECS), with a discount rate of 10 percent. Fossil fuel prices were assumed to escalate at a rate of 35 percent for the first 2 years, and at 8 percent annually thereafter. Conventional electricity prices were assumed to rise at a rate of 20 percent for the first 2 years, and at 4 percent annually thereafter.*

*

Energy price escalation rates suggested by USDA and DOE.

Present values of energy savings were calculated from the formula:

$$PV = \sum_{t=1}^{20} e_t \frac{1}{(1+r)^t} \quad (1)$$

where PV = present value;

e_t = annual energy savings;

r^t = discount rate, = 0.10;

t = time period (year).

Using the resulting present values, the allowable investment costs or breakeven costs for WECS were calculated. Breakeven costs were assumed to be the purchase price that equated the present value of the savings generated (the fossil fuel and electricity costs saved) to the present value of the annual costs associated with WECS. Assumptions were that (1) operations and maintenance costs (including property taxes and other miscellaneous costs) are 5 percent of fixed costs, and (2) that the WECS have a salvage value of zero at the end of the 20-year lifetime. The equation for calculating the present value of annual WECS costs then was:

$$AC = X + \sum_{t=1}^{20} aX/(1+r)^t \quad (2)$$

where AC = annual costs;

X = breakeven costs (investment cost or price of WECS allowed);

$a = 0.10 = 0.05$ annual depreciation + 0.05 operations and maintenance;

$r = 0.10$ = discount rate;

t = time period (year).

Setting $a = 0.10$ for each year the last term in equation (2) becomes a constant:

$$AC = X + 0.851X = 1.851X. \quad (3)$$

Annual costs then are set equal to benefits, or the present value of savings, from equations (1) and (3):

$$PV = AC = 1.851X. \quad (4)$$

Thus, the breakeven costs (X) are equal to the present value of savings divided by 1.851.

Breakeven costs were calculated assuming the displacement of conventional energy sources by wind energy for the processing operations presented in tables 21 through 31. These calculations, presented in tables 32 through 36, are used as base cases; however, variations of these base cases can be envisioned easily. For instance, a wind machine might be used to generate only a part of the electricity or thermal energy required. This scenario is in fact a likely one; SWECS are likely to be used on a supplemental basis rather than as stand-alone systems. SWECS then would be used when the wind blows, with conventional sources used as backup. In some heating applications, SWECS might be useful only as a supplemental source because of the high temperatures required. While warm water frequently is used for cleaning in processing plants, operations such as cooking, canning, and blanching require temperatures close to boiling. Other operations, such as scalding (hogs, poultry), require temperatures of around 52° 60°C (125°/140°F) (see section III). In these cases, SWECS might be used most efficiently to preheat water to an intermediate temperature, possibly through a heat pump.

If wind power were used to drive a heat pump, some combination of the base case breakeven costs listed might be relevant. For instance, the evaporator might be used to chill an ice builder to store cooling capacity the condenser, while the condenser heated water. SWECS thus might be able to supply both some of the electrical requirements for refrigeration/cooling and some of the thermal energy requirements. Using the data in table 33 as an example, SWECS might supply some energy both to scalders and to chillers in poultry plants, or to scalders and to some of the process refrigeration operations. Then the true breakeven costs might be higher than those listed in table 33, which assume displacement of conventional energy sources for an individual operation. Milk cooling and water heating on a dairy farm are another example of a likely use of a wind machine with a heat pump.

Once breakeven costs were determined, a payback analysis was performed, presenting annual outlays required for SWECS operation and resulting savings in conventional energy costs for these systems. Although SWECS lifetimes were assumed to be 20 years, loan periods were assumed to be 10 years. Interest rates of 9 and 10 percent were assumed, as were loans of both 20 percent and 50 percent equity. Payback periods were analyzed assuming an investment equal to the breakeven costs listed in tables 32 through 36.

Payback (the point at which total accrued savings equalled or exceeded total outlays) occurred between the eighth and twelfth years. Over the 20-year lifetime assumed for the SWECS, savings were about double the outlays. There was little sensitivity to change in percent equity or to the one percent change in interest rate; the largest difference between the most and least favorable cases (50 percent equity, 9 percent interest; and 20 percent equity, 10 percent interest, respectively) was 2 years. Some examples of the payback analysis are presented in appendix E.

C. Breakeven Costs versus Projected SWECS Costs

SWECS Energy Output

The first step in comparing breakeven costs with currently projected wind systems costs was to calculate power output for different sizes of SWECS. The systems selected were small wind energy systems (SWECS) tested at Rocky Flats, all of which were rated at 20 miles per hour.²⁰ Data from these systems were used because comparable power curves were available. These systems were

**Table 32. BREAKEVEN COSTS OF WECS FOR USE IN
SELECTED PROCESSES: MEAT, POULTRY PLANTS^a**

Type Plant	Process	Size	Breakeven Costs (\$000) Assuming Displacement of:		
			Natural Gas	Fuel Oil #2	Conventional Electricity
Hog	Singeing	300 (hogs/yr)	0.07		
		10,000	2.40		
		100,000	23.50		
		1.5 million	353.00		
Hog	Water Heating	300 (hogs/yr)	0.60	1.30	
		10,000	18.70	43.70	
		100,000	187.40	436.70	
		1.5 million	2,810.30	6,550.90	
Poultry ^b	All	15 (m kg/yr)	304.00	706.00	399.00
		30	609.00	1,411.00	790.00
		40	803.00	1,868.00	1,056.00
		75	1,508.00	3,514.00	1,979.00
Poultry ^c	All	15 (m kg/yr)	872.00	2,048.00	1,405.00
		30	1,757.00	4,802.00	2,811.00
		40	2,338.00	5,452.00	3,751.00
		75	4,386.00	10,211.00	7,027.00

^aFrom data in tables 21, 22, 23.

^bAssuming lower estimates of energy required per unit processed (see table 23).

^cAssuming higher estimates of energy required per unit processed (see table 23).

**Table 33. BREAKEVEN COSTS OF WECS FOR ELECTRICITY
GENERATION IN POULTRY PLANTS:
SELECTED PROCESSES^a**

Plant Size (m kg/yr)	Processes	Breakeven Costs (\$000)	
15	Scalders	18.3 -	47.4
	Chillers	7.5 -	11.6
	Process refrigeration	345.9 -	466.5
	Compressors, condensers	312.7 -	416.6
	Ice handling	8.3 -	34.1
30	Scalders	37.4 -	94.8
	Chillers	15.0 -	24.1
	Process refrigeration	691.9 -	933.1
	Compressors, condensers	625.4 -	833.3
	Ice handling	17.5 -	67.4
40	Scalders	49.9 -	127.2
	Chillers	20.0 -	31.6
	Process refrigeration	922.3 -	1,244.1
	Compressors, condensers	833.3 -	1,111.0
	Ice handling	23.3 -	90.6
75	Scalders	93.1 -	237.8
	Chillers	37.4 -	59.9
	Process refrigeration	1,729.1 -	2,331.8
	Compressors, condensers	1,562.6 -	2,083.2
	Ice handling	43.2 -	169.6

^aFrom data in table 24.

Table 34. BREAK-EVEN COSTS OF WECS FOR USE IN DAIRY FARMS AND PLANTS^a

Type Plant	Size	Breakeven Costs (\$000) Assuming Displacement of:		
		Natural Gas	Fuel Oil #2	Conventional Electricity
Farm ^b	20 (cows/yr)			1.6
	50			3.9
	100			7.8
	500			39.3
Fluid milk	3 (m kg/yr)	25.9	62.3	48.6
	10	86.1	204.6	161.9
	80	689.7	1,610.3	1,295.2
Fluid milk, producing Solids ^{c,d}	3 (m kg/yr)	138.4	332.1	24.9
	10	470.4	1,093.1	74.8
	80	3,749.7	8,730.8	623.7
Fluid milk, producing Solids ^{c,e}	3 (m kg/yr)	152.2	359.7	
	10	525.8	940.9	
	80	4,178.6	9,727.1	
Cheese ^f	1 (m kg/yr)	581.1	1,369.8	24.9
	3	1,757.2	4,095.6	74.8
	5	2,933.3	6,835.2	124.7
Cheese ^g	1 (m kg/yr)			74.8
	3			216.2
	5			365.9

^aFrom data in tables 25 through 28.

^bBreakeven costs assuming displacement of conventional electricity used in both water heating and milk cooling.

^cLower breakeven costs for electricity in fluid milk plants producing solids than in other fluid milk plants because less refrigeration is required.

^dUses low estimate of energy required per unit processed (see table 27).

^eUses high estimate of energy required per unit processed. Electricity requirements are the same as above.

^fUses low estimate of energy required per unit processed (see table 28).

^gUses high estimate of energy required per unit processed. Fossil fuel costs are the same as above.

**Table 35. BREAKEVEN COSTS OF WECS FOR USE IN
VEGETABLE-PROCESSING PLANTS^a**

Type Plant	Size (m kg/yr)	Process	Breakeven Costs (\$000) Assuming Displacement of:		
			Natural Gas	Fuel Oil #2	Conventional Electricity
Vegetable ^b	21	All			581.0
		Blanching and Sterilization	324.1	756.2	
Spinach ^c	2.2	All			41.2
		Blanching	61.4	142.3	
		Exhaust box	87.6	204.6	
		Retorting	27.9	62.3	
Peas ^c	1.7	Boiler feed water	40.6	115.7	
		Topper water	27.6	62.3	
		Flume water	20.9	44.5	
		Blanching	22.9	53.4	
		Cleaning	9.4	17.8	
Corn ^c	2.4	Boiler feed water	51.4	115.7	
		Topper water	26.8	62.3	
		Flume water	22.0	53.4	
		Cleaning	9.4	17.8	

^aFrom data in tables 29 and 30.

^bSize refers to gross weight of production.

^cSize refers to raw produce processed.

Table 36. BREAKEVEN COSTS OF WECS FOR USE IN CITRUS-PACKING PLANTS^a

Size Plant (m kg/yr)	Breakeven Costs (\$000) Assuming Displacement of:		
	Natural Gas	Fuel Oil #2	Conventional Electricity
20	27.7- 83.0	69.2-207.6	74.8-274.3
30	41.5-124.5	96.9-304.4	116.4-415.6
40	55.4-166.0	138.4-401.3	157.9-556.9

^aFrom data in table 31.

not commercially available as of September 1979, although some other systems of comparable size were (where "commercially available" is defined as production of at least three units, one of which is operational).²¹ Comparable power curves were not available for the commercially available systems. The systems from which data were obtained for this report are listed in appendix F.

Mean power output was calculated using the Rayleigh distribution and the power curves supplied by Rocky Flats. The probability density function for the Rayleigh distribution is given by:

$$F(V) = \pi/2 \frac{V}{\bar{V}^2} \exp \left[-\pi/4 \left(\frac{V}{\bar{V}} \right)^2 \right]$$

where V = wind velocity;

$\bar{V}$ = site mean wind velocity.

Outputs were calculated for four average wind speeds: 4.4 m/s (100 W/m²); 5.6 m/s (200 W/m²); 6.4 m/s (300 W/m²); and 7.0 m/s (400 W/m²). For each assumed average speed V , the frequency of occurrence for each speed V (given by the above function) was multiplied by the power produced by the SWECS at that speed (obtained from the power curves). These values then were summed for total mean power output in kW, and multiplied by the appropriate number of seasonal hours. Resulting figures were multiplied by 0.9 based on the assumption that a turbine would be available for service 90 percent of the time the wind is in the operating range.²² Capacity factor (mean power output/rated power) and mean power output/power in the wind also were calculated. Table 37 presents performance for small wind systems of different power ratings (where different systems of a given rating had been tested, their results were averaged), including annual energy output. Table 38 shows energy output over shorter time periods.

Comparison with Projected SWECS Costs

Using the data on energy requirements presented in tables 21 through 31 and energy outputs of different sizes of SWECS (tables 37 and 38), it was determined what SWECS or combinations of SWECS would be required to satisfy the energy requirements in the different wind regimes. Projected costs for SWECS* obtained from Rocky Flats (see table 39) were compared with breakeven costs. Site preparation and installation costs are not included in table 39, and would depend on the specific site as well as the size and type of machine. Estimates for SWECS site preparation and installation range between several hundred and 2 to 3 thousand dollars. In addition, no storage costs are included.

Table 40 shows these SWECS requirements and the ratio of SWECS cost projected at the 10,000th unit to breakeven costs (from tables 32 through 36), for sizes and types of processing plants and for certain selected processes. The same calculations can be made for certain selected processes. The same calculations can be made for other plant types and sizes, using the data on

**Table 37. PERFORMANCE STATISTICS FOR GENERIC WIND SYSTEMS
AT FOUR MEAN WIND VELOCITIES^a**

System Rated kW	Mean Power (kW)	Capacity Factor	Mean Power/ Power in Wind	Annual Energy ^b (kWh)	x 0.9
4.4 m/s (100 W/m²)					
1	0.184	0.18	0.11	1,600	1,500
2	0.556	0.28	0.28	4,900	4,400
8	1.748	0.22	0.23	15,300	13,800
40	5.779	0.15	0.21	50,600	45,500
5.6 m/s (200 W/m²)					
1	0.357	0.36	0.11	3,100	2,800
2	0.930	0.47	0.24	8,100	7,300
8	3.221	0.40	0.21	28,200	25,400
40	11.200	0.28	0.23	98,100	88,300
6.4 m/s (300 W/m²)					
1	0.476	0.48	0.10	4,200	3,800
2	1.171	0.59	0.20	10,300	9,200
8	4.219	0.53	0.18	37,000	33,300
40	14.836	0.37	0.18	130,000	117,000
7.0 m/s (400 W/m²)					
1	0.560	0.56	0.08	4,900	4,400
2	1.340	0.67	0.17	11,800	10,600
8	4.925	0.62	0.16	43,100	38,800
40	17.426	0.44	0.16	152,600	137,400

^aWhere more than one system of a given rating was analyzed, an average of the mean powers obtained from the different systems is presented.

^bRounded to nearest hundred.

**Table 38. ENERGY OUTPUT OVER DIFFERENT TIME PERIODS
FOR GENERIC WIND SYSTEMS AT
FOUR MEAN WIND VELOCITIES**

System Rated kW	Energy Output (kWh) ^a Over:				
	1 Month	6 Weeks	2 Months	3 Months	6 Months
4.4 m/s (100 W/m²)					
1	130	190	250	380	760
2	370	550	730	1,100	2,200
8	1,150	1,730	2,300	3,450	6,900
40	3,790	5,690	7,580	11,370	22,750
5.6 m/s (200 W/m²)					
1	230	350	470	700	1,400
2	610	920	1,220	1,830	3,650
8	2,120	3,180	4,230	6,350	12,700
40	7,360	11,040	14,720	22,080	44,150
6.4 m/s (300 W/m²)					
1	320	480	630	950	1,900
2	770	1,160	1,540	2,310	4,600
8	2,780	4,170	5,560	8,340	16,650
40	9,750	14,630	19,500	29,250	58,500
7.0 m/s (400 W/m²)					
1	370	560	740	1,110	2,200
2	880	1,320	1,760	2,640	5,300
8	3,230	4,850	6,460	9,690	19,400
40	11,450	17,180	22,900	34,350	68,700

^aIncludes 0.9 operational factor.

Table 39. PROJECTED SWECS FOB PRICES (\$)

Rated Power (kW)	10th Unit	100th Unit	10,000th Unit
2	5,700	3,600	3,100
8	20,000	10,000	8,000
40	50,000	25,000	20,000

Source: Rockwell International Corporation, Wind Systems Program, Rocky Flats Plant, Energy System Group, "Systems Summary of Small Wind Energy Conversion Systems (SWECS) Development," 1979.

Table 40. NUMBER, SIZE, AND RATIO OF PROJECTED TO BREAKEVEN COST OF SWECS REQUIRED TO SUPPLY THERMAL ENERGY OR ELECTRICITY IN FOOD-PROCESSING PLANTS

Type Plant	Size (Annual Production) ^c	Process	Energy Source Replaced	Average Wind Power = 100 W/m ²			Average Wind Power = 400 W/m ²		
				SWECS #	Required ^a Size (kW)	SWECS Cost ^b / Breakeven Cost	SWECS #	Required ^a Size (kW)	SWECS Cost ^b / Breakeven Cost
Hog slaughtering	300 hogs	Singeing	NG	1	1	44	1	1	44
	100,000 hogs			6	40	5	2	40	1.7
Hog slaughtering	300 hogs	Water heating	FO #2	2	1.2	4.8	1	2	2.4
	100,000 hogs			42	40	1.9	14	40	0.6
Poultry ^d	15 m kg	Scalders	Elec	4	40	1.7	3	2,8,40	0.7
		Chillers	Elec	1	40	1.7	2	2,8	1.0
		Process refrigeration	Elec	40	40	1.7	13	40	0.6
Dairy farm	20 cows	Milk cooling and water heating	Elec	2	1.2	3.9	1	2	1.9
	500 cows			4	40	2.0	2	2,40	0.6
Fluid milk	3 m kg received	All	FO #2	6	40	1.9	2	40	0.6
			Elec	5	2(11,40)(4)	1.7	3	2,8,40	0.6
Cheese ^d	1 m kg	All	FO #2	133	40	1.9	44	40	0.6
			Elec	8	2(2,40)(5)	5.1	2	40	1.6
Vegetable ^e	21 m kg (gross weight)	Blanching and sterilization	FO #2	47	40	3.9	49	40	1.3
Peas ^f	1.7 m kg (raw pro- duce received)	Boiler feedwater	FO #2	74	40	12.8	25	40	4.3
		Topper water	FO #2	50	40	16.1	17	40	5.5
		Flume water	FO #2	38	40	17.1	13	40	5.8
		Blanching	FO #2	42	40	15.7	14	40	5.2
		Cleaning	FO #2	17	40	19.1	6	40	6.7
Citrus Packing ^d	20 m kg	All	FO #2	20	40	1.9	7	40	0.7
			Elec	24	40	1.8	8	40	0.6

^aNumbers of SWECS required should be regarded as approximate, since estimates of energy requirements and SWECS output both are only approximate. Configurations of SWECS different from those listed here are possible. In many cases, surplus electricity would be available with the configurations listed. These estimates do not take into account possible use of heat pumps. Conversion of 3600 kJ/kWh assumed to obtain requirements for replacement of fossil fuels.

^bCosts were projected for the 10,000th unit, from table 39. Costs for the 1-kW machine were assumed to be the same as those for the 2-kW machine, as projections were not available for the former.

^cPlant assumed to operate over the entire year unless otherwise noted.

^dHigh estimate of energy required used (see tables 21 through 31).

^ePlant assumed to operate for 6 months. (Plants studied by Ve-gara et al.¹² operated for more of the year, with production ceasing only from March to May, but peak production occurred during August through October. Actual operating time of vegetable plant depends on the products.)

^fPlant assumed to operate for 6 weeks.

energy requirements in table 21 through 31, information on SWECS energy output from tables 37 and 39, and breakeven cost data. Comparisons are shown for wind regimes of 100 W/m² and 400 W/m², the least and most favorable wind conditions analyzed in section IV, respectively. Dairy, meat/poultry, and citrus-packing plants were assumed to operate all year, while vegetable plants were assumed to operate for shorter periods.

Some of the cases most favorable to wind energy substitution were analyzed: fuel oil No. 2 breakeven costs rather than those of natural gas were used in most instances. Fuel oil No. 2 is the fuel most economical to replace, since it is more expensive than natural gas (or fuel oil No. 6) on a heat-equivalent basis. However, natural gas is listed as the energy source to be replaced in the singeing operation in hog-slaughtering plants, since the cited literature addressed natural gas requirements only for this operation.

Table 40 assumes that all the energy requirements for the processes listed would be replaced by electricity supplied by SWECS, although in fact the wind would most likely be used as a supplemental power source in many of these cases. For processes requiring water of high temperatures, currently using fossil fuels, wind energy could be used for pre-heating. The economics of replacing fuels with wind energy, however, would be the same. For the larger plants, use of machines larger than the SWECS compared here would be more economical, if any significant percentage of the energy required were to be supplied with wind power. Larger machines should be able to supply electricity more cheaply, and with more efficient use of land space.

Table 40 indicates that use of SWECS is economically viable for some plants operating year-round, if they can take advantage of winds averaging 400 W/m². These plants also could substitute wind power economically if located in an area with winds of 200 W/m² or 300 W/m². In none of the cases analyzed would wind systems be viable where wind power averages only 100 W/m². In many cases, the comparison is actually slightly more favorable than that indicated in table 40, because some electricity beyond that required by the process listed would be available from the particular wind machines listed. In the case of hog singeing in a 300 hog/year plant, for instance, the ratio of SWECS to breakeven cost listed is 44. However, only 725 kWh annually are required for this operation, whereas a 1-kW machine would produce 1,500 kWh even in the 100 W/m² wind regime. Were all this electricity used in place of conventionally supplied electricity, the ratio would be cut approximately in half.

The ratio of projected SWECS cost to breakeven cost also would fall if a heat pump were used in conjunction with the wind turbine to supply energy for heating and cooling simultaneously. This procedure would be possible in the processing plants analyzed, as they have simultaneous demands for cooling or chilling the product, as well as for heating water for cleaning and processing. On dairy farms, for instance, the milk must be cooled and there is a continuous demand for warm water for sanitation. Meat/poultry and vegetable plants must chill the product, and utilize warm water for cleaning and the hotter water or steam for operations such as scalding, singeing, blanching, and cooking.

D. Summary

With the projected costs and energy prices assumed, the installation of SWECS could be economically viable for some processing plants operating year-round with winds averaging 200 W/m^2 or above. For those plants with seasonal peaks in their operations, viability will depend in great part on wind availability during those seasons. Seasonal processing plants operating for less than 6 months of the year probably would not find wind systems viable in any wind regime.

Coupling a heat pump to the wind turbine would improve the ratios of projected SWECS to breakeven costs further. In addition, changes in some of the underlying parameters of this analysis could result in conditions significantly more favorable to SWECS use. The baseline conventional energy prices used were national averages, which vary substantially by region. Plant operators in some areas undoubtedly are paying higher prices for their fuels and electricity. Further, the prices used in this study, which were the most recently compiled statistics available, lag current energy prices by a few months. Conventional energy prices may escalate either more or less rapidly than the rates assumed.

Because electricity is more expensive than fossil fuels (on a heat- or kWh-equivalent basis), SWECS should be able to replace electricity more economically than fossil fuels. (Ratios of SWECS to breakeven cost are not always lower for replacement of electricity than for replacement of fuel oil in table 40, but these results also depend on amount of energy being replaced.) The assumption of higher escalation rates for fossil fuels than for electricity over time narrows these differentials, but electricity generated from oil or natural gas will continue to be significantly more expensive than the fuels themselves. Among the fuels, it currently is most advantageous to substitute for fuel oil No. 2, and least advantageous to replace natural gas. However, natural gas prices are rising as deregulation proceeds, and natural gas has the further disadvantage for some plants of being an interruptible source of energy.

Even though projected WECS costs approach or fall below breakeven costs in some cases, the payback periods of 8 to 12 years are fairly long. Further, there is not much sensitivity due to changes in the percent of equity on loans or to small changes in interest rates. Whether or not these lengths of payback are acceptable depends on the time horizons of processing plant operators.

VI. SUMMARY AND CONCLUSIONS

The food-processing plant inventory conducted indicated that there are nearly 7,000 meat plants, over 240,000 dairy farms, nearly 3,000 dairy plants, around 1,300 fruit/vegetable processing establishments, and about 130 aquaculture plants in the United States. These estimates in the case of fruit/vegetable and aquaculture plants are likely to be on the conservative side. Numbers of meat and dairy plants are slightly underestimated, since data were obtained for federally inspected facilities only. Meat-slaughtering and processing facilities are concentrated in the Midwest, which has nearly one third of the total; the states of California, New York, and Pennsylvania also each contain over 700 meat plants. Wisconsin and Minnesota alone contain nearly one-third of the dairy farms and one-fifth of all dairy plants. Other states with large numbers of dairy farms and plants include California, Iowa, New York, Ohio, and Pennsylvania. Large numbers of fruit and vegetable plants are located in California, Florida, Michigan, New York, and Wisconsin; aquaculture plants are concentrated in the Southeast; with a few located also in the Pacific Northwest, Rocky Mountain states, and New England.

All these types of food-processing plants require heated water and refrigeration/cooling processes in their operations. Chilling of products is required before or during processing, refrigeration or freezing is needed for storage afterward; warm or hot water is necessary for cleaning and various processing operations. Among the latter operations are included the removal of hair from hogs and feathers from chickens (scalding or singeing), cooking and canning of meat, vegetable, fruit, and some dairy products; clarification, separation, and pasteurization of dairy products; and the washing, blanching, and peeling of fruits and vegetables.

Temperature requirements for these operations vary substantially. Freezing temperatures commonly are around -40°C , and temperatures for cooled storage slightly above 0°C . Cooking and canning heat requirements for meats range up to over 200°C (as high as 400°F) and 130°C (265°F), respectively, depending on the process. Scalding and singeing require water up to 58°C (136°F) as well as steam. In dairy-processing plants, the highest temperatures are required for pasteurization, and may be as high as 100°C . Other dairy processes such as clarification and separation require lower temperatures ranging up to 74°C (165°F). Canning in fruit and vegetable plants is performed at temperatures between 100° and 150°C (212° to over 300°F), depending on the specific product and process. Warm rather than hot water frequently is used for cleaning (often between 57° and 82°C), but hotter water and steam also are used for improved sanitation.

These heating and cooling processes consume substantial energy. The primary energy sources used are natural gas, fuel oil, LPG, and electricity. Fuels are used most frequently for hot water and steam generation, while electricity is used for refrigeration, freezing, and ice-making equipment. Electricity also may be used to generate heat for hot water. Energy requirements were estimated for various sizes and types of processing plants, and for certain selected processes. Data were obtained from energy audits performed on individual plants. Relatively few of these audits are available, however, and energy use varies considerably by individual establishments.

Use of the wind to replace or supplement conventional energy sources requires a match between plant locations and areas and seasons of good wind availability. Winds are best in the Midwest, Rocky Mountain states, and Southwest. The Southeast is the region with poorest wind availability. Because of the seasonal variation in wind power, however, many plants even in some of these areas may be able to utilize wind power for only a part of the year. The best winds generally occur during winter and spring, while summer and early fall are the calmest months; fruit and vegetable plants that operate primarily or only during the summer and fall may be unable to tap this resource at all. At 50 meters, wind power averages over 100 W/m^2 during every month in 21 states. It averages over 400 W/m^2 during the winter and spring in many of the western states (including part of the Southwest) and some sites in New England, but during the rest of the year drops substantially below this level except in a few Rocky Mountain and southwestern areas. At the lower height of 20 meters, which is a more likely height for a small wind turbine, there is similar seasonal variation in wind power but at a much lower level.

To determine the economic viability of wind power in food-processing applications, several assumptions first were made: mid- to late-1979 energy prices (averages for the nation); price escalation rates of: (a) 35 percent annually for 2 years and 8 percent annually for the duration of a 20-year SWECS lifetime for fossil fuels; and (b) 20 percent annually for 2 years and 4 percent annually thereafter for electricity. SWECS costs projected at the 10,000th unit; 9 and 10 percent interest rates; and 20 and 50 percent equity on 10-year loans. With the breakeven cost estimated, SWECS installation could be economically viable for some processing plants that operate year-round with winds averaging 200 W/m^2 or above. Seasonal plants operating for less than 6 months of the year, however, probably would not find wind systems viable in any wind regime. Payback periods are between 8 and 12 years, with little sensitivity to the changes in interest rate or percent equity.

Conventionally supplied electricity is the most likely energy source to be replaced by wind energy, since it is more expensive than fossil fuels on a heat-equivalent basis. Of the fossil fuels, fuel oil No. 2 is the most expensive and thus would be most economical to replace. Because of the intermittent nature of the wind and the expense of most types of energy storage, wind energy is most likely to be used as a supplemental power source. Further, it probably would not be economical to use wind energy alone in processes requiring very high temperatures; SWECS in these cases could be used for intermediate or pre-heating. SWECS economics in processing plants requiring both heating and cooling operations should be improved further by the use of heat pumps.

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APPENDIX A

SIZES AND TYPES OF FOOD-PROCESSING PLANTS

**Table A-1. SLAUGHTERING PLANTS BY SIZE
GROUPS AND TYPE ANIMAL^a**

Size Groups	Plants		Slaughterer	
	Number	%	000 Head	%
Cattle				
Under 1,000	779	50.9	315	0.8
1,000-9,999	376	24.5	1,262	3.4
10,000-49,999	185	12.1	4,603	12.5
50,000 and over	191	12.5	30,768	83.3
Total	1,531	100.0	36,948	100.0
Calves				
Under 500	679	79.5	31	0.9
500-4,999	90	10.5	167	4.6
5,000 and over	85	10.0	3,422	94.5
Total	854	100.0	3,620	100.0
Hogs				
Under 1,000	838	68.2	233	0.3
1,000-9,999	195	15.8	616	0.8
10,000-99,999	87	7.1	3,310	4.5
100,000 and over	109	8.9	69,980	94.4
Total	1,229	100.0	74,139	100.0
Sheep and Lambs				
Under 100	654	74.3	13	0.3
100-999	161	18.3	42	0.8
1,000 and over	65	7.4	5,114	98.9
Total	800	100.0	5,169	100.0

^aPlants may be included in more than one animal category.

Source: American Meat Institute, *Meatfacts* (Washington, D.C., 1979), p. 13.

Table A-2. AVERAGE DAIRY FARM SIZE, BY STATE

State	Cows/Farm	State	Cows/Farm
Alabama	92	Montana	36
Alaska	56	Nebraska	25
Arizona	402	Nevada	191
Arkansas	67	New Hampshire	45
California	263	New Jersey	58
Colorado	66	New Mexico	176
Connecticut	62	New York	52
Delaware	55	North Carolina	68
Florida	419	North Dakota	22
Georgia	123	Ohio	34
Hawaii	391	Oklahoma	63
Idaho	41	Oregon	63
Illinois	37	Pennsylvania	42
Indiana	32	Rhode Island	40
Iowa	27	South Carolina	115
Kansas	34	South Dakota	29
Kentucky	35	Tennessee	37
Louisiana	85	Texas	106
Maine	43	Utah	58
Maryland	60	Vermont	55
Massachusetts	51	Virginia	51
Michigan	42	Washington	88
Minnesota	29	West Virginia	40
Mississippi	69	Wisconsin	37
Missouri	38	Wyoming	32

**Table A-3. FRUIT AND VEGETABLE-PROCESSING PLANTS SPECIALIZING
IN INDIVIDUAL PRODUCTS BY STATE^a**

State	Product(s) ^b	Form	# Plants
Arizona	Peppers, olives, radishes	Canned, glass	1
	Chiles	Canned	1
	Grapefruit concentrate	Frozen	1
California	Pickles/olives/relishes	Canned, glass	15
	Tomatoes/tomato products	Canned	6
	Apples/apple products	Canned, glass	6
	Vinegar	Glass	4
	Onion/garlic	Dehydrated	3
	Cherries	Frozen, glass	2
	Raisins	Dried	1
	Date pulp and puree	Canned	1
	Strawberries	Frozen	1
	Figs and peaches	Canned	1
	Carrots	Frozen	1
	Artichokes & mushrooms	Frozen	1
	Potatoes	Frozen	1
	Peppers	Canned	1
	Onion rings	Frozen	1
Colorado	Tomato products	Canned	1
	Onions & strawberries	Frozen	1
	Beans, peas, & sauerkraut	Canned	1
	Potatoes	Dehydrated	1
	Apples & cherries	Frozen	1
	Vinegar	Glass	1
Delaware	Mushrooms	Canned	2
	Sauerkraut/pickles	Canned, glass	2
	Tomatoes	Canned	1
Florida	Grapefruit/orange juice	Frozen	6
	Orange juice	Concentrate	2
	Tomatoes/tomato products	Canned, frozen	3
	Peppers/celery	Canned	2
	Carrots	Frozen	1
Georgia	Dates/pimientos	Canned, glass	2
	Peas & squash	Canned	1
	Vinegar	Glass	1
Hawaii	Pineapple products	Canned, frozen	3
	Guava products	Glass, frozen	1
	Papaya	Frozen	1
Idaho	Potatoes	Dehydrated, canned, frozen	19
	Corn	Canned, frozen	1
	Corn & applesauce	Canned	1
	Pickles & relish	Glass	1
Illinois	Vinegar	Glass	2
	Potatoes	Frozen	1
	Potatoes & onions	Frozen	1
	Corn, peas	Canned	1

**Table A-3. FRUIT AND VEGETABLE-PROCESSING PLANTS SPECIALIZING
IN INDIVIDUAL PRODUCTS BY STATE^a(Cont'd)**

State	Product(s) ^b	Form	# Plants
Indiana	Tomatoes/tomato products	Canned	15
	Tomatoes & pumpkin	Canned	1
	Corn/pumpkin	Canned	2
	Pickles & relishes	Canned, glass	2
Iowa	Beans	Canned	1
	Mushrooms	Canned	1
	Corn	Canned	1
	Potato products	Frozen	1
Kansas	Beans	Canned	1
Kentucky	Cherries	Glass	1
Louisiana	Pickles, relish	Glass	2
	Yams	Canned	2
	Peppers	Canned, glass	1
Maine	Blueberries	Frozen, canned	6
	Potatoes	Frozen, dehydrated	5
Maryland	Tomatoes/tomato products	Canned	11
	Tomatoes & potatoes	Canned	1
	Corn/peas/beans	Canned	4
	Pickles/peppers	Canned, glass, brined	3
	Mushrooms	Canned	1
	Sweet potatoes	Canned	1
	Vinegar	Glass	1
Michigan	Pickles	Canned, glass	10
	Cherries	Brined, frozen	8
	Apple cider/juice/vinegar	Glass	6
	Apple & cherry products	Frozen	3
	Tomato products	Canned, glass	2
	Blueberries	Frozen	1
	Mushrooms	Canned	1
	Beans	Canned	1
Minnesota	Corn & peas	Canned	9
	Corn	Canned	2
	Potatoes	Frozen, dehydrated	3
	Pickles	Canned	1
	Vinegar	Glass	1
Mississippi	Pickles	Canned, glass	1
Missouri	Vinegar/cider	Glass	2
	Mushrooms/onions	Canned, frozen	2
	Pickles & relishes	Canned, glass	1
Montana	Cherries	Canned	1
Nebraska	Mushrooms/onions	Frozen	2
	Pickles, relishes, and vinegar	Glass	1
Nevada	Potatoes	Dehydrated	1
New Hampshire	Apple juice	Canned, glass	1

**Table A-3. FRUIT AND VEGETABLE-PROCESSING PLANTS SPECIALIZING
IN INDIVIDUAL PRODUCTS BY STATE^a(Cont'd)**

State	Product(s) ^b	Form	# Plants
New Jersey	Pickles	Canned, glass	3
	Cranberry products	Canned, glass	2
	Cranberry/apple/tomato products	Canned	2
	Beans	Canned	1
	Mushrooms & peppers	Canned	1
New York	Sauerkraut	Canned, glass	7
	Sauerkraut & pickles	Glass	1
	Pickles	Glass	3
	Apples/apple products	Frozen, canned, glass	7
	Apples & cherries	Frozen	4
	Cherries/cherry products	Frozen	4
	Beans	Dried, canned	4
	Potatoes & onions	Canned, glass	1
	Mushrooms	Canned	1
	Vinegar	Glass	1
North Carolina	Pickles	Canned, glass	1
	Sauerkraut	Canned	1
	Apple juice & cider	Glass	1
	Yams & beans	Canned	1
North Dakota	Potatoes	Dehydrated, frozen	2
Ohio	Tomatoes/tomato products	Canned	12
	Mushrooms	Canned, frozen	4
	Pickles	Glass	3
	Beans	Canned, glass	2
	Olives	Glass	1
Oregon	Berries	Frozen	6
	Cherries	Frozen, canned, glass	4
	Potatoes	Frozen	1
	Corn	Canned	1
	Peas	Canned	1
	Beans	Canned	1
Pennsylvania	Mushrooms	Canned, frozen, glass	13
	Tomato products	Canned	1
	Apple products	Canned, glass	1
	Pickles	Glass	1
Tennessee	Peppers & pimientos	Canned, glass	2
	Vinegar	Bulk	1
Texas	Pickles/relishes	Glass	2
	Vinegar	Glass	2
Utah	Cherries	Brined, frozen	2
Virginia	Apple products	Canned, glass	5
	Tomatoes	Canned	3
	Pickles	Glass	1
	Cherries	Canned, frozen, glass	1
	Mushrooms	Canned	1

**Table A-3. FRUIT AND VEGETABLE-PROCESSING PLANTS SPECIALIZING
IN INDIVIDUAL PRODUCTS BY STATE^a(Cont'd)**

State	Product(s)	Form	# Plants
Washington	Berries	Frozen	7
	Potatoes	Frozen, dehydrated	4
	Apple products	Canned, frozen	3
	Pickles & relishes	Glass	1
	Peas	Frozen	1
	Carrots & corn	Frozen	1
	Mushrooms	Canned	1
	Vinegar	Glass	1
	Rhubarb	Frozen	1
West Virginia	Tomatoes	Canned	1
	Apples & apple products	Canned	1
Wisconsin	Corn & peas	Canned	5
	Beans	Canned	4
	Peas & beans	Canned	2
	Peas & carrots	Canned	1
	Pickles/relishes/peppers	Canned, glass	3
	Sauerkraut/cauliflower	Frozen, canned, glass	2
	Potatoes	Canned, dehydrated	2
	Cranberries	Canned, glass, frozen	1
	Cherries	Canned	1
Wyoming	Potatoes	Canned, flaked	2

^aFrom data presented in *The Directory of the Canning, Freezing, Preserving Industries*, Westminster, MD (Edward E. Judge & Sons, Inc., 1978). Numbers are approximate.

^bProducts separated by slashes (/) indicate that plants listed produce one or more of these products.

**Table A-4. FRUIT AND VEGETABLE
PROCESSING PLANTS SPECIALIZING
IN INDIVIDUAL PRODUCTS,
BY PRODUCT**

Product	# Plants
Poppers, olives, relishes, pickles	62
Tomatoes, tomato products	60
Corn, peas, beans	51
Potatoes	47
Apples, apple products	40
Cherries, cherry products	32
Mushrooms	30
Other berries	26
Vinegar	23
Sauerkraut	14

APPENDIX B

SEASONALITY

Table B-1
OPENING AND CLOSING PROCESSING DATES FOR FRUITS

STATES	Apples	Apricots	BERRIES							Cherries	Figs
			Black	Blue	Cran	Goose	Logan	Rasp	Straw		
ARKANSAS	Aug. 15 Nov. 15		June 1 July 15						Apr. 1 Oct. 1		
CALIFORNIA		June 8 Aug. 15								May 10 July 10	Aug. 15 Oct. 31
COLORADO	Oct. 15 Dec. 15	July 10 Aug. 1								June 15 July 15	
DELAWARE	Oct. 1 Nov. 10										
KANSAS	Aug. 1 Nov. 1										
LOUISIANA			June 1 July 31								May 1 July 31
MAINE				Aug. 10 Sept. 15							
MARYLAND	Aug. 25 Dec. 1										
MASSACHUSETTS					Sept. 1 Dec. 31						
MICHIGAN	Aug. 1 Nov. 30		July 25 Aug. 10	July 25 Sept. 15		July 20 Aug. 20		July 5 July 20	June 10 July 10	July 1 Aug. 15	
MISSISSIPPI			June 1 July 31								May 1 July 31
MISSOURI	Aug. 15 Dec. 1		June 20 Aug. 1								
MONTANA										July 14 Aug. 15	
NEW JERSEY			June 10 July 10	June 20 Aug. 20	Sept. 1 Dec. 31			July 15 Aug. 15	June 10 July 10		
NEW YORK	Sept. 15 Dec. 31	Aug. 1 Aug. 15						July 10 Aug. 20	June 14 July 17	June 25 Aug. 15	
OHIO	Sept. 15 Dec. 31									July 5 Aug. 15	
OKLAHOMA	Aug. 15 Oct. 15		June 1 July 1								
OREGON	Sept. 15 Dec. 31	Aug. 15 Sept. 15	Aug. 1 Oct. 10			May 15 June 15	June 20 Aug. 1	June 25 Aug. 1	May 20 June 25	June 20 July 31	
PENNSYLVANIA	Aug. 15 Dec. 31									June 30 July 31	
TEXAS			June 10 July 31								May 1 July 1
UTAH	Oct. 15 Dec. 15	July 10 Aug. 1						July 1 July 20	June 15 July 15	June 15 July 15	
VIRGINIA	Aug. 15 Dec. 31										
WASHINGTON	Sept. 15 Dec. 31	Aug. 25 Sept. 20	Aug. 15 Oct. 15	Oct. 1 Oct. 30		May 15 June 15	June 25 Aug. 1	July 1 Aug. 1	June 1 July 1	June 25 July 31	
WEST VIRGINIA	Aug. 15 Nov. 30										

Table B-1
OPENING AND CLOSING PROCESSING DATES FOR FRUITS
(Cont'd)

STATES	Grapes	Grape Fruit	Lemons	Olives	Oranges	Peaches	Pears	Pineapple	Plums	Prunes
ALABAMA						June 10 Aug. 1				
ARIZONA		Nov. 1 May 1								
ARKANSAS	Aug. 15 Oct. 1					July 10 Sept. 1				
CALIFORNIA	Aug. 1 Sept. 25		All Year	Oct. 15 Feb. 15	July 1 Nov. 15	July 10 Sept. 20	July 18 Sept. 15		July 15 Sept. 30	All Year
COLORADO						Aug. 25 Sept. 25	Sept. 15 Oct. 20			
DELAWARE						Aug. 1 Sept. 1	Oct. 1 Nov. 1			
FLORIDA		Oct. 15 June 15			Dec. 1 June 1					
GEORGIA						June 10 Aug. 1				
HAWAII								Jan. 1-Mar. 15 June 15-Sept. 30		
IDAHO										Sept. 15 Oct. 15
MARYLAND						Aug. 1 Sept. 15	Oct. 1 Nov. 15			
MICHIGAN	Sept. 1 Oct. 30					Sept. 1 Oct. 15	Sept. 1 Dec. 30		Aug. 1 Aug. 30	
MISSOURI	Aug. 25 Oct. 15					July 25 Sept. 1				
NEW JERSEY						Aug. 1 Sept. 15	Sept. 20 Nov. 15			
NEW YORK	Oct. 1 Nov. 1					Sept. 1 Oct. 5	Sept. 15 Nov. 10		Aug. 10 Oct. 7	Sept. 10 Oct. 5
NORTH CAROLINA						July 15 Aug. 15				
OREGON						Aug. 15 Oct. 1	Aug. 10 Nov. 1		Aug. 15 Sept. 30	Sept. 1 Sept. 30
PENNSYLVANIA	Sept. 20 Nov. 1					Aug. 15 Sept. 15				
PUERTO RICO		Nov. 15 Apr. 30						May 1 June 30		
SOUTH CAROLINA						July 15 Aug. 15				
TEXAS		Dec. 1 May 1				June 10 Aug. 1				
UTAH						Aug. 25 Sept. 25	Sept. 15 Oct. 20			Sept. 15 Oct. 15
WASHINGTON						Aug. 15 Sept. 20	Aug. 10 Nov. 1		Aug. 15 Sept. 30	Sept. 1 Sept. 30

Source: The Almanac of the Canning, Freezing, Preserving Industries (Westminster, Md.: Edward E. Judge & Sons, Inc., 1979), pp. 611-12.

Table B-2
OPENING AND CLOSING PROCESSING DATES FOR VEGETABLES

STATES	Arti- clokes	Aspara- gus	BEANS		Beets	Corn	Carrots	Kraut	Okra	Peas
			Lima	Snap						
ALABAMA				May 1-July 10 Oct. 1-Oct. 30					May 1 Sept. 1	
ARKANSAS			July 1 Nov. 15	May 5-July 5 Oct. 1-Nov. 15		July 1 July 31			June 1 Sept. 1	
CALIFORNIA	Feb. 1 Apr. 30	Apr. 1 June 30	Sept. 1 Oct. 31	Aug. 1 Oct. 15	May 5 Dec. 20					Apr. 10 June 30
COLORADO				July 15 Oct. 1	Aug. 1 Oct. 15			All Year		June 15 Aug. 1
DELAWARE		Apr. 25 June 30	Aug. 5 Sept. 30	June 20-July 20 Sept. 5-Sept. 30		July 25 Sept. 15				May 25 June 20
FLORIDA				Jan. 1-May 15 Nov. 1-Dec. 15						
GEORGIA				May 1-June 15 Aug. 29-Sept. 15					May 15 Sept. 1	
IDAH0						Aug. 1 Sept. 15				June 1 July 20
ILLINOIS		Apr. 20 June 25	Aug. 15 Sept. 30	July 5 Sept. 30		Aug. 1 Sept. 25				June 3 July 30
INDIANA				July 1 Oct. 15		Aug. 1 Sept. 30		All Year		June 1 July 30
IOWA		Apr. 25 June 25				Aug. 1 Oct. 1				June 10 July 15
KENTUCKY				June 1-July 15 Sept. 15-Oct. 15				All Year		
LOUISIANA						June 1 July 15			May 1 Sept. 1	
MAINE				Aug. 1-Sept. 15		Aug. 20 Oct. 15				July 1 Aug. 30
MARYLAND		Apr. 20 June 30	Aug. 5 Oct. 10	June 15 July 31	June 1 July 15	July 20 Sept. 15		All Year		May 20 July 15
MICHIGAN		May 10 July 1	Sept. 1 Sept. 30	July 10 Sept. 15	Aug. 1 Nov. 20	Aug. 10 Sept. 20	Oct. 1 Nov. 25	All Year		June 15 Aug. 15
MINNESOTA		May 1 July 1	Aug. 15 Sept. 30	July 20 Sept. 20	July 20 Nov. 30	Aug. 5 Sept. 1				June 15 Aug. 1
MISSISSIPPI				May 1-July 31 Oct. 1-Nov. 1					May 1 Sept. 1	
MISSOURI				June 15 Oct. 15						
NEBRASKA				July 10-Oct. 1		Aug. 10 Oct. 1				
NEW JERSEY		Apr. 20 July 1	Aug. 1 Oct. 1	July 1 Oct. 1					Aug. 20 Oct. 1	May 20 July 10
NEW YORK		May 10 July 15		July 5 Sept. 25	Aug. 1 Dec. 31	Aug. 10 Sept. 20	Sept. 15 Dec. 31	All Year		June 20 Aug. 1
NORTH CAROLINA				June 1-July 10					June 1 Sept. 15	
OHIO		May 5 July 25		July 25 Sept. 5	July 20 Nov. 30	Aug. 1 Sept. 25		Year	All	May 28 Aug. 1
OKLAHOMA				May 15-July 10 Oct. 1-Nov. 15						
OREGON		Apr. 15 July 1		Aug. 1 Sept. 5	July 1 Oct. 15	Aug. 15 Sept. 30	Aug. 20 Oct. 15	All Year		June 10 Aug. 20
PENNSYLVANIA			July 1 Oct. 1	July 15 Sept. 20	July 25 Oct. 1	Aug. 5 Sept. 20		All Year		June 1 July 25
SOUTH CAROLINA				May 20-Aug. 10 Sept. 15-Oct. 30					June 1 Sept. 15	Aug. 5 Sept. 30
TENNESSEE			Aug. 1 Sept. 20	July 15 Sept. 20	July 10 Aug. 15	July 25 Aug. 30		All Year		May 15 June 15
TEXAS				Apr. 1-June 20 Nov. 1-Dec. 15	Nov. 15 May 15		Nov. 15 May 15			
UTAH			Aug. 5 Oct. 1	July 10 Oct. 15	June 1 Oct. 15	Aug. 15 Sept. 25	Aug. 15 Oct. 15	All Year		June 10 Aug. 10
VIRGINIA			Aug. 1 Oct. 10	June 10-July 15						May 15 June 5
WASHINGTON		May 1 July 1		Aug. 1 Sept. 5	July 1 Oct. 15	Aug. 15 Sept. 30	Aug. 20 Oct. 15	All Year		June 10 Aug. 20
WISCONSIN			Aug. 20 Sept. 29	July 10 Oct. 1	July 20 Nov. 30	Aug. 1 Oct. 1	July 25 Nov. 30	All Year		June 10 Aug. 20

Table B-2
OPENING AND CLOSING PROCESSING DATES FOR VEGETABLES
(Cont'd)

STATES	Pickles	Pimientos	Pumpkin	Rhubarb	Spinach	Sprouts	Squash	Succotash	Sweet Potato	Tomatoes
ALABAMA		Aug. 1 Nov. 15			Feb. 20-May 30 Oct. 15-Dec. 31				Aug. 1 Feb. 1	Aug. 1-Sept. 15
ARKANSAS					Feb. 20-May 30 Oct. 15-Dec. 31					Aug. 1-Oct. 20
CALIF.	All Year	Sept. 15 Dec. 15	Oct. 1 Nov. 15		Feb. 20-Apr. 20 Oct. 1-Dec. 15				Sept. 1 Dec. 31	July 10 Nov. 10
COLO.			Oct. 1 Nov. 15				Oct. 5 Nov. 15			Aug. 15 Oct. 15
DEL.					Nov. 10 Mar. 1		Oct. 1 Nov. 5		Sept. 15 Dec. 1	July 15 Oct. 1
FLORIDA									Aug. 1 Feb. 1	Mar. 1 May 15
GEORGIA		Aug. 1 Nov. 15								Aug. 1-Feb. 1
IDAHO										
ILLINOIS			Sept. 10 Oct. 30							Aug. 1 Oct. 1
INDIANA			Sept. 15 Nov. 15					Aug. 20 Sept. 15		Aug. 1 Oct. 15
IOWA										Aug. 10 Oct. 15
KY.								Aug. 10 Aug. 30		Aug. 1 Oct. 15
LOUISIANA		Oct. 1 Dec. 1							July 20 Mar. 1	
MD.			Oct. 1 Nov. 10		Apr. 1-May 15 Nov. 1-Nov. 30		Oct. 1 Nov. 10	Aug. 13 Oct. 1	Sept. 15 Dec. 1	July 15 Oct. 15
MICHIGAN	All Year		Sept. 10 Oct. 30	May 20 June 30	June 10-July 1 Sept. 20-Oct. 20		Sept. 5 Sept. 30			Aug. 1 Sept. 30
MINN.	All Year		Sept. 10 Oct. 30							
MISSOURI					May 1 June 15				Aug. 15 Feb. 1	Aug. 10 Oct. 20
NEBR.			Oct. 1 Dec. 1							Aug. 10 Oct. 1
N. J.			Oct. 1 Nov. 1		Apr. 1-May 31 Oct. 20-Nov. 30		Oct. 1 Nov. 15		Sept. 15 Nov. 15	July 15 Oct. 15
NEW YORK			Sept. 20 Nov. 15	May 20 June 30	June 5-June 20 Sept. 23-Oct. 10		Sept. 15 Nov. 1	Sept. 1 Oct. 1		Aug. 5 Oct. 5
NORTH CAROLINA	All Year	Aug. 10 Sept. 30							Sept. 1 Dec. 31	July 10 Sept. 1
OHIO			Sept. 10 Nov. 20							Aug. 1 Oct. 1
OKLA.					Feb. 20-May 30 Oct. 15-Dec. 31					Aug. 1-Oct. 20
OREGON	All Year		Oct. 1 Nov. 30	May 1 June 10			Oct. 10 Nov. 10			Aug. 15 Oct. 1
PA.								Aug. 20 Sept. 15		Aug. 5 Oct. 5
SOUTH CAROLINA										June 30 Aug. 15
TENN.		Aug. 15 Nov. 15	Sept. 15 Nov. 15		Mar. 1-June 1 Sept. 15-Oct. 10			Aug. 10 Sept. 10	Sept. 1 Dec. 1	Apr. 25-June 1 Sept. 15-Oct. 10
TEXAS					Nov. 10 Mar. 20				Oct. 1 Feb. 1	May 15-June 20 Dec. 1-Jan. 15
UTAH			Oct. 1 Nov. 15				Oct. 1 Nov. 15			Aug. 15 Oct. 15
VIRGINIA					Apr. 1-May 25 Oct. 25-Nov. 30				Sept. 1 Dec. 15	July 15 Sept. 15
WASH.	All Year		Oct. 1 Nov. 30	May 1 June 10	Sept. 1 Oct. 15		Oct. 10 Nov. 10			Aug. 15 Oct. 1
WEST VIRGINIA										Aug. 1 Sept. 30
WISC.	All Year		Sept. 10 Nov. 20	May 10 May 30	June 1-June 20		Sept. 10 Nov. 20			Aug. 10 Oct. 10

Source: The Almanac of the Canning, Freezing, Preserving Industries (Westminster, Md.: Edward E. Judge & Sons, Inc., 1979), pp. 613-14.

APPENDIX C

ENERGY CONSUMPTION IN FOOD PROCESSING

**Table C-1. TOTAL QUANTITY OF PURCHASED FUELS AND
ELECTRIC ENERGY USED FOR HEAT AND POWER IN
FOOD PROCESSING, BY STATE (1976)**

State	Purchased Fuels and Electric Energy ^a (TJ)			
	Total Food	Meat	Dairy	Fruit/Vegetable
California	103,920	6,540	6,010	31,760
Illinois	91,150	5,910	4,540	4,850
Iowa	64,140	12,770	3,380	—
Texas	45,260	6,750	2,430	4,010
Minnesota	44,520	6,440	10,760	2,530
Wisconsin	42,520	4,640	15,930	4,540
Pennsylvania	40,410	3,690	4,960	5,280
New York	40,300	2,220	8,860	5,490
Ohio	36,930	3,800	5,170	5,380
Indiana	31,860	2,640	2,110	3,060
Florida	28,170	1,480	840	14,240
Michigan	27,010	3,480	3,380	3,800
Louisiana	26,060	630	840	530
New Jersey	25,850	1,580	950	4,110
Missouri	25,000	—	3,480	—
Nebraska	24,370	5,700	1,270	—
Idaho	24,160	630	740	11,710
Washington	23,000	—	1,270	7,490
Colorado	22,580	2,950	420	—
Tennessee	20,680	2,320	1,580	1,900
Georgia	18,150	3,690	740	950
Kentucky	15,090	1,160	1,370	—
Maryland	14,240	1,580	1,370	1,370
Kansas	13,400	2,950	1,060	—
Virginia	13,400	3,170	1,060	1,160
North Carolina	12,870	2,110	950	—
Arkansas	12,030	2,220	630	2,430
Oregon	10,340	840	1,060	3,800
Massachusetts	9,600	950	1,790	320
Alabama	8,550	2,220	840	320
Mississippi	8,440	2,430	420	—
North Dakota	7,700	—	630	530
Hawaii	6,440	110	—	1,060
Maine	5,280	530	210	2,320
Oklahoma	5,280	1,270	630	530
Arizona	4,960	420	210	210
Montana	4,850	420	110	—
Utah	4,220	530	1,270	—
Wyoming	3,900	—	—	—
South Carolina	3,800	530	420	—
South Dakota	3,800	1,690	1,370	—
Connecticut	3,060	—	740	—
Delaware	2,640	530	—	530
Rhode Island	1,790	—	—	—
New Hampshire	1,480	—	—	—
Vermont	1,480	—	950	—
Alaska	1,370	—	—	—
New Mexico	1,270	420	—	—
West Virginia	840	110	—	—
Nevada	740	—	—	—

^aNo purchased fuel or electric energy shown indicates less than 0.05 unit purchased or amount not shown to avoid disclosure of individual operations.

Source: U.S. Department of Commerce, Bureau of the Census *Annual Survey of Manufactures 1976: Fuels and Electric Energy Consumed*, May 1978.

**Table C-2. FUEL AND ELECTRIC ENERGY USE IN
FOOD PROCESSING, BY STATE AND FUEL (1976)^a**

State	Total Food	Meat	Dairy	Fruit/Vegetable
Fuel Oil (000 bbls)				
Pennsylvania	2,923.2	203.0	270.3	321.4
New York	2,466.9	58.8	522.1	380.1
New Jersey	2,165.7	97.9	52.5	524.8
Illinois	1,956.0	148.4	30.3	—
Florida	1,901.3	—	—	994.6
Ohio	1,874.8	—	135.7	53.8
Minnesota	984.9	—	315.8	4.7
Iowa	979.9	145.7	—	—
Maryland	942.5	—	52.2	108.1
Indiana	924.7	—	—	155.9
North Carolina	883.5	—	—	—
Tennessee	848.5	—	—	—
Virginia	777.5	—	39.8	92.1
Hawaii	745.3	—	—	—
California	744.9	—	—	73.7
Michigan	707.9	14.0	71.2	36.2
Missouri	628.9	—	103.1	—
Wisconsin	622.8	26.5	316.4	86.3
Massachusetts	599.6	28.5	88.7	29.8
Maine	550.6	54.5	—	—
Georgia	529.1	50.1	—	6.4
Nebraska	424.9	213.4	—	—
Kentucky	391.8	—	—	—
Colorado	285.1	—	—	—
Delaware	251.6	—	—	—
Texas	244.1	2.2	—	—
Washington	201.6	—	8.8	115.8
Kansas	200.7	—	—	—
South Carolina	197.9	—	—	—
South Dakota	166.8	—	—	—
Oregon	158.5	—	—	—
Connecticut	147.7	—	24.8	—
Arkansas	110.9	—	—	—
Montana	94.0	—	—	—
Vermont	77.5	—	—	—
Mississippi	57.2	—	—	—
Wyoming	41.8	—	—	—
North Dakota	34.6	—	—	—
Utah	6.1	—	—	—
Natural Gas (bcf)				
California	68.8	2.3	3.8	22.3
Illinois	45.2	2.8	2.5	2.3
Iowa	32.8	6.8	1.8	—
Texas	29.3	3.8	1.0	3.1
Wisconsin	25.6	2.6	8.6	3.0
Louisiana	18.5	—	—	0.2
Wyoming	14.6	—	—	—

**Table C-2. FUEL AND ELECTRIC ENERGY USE IN
FOOD PROCESSING, BY STATE AND FUEL (1976)^a (Cont'd)**

State	Total Food	Meat	Dairy	Fruit/Vegetable
Natural Gas (bcf) (Cont'd)				
Minnesota	14.5	2.7	3.9	1.3
Ohio	13.5	1.5	2.3	2.2
Indiana	12.4	1.2	0.9	0.5
Missouri	12.4	—	1.7	—
Colorado	12.3	2.1	—	—
Washington	11.1	0.6	0.7	4.3
Michigan	10.7	1.4	1.8	2.6
Idaho	10.1	—	0.3	8.3
Nebraska	9.9	2.5	0.3	—
Tennessee	9.0	0.9	0.5	0.3
Pennsylvania	8.4	0.4	1.0	1.4
Florida	8.0	—	—	4.6
Georgia	8.0	1.1	0.3	0.5
Kansas	8.0	1.8	0.4	—
New York	7.7	0.3	1.6	0.9
Arkansas	7.1	1.3	0.3	—
Kentucky	6.4	0.3	—	—
Mississippi	5.0	1.2	0.2	—
Alabama	4.3	1.1	0.2	—
Oregon	3.8	0.3	0.3	1.9
Maryland	3.5	0.1	0.3	0.1
New Jersey	3.4	0.2	—	0.1
Virginia	3.2	0.8	0.3	—
Oklahoma	3.1	—	0.3	0.3
Montana	2.9	—	—	—
Alaska	2.3	—	—	—
Utah	2.3	0.2	0.9	—
Arizona	2.1	0.2	0.1	—
North Carolina	2.1	—	0.2	—
Massachusetts	2.0	0.3	—	—
South Dakota	1.3	0.8	0.3	—
South Carolina	1.1	0.1	0.2	—
Connecticut	0.8	—	0.1	—
North Dakota	0.8	—	0.2	0.3
Rhode Island	0.8	—	—	—
New Mexico	0.7	0.3	—	—
Hawaii	0.5	—	—	—
Nevada	0.5	—	—	—
West Virginia	0.3	—	—	—
Delaware	0.1	—	—	—
Coal (000 tons)				
Illinois	513.4	—	—	—
Iowa	479.9	—	—	—
Minnesota	453.2	—	—	—
Indiana	247.6	—	—	39.6
Ohio	241.9	3.9	12.8	—
Michigan	109.0	—	—	—
Pennsylvania	34.9	—	—	—
Wisconsin	29.1	—	—	—

**Table C-2. FUEL AND ELECTRIC ENERGY USE IN
FOOD PROCESSING, BY STATE AND FUEL (1976)^a (Cont'd)**

State	Total Food	Meat	Dairy	Fruit/Vegetable
Electric Energy (millions kWh)				
California	3,261.0	474.3	402.9	979.1
Illinois	3,000.2	341.1	265.5	227.8
New York	2,467.8	237.3	600.2	246.2
Texas	2,445.0	558.2	224.3	151.7
Pennsylvania	1,858.0	264.0	281.2	195.2
Iowa	1,734.4	499.1	116.6	—
Ohio	1,643.3	223.5	320.8	188.3
Wisconsin	1,502.7	211.4	458.4	145.9
Florida	1,356.9	113.0	124.7	599.4
New Jersey	1,179.7	112.5	79.6	153.5
Minnesota	1,138.9	220.9	291.2	96.8
Michigan	1,104.9	263.2	172.9	161.0
Indiana	1,088.0	164.6	144.1	73.1
Georgia	1,066.7	300.7	73.2	75.1
Tennessee	997.3	163.0	96.8	65.2
Washington	945.9	35.6	70.6	422.3
Missouri	933.2	—	172.0	—
Virginia	785.1	244.0	71.8	65.2
North Carolina	767.8	209.7	105.7	—
Nebraska	767.3	306.3	53.7	—
Louisiana	711.1	66.3	73.0	23.4
Kansas	686.2	177.3	75.4	—
Arkansas	679.6	201.5	32.9	101.2
Oregon	590.7	75.4	79.6	257.0
Alabama	560.9	174.7	64.3	25.5
Maryland	554.3	99.7	107.2	48.7
Colorado	549.0	193.9	42.6	—
Idaho	531.6	42.0	37.2	397.0
Massachusetts	464.5	62.5	151.0	10.1
Mississippi	454.7	183.0	23.7	51.8
Kentucky	453.0	83.8	66.4	—
Oklahoma	328.7	64.9	37.1	44.0
Wyoming	284.5	—	—	—
Maine	219.5	24.1	25.2	107.8
Utah	201.7	51.7	60.3	—
Arizona	193.0	28.7	30.1	—
Hawaii	186.5	—	—	38.0
South Carolina	176.7	39.9	30.4	—
South Dakota	169.3	86.5	43.0	—
Delaware	161.3	37.6	—	17.5
Connecticut	156.3	—	64.9	—
Alaska	129.0	—	—	—
Montana	92.8	42.6	—	—
New Hampshire	87.9	—	—	—
North Dakota	87.1	—	22.8	7.7
New Mexico	78.9	24.3	—	—
West Virginia	64.3	—	—	—

**Table C-2. FUEL AND ELECTRIC ENERGY USE IN
FOOD PROCESSING, BY STATE AND FUEL (1976)^a (Cont'd)**

State	Total Food	Meat	Dairy	Fruit/Vegetable
Electric Energy (millions kWh) (Cont'd)				
Nevada	45.9	—	—	—
Rhode Island	41.6	—	—	—
Vermont	37.4	—	22.8	—

^aNo purchased fuel or electric energy shown indicates less than 0.05 unit purchased or amount not shown to avoid disclosure of individual operations.

^bStates with no purchases of a given fuel in the "food and kindred products" category excluded.

Source: Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures 1976: Fuels and Electric Energy Consumed*, May 1978.

Table C-3. FUEL AND ELECTRIC ENERGY USE IN MEAT PROCESSING, BY STATE (1976)^a

State	TJ Consumed			State	TJ Consumed		
	Electric	Fuel Oil	Natural Gas		Electric	Fuel Oil	Natural Gas
Alabama	629	—	1,196	Montana	153	—	—
Alaska	—	—	—	Nebraska	1,102	1,368	2,719
Arizona	103	—	217	Nevada	—	—	—
Arkansas	726	—	1,414	New Hampshire	—	—	—
California	1,707	—	2,501	New Jersey	405	645	217
Colorado	698	—	2,284	New Mexico	88	—	322
Connecticut	—	—	—	New York	855	269	326
Delaware	135	—	—	North Carolina	755	—	—
Florida	407	—	—	North Dakota	—	—	—
Georgia	1,082	411	1,196	Ohio	805	—	1,632
Hawaii	—	—	—	Oklahoma	233	—	—
Idaho	151	—	—	Oregon	271	—	326
Illinois	1,228	960	3,045	Pennsylvania	951	896	435
Indiana	593	—	1,305	Rhode Island	—	—	—
Iowa	1,797	922	7,397	South Carolina	143	—	109
Kansas	638	—	1,958	South Dakota	311	—	870
Kentucky	302	—	326	Tennessee	587	—	979
Louisiana	238	—	—	Texas	2,010	15	4,133
Maine	87	362	—	Utah	186	—	217
Maryland	359	—	109	Vermont	—	—	—
Massachusetts	225	190	326	Virginia	879	—	870
Michigan	947	92	1,522	Washington	128	—	653
Minnesota	795	—	2,937	West Virginia	—	—	—
Mississippi	658	—	1,305	Wisconsin	761	172	2,828
Missouri	—	—	—	Wyoming	—	—	—

^aData from U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufacturers 1976: Fuels and Electric Energy Consumed*, May 1978. Converted to Btus using 3412 Btus/kWh, 1031 Btus/cf natural gas, 6.0 million Btus/bbl distillate fuel oil, and 6.3 million Btus/bbl residual fuel oil.

Table C-4. FUEL AND ELECTRIC ENERGY USE IN DAIRY PROCESSING, BY STATE (1976)^a

State	TJ Consumed			State	TJ Consumed		
	Electric	Fuel Oil	Natural Gas		Electric	Fuel Oil	Natural Gas
Alabama	231	—	217	Montana	—	—	—
Alaska	—	—	—	Nebraska	193	—	326
Arizona	109	—	109	Nevada	—	—	—
Arkansas	118	—	326	New Hampshire	—	—	—
California	1,451	—	4,133	New Jersey	287	343	—
Colorado	153	—	—	New Mexico	—	—	—
Connecticut	233	157	109	New York	2,161	3,429	1,741
Delaware	—	—	—	North Carolina	381	—	217
Florida	448	—	—	North Dakota	82	—	217
Georgia	264	—	326	Ohio	1,155	864	2,501
Hawaii	—	—	—	Oklahoma	134	—	326
Idaho	134	—	326	Oregon	287	—	326
Illinois	956	199	2,720	Pennsylvania	1,012	1,780	1,088
Indiana	519	—	979	Rhode Island	—	—	—
Iowa	420	—	1,961	South Carolina	110	—	217
Kansas	271	—	435	South Dakota	155	239	326
Kentucky	239	—	—	Tennessee	348	—	544
Louisiana	263	—	—	Texas	807	—	1,088
Maine	91	—	—	Utah	217	—	—
Maryland	386	330	326	Vermont	82	—	—
Massachusetts	543	279	—	Virginia	258	315	326
Michigan	622	468	1,958	Washington	254	56	762
Minnesota	1,049	1,562	4,242	West Virginia	—	—	—
Mississippi	85	—	217	Wisconsin	1,650	2,047	9,144
Missouri	619	683	1,849	Wyoming	—	—	—

^aData from U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufacturers 1976: Fuels and Electric Energy Consumed*, May 1978. Converted to Btus using 3412 Btus/kWh, 1031 Btus/cf natural gas, 6.0 million Btus/bbl distillate fuel oil, and 6.3 million Btus/bbl residual fuel oil.

**Table C-5. FUEL AND ELECTRIC ENERGY USE IN FRUIT AND VEGETABLE PROCESSING,
BY STATE (1976)^a**

State	TJ Consumed			State	TJ Consumed		
	Electric	Fuel Oil	Natural Gas		Electric	Fuel Oil	Natural Gas
Alabama	92	—	—	Montana	—	—	—
Alaska	—	—	—	Nebraska	—	—	—
Arizona	—	—	—	Nevada	—	—	—
Arkansas	364	—	—	New Hampshire	—	—	—
California	3,525	474	24,256	New Jersey	553	3,438	109
Colorado	—	—	—	New Mexico	—	—	—
Connecticut	—	—	—	New York	886	2,478	979
Delaware	63	—	—	North Carolina	—	—	—
Florida	2,157	6,515	5,004	North Dakota	27	—	326
Georgia	270	40	544	Ohio	377	341	2,393
Hawaii	137	—	—	Oklahoma	158	—	326
Idaho	1,430	—	9,029	Oregon	925	—	2,067
Illinois	820	—	2,501	Pennsylvania	703	2,075	1,522
Indiana	263	986	544	Rhode Island	—	—	—
Iowa	—	—	—	South Carolina	—	—	—
Kansas	—	—	—	South Dakota	—	—	—
Kentucky	—	—	—	Tennessee	234	—	326
Louisiana	84	—	217	Texas	546	—	3,372
Maine	388	—	—	Utah	—	—	—
Maryland	175	685	109	Vermont	—	—	—
Massachusetts	36	189	—	Virginia	234	606	—
Michigan	579	241	2,828	Washington	1,520	749	4,677
Minnesota	348	352	1,414	West Virginia	—	—	—
Mississippi	188	—	—	Wisconsin	525	555	3,263
Missouri	—	—	—	Wyoming	—	—	—

^aData from U.S. Department of Commerce, Bureau of the Census *Annual Survey of Manufacturers 1976: Fuels and Electric Energy Consumed*, May 1978. Converted to Btus using 3412 Btus/kWh, 1031 Btus/cf natural gas, 6.0 million Btus/bbl distillate fuel oil, and 6.3 million Btus/bbl residual fuel oil.

APPENDIX D
WIND DATA

**Table D-1. NUMBER OF STATIONS WITH SUITABLE
WIND DATA, BY STATE**

State	Stations	State	Stations
Alabama	10	Montana	14
Arizona	14	Nebraska	13
Arkansas	7	Nevada	16
California	65	New Hampshire	3
Colorado	11	New Jersey	7
Connecticut	3	New Mexico	18
Delaware	3	New York	26
Washington, D.C.	4	North Carolina	15
Florida	27	North Dakota	7
Georgia	15	Ohio	12
Hawaii	9	Oklahoma	11
Idaho	8	Oregon	21
Illinois	13	Pennsylvania	19
Indiana	12	Rhode Island	2
Iowa	9	South Carolina	10
Kansas	13	South Dakota	8
Kentucky	8	Tennessee	9
Louisiana	9	Texas	49
Maine	5	Utah	11
Maryland	5	Vermont	2
Massachusetts	9	Virginia	9
Michigan	22	Washington	20
Minnesota	9	West Virginia	3
Mississippi	5	Wisconsin	8
Missouri	14	Wyoming	8
Total			630

**Table D-2. RANGES OF AVERAGE ANNUAL WIND SPEEDS
AND PEAK AVERAGE WIND SPEEDS, BY STATE**

State	Wind Speeds (Meters per second) ^a			
	Average Annual ^b		Average Annual ^c	
	Low	High	Low	High
Alabama	2.4	3.7	3.2	4.8
Arizona	2.1	4.6	2.7	5.5
Arkansas	3.0	4.0	3.9	4.7
California	1.5	6.7	1.7	9.3
Colorado	2.1	6.0	3.1	6.9
Connecticut	4.0	5.4	4.7	6.8
Delaware	4.0	6.5	5.1	7.6
Florida	2.7	4.9	3.3	5.3
Georgia	1.9	4.4	2.3	5.3
Hawaii	2.9	6.3	4.0	7.5
Idaho	3.8	5.0	4.5	5.9
Illinois	3.7	5.5	4.9	6.5
Indiana	3.6	5.5	4.6	6.3
Iowa	4.4	5.8	5.3	7.3
Kansas	3.2	6.7	4.1	7.8
Kentucky	2.3	4.6	3.3	5.4
Louisiana	2.3	4.3	3.2	5.0
Maine	3.5	4.4	4.1	5.1
Maryland	2.3	4.9	3.1	5.0
Massachusetts	2.8	8.8	3.6	10.4
Michigan	3.0	5.6	3.9	7.0
Minnesota	3.4	5.5	4.0	6.3
Mississippi	1.8	3.5	2.7	4.2
Missouri	3.1	5.4	4.0	6.4
Montana	2.5	6.9	3.2	9.3
Nebraska	3.9	6.2	5.0	7.0
Nevada	2.4	4.5	3.1	5.5
New Hampshire	2.5	3.4	3.1	4.3
New Jersey	3.1	4.7	3.9	5.6
New Mexico	2.9	6.7	3.6	7.5
New York	2.9	6.4	3.7	7.6
North Carolina	2.2	5.4	5.4	6.1
North Dakota	4.2	6.7	4.9	7.4
Ohio	3.2	5.5	4.1	6.5
Oklahoma	4.1	6.4	5.1	7.4
Oregon	1.3	6.8	2.0	7.9
Pennsylvania	2.8	6.9	3.7	8.1
Rhode Island	4.3	4.9	4.9	5.5
South Carolina	2.5	4.2	3.3	5.0
South Dakota	4.2	5.8	5.5	7.0
Tennessee	2.7	4.1	3.6	5.1
Texas	3.0	8.1	4.2	9.1
Utah	2.0	5.2	2.8	5.8
Vermont	3.7	4.0	4.4	4.5
Virginia	1.9	4.5	2.7	5.2
Washington	2.0	6.7	2.4	8.6
West Virginia	2.9	3.0	3.6	4.0
Wisconsin	2.9	4.5	3.3	6.0
Wyoming	3.8	7.2	3.4	8.9

^aHeight at which wind speeds were measured varies, but is below 20 meters.

^bReading at station with the lowest average annual wind speed, and at station with highest average annual wind speed.

^cAverage reading during peak month, for station with lowest and station with highest reading.

Source: J. W. Reed, *Wind Power Climatology of the United States: Supplement* (Albuquerque, N.M.: Sandia Laboratories, 1979).

**Table D-3. PERCENT OF TOTAL AREA THAT WILL
SUPPORT WIND TURBINES AT 10, 20, AND 50
METERS, BY STATE***

State	Percent of Area			
	10m	20m	50m	None
Alabama	5	10	40	45
Arizona	25	35	35	5
Arkansas	2	42	56	—
California	25	30	25	20
Colorado	55	15	20	10
Connecticut	35	50	15	—
Delaware	60	40	—	—
Florida	7	48	30	15
Georgia	—	10	45	45
Hawaii	12	38	50	—
Idaho	50	35	14	1
Illinois	85	10	5	—
Indiana	60	20	15	5
Iowa	100	—	—	—
Kansas	93	5	2	—
Kentucky	—	50	25	25
Louisiana	20	10	25	45
Maine	10	90	—	—
Maryland	30	45	20	5
Massachusetts	60	20	15	5
Michigan	80	15	5	—
Minnesota	80	14	6	1
Mississippi	—	1	74	25
Missouri	70	20	10	—
Montana	70	20	10	—
Nebraska	100	—	—	—
Nevada	35	35	20	10
New Hampshire	—	70	20	10
New Jersey	40	53	5	2
New Mexico	70	20	10	—
New York	30	60	5	5
North Carolina	5	15	65	15
North Dakota	85	15	—	—
Ohio	40	35	15	2
Oklahoma	90	10	—	—
Oregon	15	30	20	35
Pennsylvania	30	40	20	10
Rhode Island	90	10	—	—
South Carolina	—	25	60	15
South Dakota	100	—	—	—
Tennessee	—	10	70	20
Texas	65	30	5	—
Utah	15	35	35	15
Vermont	—	55	30	15
Virginia	5	35	20	40
Washington	15	30	35	20
West Virginia	—	15	55	30
Wisconsin	60	40	—	—
Wyoming	65	20	15	—

*Percent of total area that will support turbines at a height of 10 meters also will support them at 20 and 50 meters; the area that will support turbines at 20 meters also will support them at 50 meters. For example, in Alabama 55 percent of the state has winds sufficient at 50 meters to support turbines, but 40 percent of the state has winds sufficient only at this height and not at heights of 10 or 20 meters. Original data are from J. W. Reed, *Wind Power Climatology of the United States—Supplement* (Albuquerque, N.M.: Sandia Laboratories, 1979).

APPENDIX E

SAMPLE PAYBACK PERIOD ANALYSES

**Table E-1. PAYBACK PERIOD ANALYSIS: WATER HEATING IN
300-HOG/YEAR SLAUGHTERING PLANT,
ASSUMING REPLACEMENT OF NATURAL GAS^a**

Year	50% Equity, 9% Interest		Savings	Σ Savings	20% Equity, 10% Interest	
	Outlays	Σ Outlays			Outlays	Σ Outlays
0	277	277	0	0	111	111
1	71	348	54	54	98	209
2	71	418	73	127	98	307
3	71	489	70	206	98	405
4	71	560	85	291	98	503
5	71	631	92	383	98	601
6	71	702	99	482	98	699
7	71	773	107	589	98	797
8	71	843	116	705	98	895
9	71	914	125	830	98	993
10	71	985	135	965	98	1,091
11*	28	1,013	146	1,111	28	1,119
12*	28	1,041	158	1,269	28	1,147
13	28	1,068	170	1,439	28	1,175
14	28	1,096	184	1,623	28	1,203
15	28	1,124	199	1,822	28	1,231
16	28	1,151	214	2,036	28	1,259
17	28	1,179	232	2,268	28	1,287
18	28	1,207	250	2,518	28	1,315
19	28	1,234	270	2,788	28	1,343
20	28	1,262	292	3,080	28	1,371

^aSavings and outlays in dollars.

**Table E-2. PAYBACK PERIOD ANALYSIS: MILK COOLING AND
WATER HEATING ON A 100-COW DAIRY FARM,
ASSUMING REPLACEMENT OF CONVENTIONAL ELECTRICITY^a**

Year	50% Equity, 9% Interest		Savings	Σ Savings	20% Equity, 10% Interest	
	Outlays	Σ Outlays			Outlays	Σ Outlays
0	3,919	3,919	0	0	1,567	1,567
1	988	4,907	1,130	1,130	1,386	2,953
2	988	5,895	1,356	2,486	1,386	4,339
3	988	6,883	1,411	3,897	1,386	5,725
4	988	7,871	1,467	5,364	1,386	7,111
5	988	8,859	1,526	6,890	1,386	8,497
6	988	9,847	1,587	8,477	1,386	9,883
7	988	10,835	1,650	10,127	1,386	11,269
8*	988	11,823	1,716	11,843	1,386	12,655
9	988	12,811	1,785	13,628	1,386	14,041
10*	988	13,799	1,856	15,484	1,386	15,427
11	392	14,191	1,931	17,415	392	15,819
12	392	14,583	2,008	19,423	392	16,211
13	392	14,975	2,088	21,511	392	16,603
14	392	15,367	2,172	23,683	392	16,995
15	392	15,759	2,259	25,942	392	17,387
16	392	16,151	2,349	28,291	392	17,779
17	392	16,543	2,443	30,734	392	18,171
18	392	16,935	2,541	33,275	392	18,563
19	392	17,327	2,642	35,917	392	18,955
20	392	17,719	2,748	38,665	392	19,347

^aSavings and outlays in dollars.

**Table E-3. PAYBACK PERIOD ANALYSIS: FLUID MILK PLANT
RECEIVING 10 MILLION KG/YEAR,
ASSUMING REPLACEMENT OF ELECTRICITY^a**

Year	50% Equity, 9% Interest		Savings	Σ Savings	20% Equity, 10% Interest	
	Outlays	Σ Outlays			Outlays	Σ Outlays
0	37	37	0	0	15	15
1	10	47	11	11	14	28
2	10	57	13	24	14	42
3	10	66	13	37	14	55
4	10	76	14	51	14	69
5	10	85	15	66	14	82
6	10	95	15	81	14	96
7	10	104	16	97	14	109
8	10	114	16	113	14	123
9*	10	124	17	130	14	136
10	10	133	18	148	14	150
11*	4	137	18	166	4	154
12	4	141	19	185	4	157
13	4	144	20	205	4	161
14	4	148	21	226	4	165
15	4	152	22	248	4	169
16	4	156	22	270	4	172
17	4	159	23	293	4	176
18	4	163	24	317	4	180
19	4	167	25	342	4	184
20	4	171	26	368	4	187

^aOutlays and savings in thousands of dollars. They are based on energy costs of a low-cost-per-unit plant receiving fluid milk and producing milk as well as some solids. Low cost per unit is defined in table 27.

Table E-4. PAYBACK PERIOD ANALYSIS: THERMAL ENERGY REQUIREMENTS FOR BLANCHING AND STERILIZATION IN A 21 M KG VEGETABLE-PROCESSING PLANT, ASSUMING REPLACEMENT OF FUEL OIL NO. 2^a

Year	50% Equity, 9% Interest		Savings	Σ Savings	20% Equity, 10% Interest	
	Outlays	Σ Outlays			Outlays	Σ Outlays
0	378	378	0	0	151	151
1	95	473	74	74	134	285
2	95	568	100	174	134	419
3	95	663	108	282	134	553
4	95	758	116	398	134	687
5	95	853	125	523	134	821
6	95	948	136	659	134	955
7	95	1,043	146	805	134	1,089
8	95	1,138	158	963	134	1,223
9	95	1,233	171	1,134	134	1,357
10	95	1,328	184	1,318	134	1,491
11*	38	1,366	199	1,517	38	1,529
12	38	1,404	215	1,732	38	1,567
13	38	1,442	232	1,964	38	1,605
14	38	1,480	251	2,215	38	1,643
15	38	1,518	271	2,486	38	1,681
16	38	1,556	293	2,779	38	1,719
17	38	1,594	316	3,095	38	1,757
18	38	1,632	341	3,436	38	1,795
19	38	1,670	369	3,805	38	1,833
20	38	1,708	398	4,203	38	1,871

^aSavings and outlays in thousands of dollars. Size plant refers to gross weight produced (see table 29).

APPENDIX F

DEVELOPMENTAL SWECS TESTED AT ROCKY FLATS

System	Out @ 20 mph (kW)	Description
ASI/Pinson 1 kW	1	Three-bladed, vertical-axis rotor
Northwind 2 kW	2	Three-bladed, horizontal-axis rotor
Enertech 2 kW	2	Two-bladed, horizontal-axis rotor
UTRC 8 kW	9	Two-bladed, horizontal-axis rotor
Grumman 8 kW	11	Three-bladed, horizontal-axis rotor
Windworks 8 kW	8	Three-bladed, horizontal-axis rotor
Kaman 40 kW	40	Two-bladed, horizontal-axis rotor
McDonnell 40 kW	40	Three-bladed, vertical-axis rotor

Source: Rockwell International Corporation, Wind Systems Program, Rocky Flats Plant, Energy Systems Group, "System Summary of Small Wind Energy Conversion Systems (SWECS) Development," 1979.

APPENDIX G

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