LBNL-59289-Revision

Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and Vegetable Processing Industry

An ENERGY STAR® Guide for Energy and Plant Managers

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March 2008

This work was funded by U.S. Environmental Protection Agency's Climate Protection Partnerships Division as part of ENERGY STAR. ENERGY STAR is a government-backed program that helps businesses protect the environment through superior energy efficiency. The work was supported by the U.S. Environmental Protection Agency through the U.S. Department of Energy Contract No. DE-AC02-05CH11231.

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ABSTRACT

The U.S. fruit and vegetable processing industry—defined in this Energy Guide as facilities engaged in the canning, freezing, and drying or dehydrating of fruits and vegetables—consumes over $800 million worth of purchased fuels and electricity per year. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility. There are a variety of opportunities available at individual plants in the U.S. fruit and vegetable processing industry to reduce energy consumption in a cost-effective manner. This Energy Guide discusses energy efficiency practices and energy-efficient technologies that can be implemented at the component, process, facility, and organizational levels. A discussion of the trends, structure, and energy consumption characteristics of the U.S. fruit and vegetable processing industry is provided along with a description of the major process technologies used within the industry. Next, a wide variety of energy efficiency measures applicable to fruit and vegetable processing plants are described. Many measure descriptions include expected savings in energy and energy-related costs, based on case study data from real-world applications in fruit and vegetable processing facilities and related industries worldwide. Typical measure payback periods and references to further information in the technical literature are also provided, when available. Given the importance of water in fruit and vegetable processing, a summary of basic, proven measures for improving plant-level water efficiency are also provided. The information in this Energy Guide is intended to help energy and plant managers in the U.S. fruit and vegetable processing industry reduce energy and water consumption in a cost-effective manner while maintaining the quality of products manufactured. Further research on the economics of all measures—as well as on their applicability to different production practices—is needed to assess their cost effectiveness at individual plants.

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1 Introduction

As U.S. manufacturers face an increasingly competitive environment, they seek out opportunities to reduce production costs without negatively affecting the yield or the quality of their finished products. The volatility of energy prices in today's marketplace can also negatively affect predictable earnings. The challenge of maintaining high product quality while simultaneously reducing production costs can often be met through investments in energy efficiency, which can include the purchase of energy-efficient technologies and the implementation of plant-wide energy efficiency practices. Energy-efficient technologies can often offer additional benefits, such as quality improvement, increased production, and increased process efficiency, all of which can lead to productivity gains. Energy efficiency is also an important component of a company's overall environmental strategy, because energy efficiency improvements can often lead to reductions in emissions of both greenhouse gases and other important air pollutants. Investments in energy efficiency are therefore a sound business strategy in today's manufacturing environment.

ENERGY STAR® is a voluntary program operated by the U.S. Environmental Protection Agency (EPA). The primary purpose of the ENERGY STAR program is to help U.S. industry improve its competitiveness through increased energy efficiency and reduced environmental impact. Through ENERGY STAR, the U.S. EPA stresses the need for strong and strategic corporate energy management programs and provides a host of energy management tools and strategies to help companies implement such programs. This Energy Guide reports on research conducted to support the U.S. EPA's ENERGY STAR Fruit and Vegetable Processing Focus, which works with U.S. fruit and vegetable processors to develop resources and reduce information barriers for energy efficiency improvement. For further information on ENERGY STAR and its available tools for facilitating corporate energy management practices, visit http://www.energystar.gov/.

This Energy Guide provides a detailed overview of available measures for energy efficiency in the U.S. fruit and vegetable processing industry. Given the importance and rising costs of water as a resource in fruit and vegetable processing, this Energy Guide also provides information on proven measures for improving plant-level water efficiency. Moreover, water efficiency improvement can also reduce energy use for water heating, treatment, and pumping.

The fruit and vegetable processing industry in the United States—defined in this Energy Guide as facilities engaged in the canning, freezing, and drying or dehydrating of fruit and vegetable products—is an important industry from both an economic and energy use perspective. In 2004, the industry generated nearly $38 billion in product shipments and employed nearly 112,000 people directly in over 1,300 different facilities (U.S. Census Bureau 2005a, 2005b). Although fruit and vegetable processing facilities can be found throughout the United States, the states of California, Oregon, Washington, and Wisconsin account for roughly one half of total industry employment. The industry spent nearly $810 million on energy costs in 2002: $370 million for purchased electricity and $440 million for purchased fuels, which consisted primarily of natural gas (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d).[1] Because the costs of electricity and natural gas are rising rapidly in the United States, energy efficiency improvements are becoming an increasingly important focus area in the U.S. fruit and vegetable processing industry for managing costs and maintaining competitiveness.

This Energy Guide begins with an overview of the trends, structure, and production characteristics of the U.S. fruit and vegetable processing industry in Chapter 2. A description of the main production processes employed in fruit and vegetable processing is provided in Chapter 3. In Chapter 4, the use of energy in the fruit and vegetable processing industry is discussed along with an overview of the main end uses of energy in typical canning, freezing, and drying or dehydrating facilities. Chapters 5 through 13 describe a wide range of available measures for improving energy efficiency in U.S. fruit and vegetable processing facilities, with a focus on energy-efficient technologies and practices that have been successfully demonstrated in facilities in the United States and abroad.

Although new energy-efficient technologies are developed continuously (see for example Martin et al. 2000), this Energy Guide focuses primarily on those technologies and practices that were both proven and currently commercially available at the time of this writing. However, because emerging technologies can often play an important role in reducing industrial energy use, Chapter 14 offers a brief overview of selected promising emerging energy-efficient technologies of relevance to fruit and vegetable processing.

Given that the U.S. fruit and vegetable processing industry manufactures a wide variety of products and employs a diversity of production methods, it is impossible to address all end uses of energy within the industry. This Energy Guide therefore focuses on only the most important end uses of energy in typical canning, freezing, and drying or dehydrating facilities.

Lastly, recognizing the importance of water as a resource in fruit and vegetable processing as well as its rising costs, this Energy Guide concludes with information on basic, proven measures for improving plant-level water efficiency in Chapter 15. Many of the water efficiency strategies discussed in Chapter 15 can lead to energy savings as well.

Table 1.1 provides a summary of key economic and energy use data presented in this Energy Guide for the U.S. fruit and vegetable processing industry.

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[1] Due to changes in the way sub-sector-level data are reported by the U.S. Census Bureau in its 2003 and 2004 Annual Survey of Manufactures, 2002 is the most recent year for which energy purchase data are available for the U.S. fruit and vegetable processing industry sub-sectors discussed in this Energy Guide.

Table 1.1: Key economic and energy use data for the U.S. fruit and vegetable processing industry

Value of Product Shipments (2004)	
Frozen fruit, juice, and vegetable manufacturing	$8.7 billion
Fruit and vegetable canning	$18.3 billion
Specialty canning	$6.9 billion
Dried and dehydrated foods manufacturing	$4 billion
Total	**$37.9 billion**
Employment (2004)	
Frozen fruit, juice, and vegetable manufacturing	35,730
Fruit and vegetable canning	47,970
Specialty canning	13,790
Dried and dehydrated foods manufacturing	14,300
Total	**111,790**
Number of Establishments (2004)	
Frozen fruit, juice, and vegetable manufacturing	247
Fruit and vegetable canning	764
Specialty canning	130
Dried and dehydrated foods manufacturing	186
Total	**1,327**
Electricity Expenditures (2002)	
Frozen fruit, juice, and vegetable manufacturing	$147 million
Fruit and vegetable canning	$144 million
Specialty canning	$31 million
Dried and dehydrated foods manufacturing	$48 million
Total	**$370 million**
Site Electricity Use (2002)	
Frozen fruit, juice, and vegetable manufacturing	9.9 TBtu
Fruit and vegetable canning	8.5 TBtu
Specialty canning	2.1 TBtu
Dried and dehydrated foods manufacturing	2.4 TBtu
Total	**22.9 TBtu**
Fuel Expenditures (2002)	
Frozen fruit, juice, and vegetable manufacturing	$129 million
Fruit and vegetable canning	$190 million
Specialty canning	$42 million
Dried and dehydrated foods manufacturing	$79 million
Total	**$440 million**
Fuel Use (2002)	
Frozen fruit, juice, and vegetable manufacturing	21 TBtu
Fruit and vegetable canning	36 TBtu
Specialty canning	8 TBtu
Dried and dehydrated foods manufacturing	13 TBtu
Total	**78 TBtu**
Top 5 States for Industry Employment (2002)	
(1) California, (2) Washington, (3) Oregon, (4) Wisconsin, (5) Florida	

2 The U.S. Fruit and Vegetable Processing Industry

This Energy Guide defines the U.S. fruit and vegetable processing industry as facilities engaged in the canning, freezing, and drying or dehydrating of fruits and vegetables, which constitute the three major methods of fruit and vegetable preservation employed by the U.S. food industry today. More specifically, this Energy Guide considers the four U.S. food industry sub-sectors defined by the North American Industry Classification System (NAICS) codes listed in Table 2.1. Also summarized in Table 2.1 are the key products manufactured by each sub-sector. It can be seen in Table 2.1 that the U.S. fruit and vegetable processing industry manufactures a wide variety of products, many of which are staples in the typical American home. Such staples include frozen concentrated orange juice, canned tomato sauces, ketchup, frozen French fried potatoes, canned soups and stews, frozen fruits and vegetables, dehydrated potatoes, and fruit jams and jellies.

Table 2.1: NAICS codes and key products of the U.S. fruit and vegetable processing industry

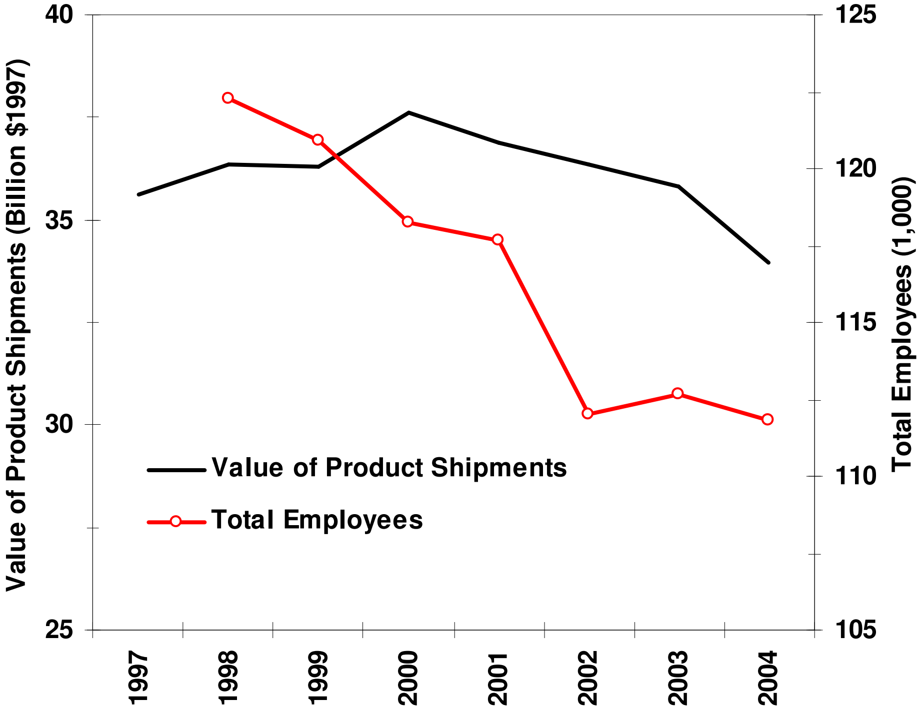
NAICS Code	Sector description	Key products
311411	Frozen fruit, juice, and vegetable manufacturing	Frozen French fried potatoes, frozen concentrated orange juice, frozen potato patties and puffs, frozen corn, frozen onions, frozen strawberries, frozen apples and applesauce, frozen peas, frozen green beans, frozen broccoli.
311421	Fruit and vegetable canning	Canned tomato products (spaghetti and pizza sauces, ketchup, tomato paste, tomato sauce, salsa, stewed tomatoes, and tomato juice), canned orange juice, canned pickles, canned fruit jams, jellies, and preserves, canned peaches, canned corn, canned green beans, canned salsa, canned olives.
311422	Specialty canning	Canned soups and stews, canned baked beans, canned chili con carne, canned spaghetti and ravioli, canned baby foods.
311423	Dried and dehydrated foods manufacturing	Dried and dehydrated potatoes, apples, prunes, onions, and raisins, soup mixes.

The primary purpose of fruit and vegetable processing is to preserve fruits and vegetables in a stable form that enables extended storage and shipment to distant markets, which allows consumers to purchase a wide variety of fruit and vegetable products at all times of year. Fruit and vegetable processing can also be used to provide consumers with food products that are more convenient to prepare and consume. Of all the fruits and vegetables consumed in the United States each year, roughly one half are processed into canned, frozen, or dehydrated consumer products. In 2003, around 370 pounds of fruits and vegetables per capita were processed for consumption in the United States (USDA 2005a). Americans purchased nearly $21 billion worth of processed fruit and vegetable products directly in 1999, or nearly 10% of their total grocery budget (Reed et al. 2004).

2.1 Economic Trends

In 2004, the U.S. fruit and vegetable processing industry generated nearly $38 billion in product shipments, or about 7.5% of the value of shipments of the entire U.S. food industry (NAICS 311) (U.S. Census Bureau 2005b, 2005c). This number is up from around $36 billion in product shipments in 1997. In real (i.e., inflation adjusted) dollars, however, the economic output of the U.S. fruit and vegetable industry declined by roughly 5% between 1997 and 2004, as depicted in Figure 2.1.[2]

Figure 2.1: Trends in industry value of product shipments and employment, 1997-2004



Sources: U.S. Census Bureau (2005a, 2005b, 2005c)

Also shown in Figure 2.1 is a corresponding decline in total industry employment over roughly the same period. In 2004, the industry employed 112,000 people directly, down from 122,000 employees in 1997 (U.S. Census Bureau 2005a). Over the same period, the total number of establishments in the U.S. fruit and vegetable processing industry also declined slightly, from 1,407 facilities in 1997 to 1,327 facilities in 2004 (U.S. Census Bureau 2005a). These recent declines might be explained in part by market and economic pressures facing many sub-sectors of the U.S. food industry, including increasing competition from overseas imports, susceptibility to variations in harvest yields, continued industry consolidation, rising labor costs, and rising energy costs.

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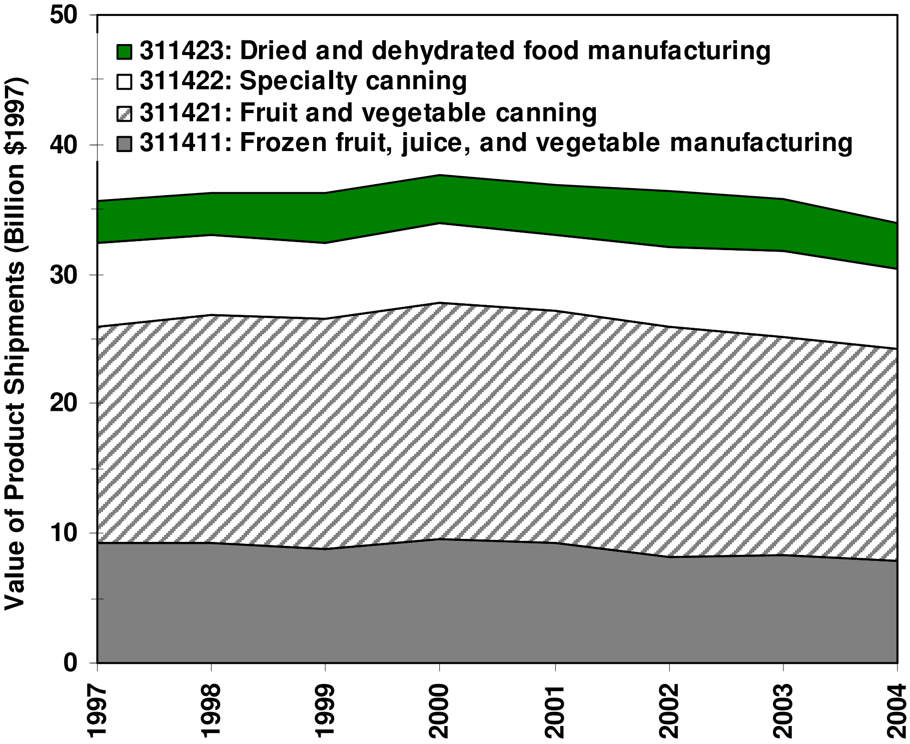
[2] Value of shipments data in Figure 2.1 were adjusted for inflation using producer price index data for the U.S. fruit and vegetable processing from the U.S. Bureau of Labor Statistics (2007).

Figure 2.2 depicts the trends in value of product shipments by sub-sector of the U.S. fruit and vegetable processing industry between 1997 and 2004, in real (1997) dollars. The fruit and vegetable canning sub-sector (NAICS 311421) was the largest economic contributor by a significant margin, accounting for nearly one half of total industry value of product shipments. The frozen fruit, juice, and vegetable manufacturing sub-sector (NAICS 311411) was the next largest economic contributor, accounting for roughly one quarter of industry value of product shipments. Of the four sub-sectors comprising the U.S. fruit and vegetable processing industry, only one—dried and dehydrated foods (NAICS 311423)—has experienced recent growth in real economic output, growing by approximately 10% in real dollars between 1997 and 2004 (U.S. Census Bureau 2005b).

Figure 2.2: Industry value of product shipments by sub-sector, 1997-2004



Source: U.S. Census Bureau (2005b)

2.2 Sub-Sector Overviews

Fruit and vegetable canning (NAICS 311421) is the largest sub-sector of the U.S. fruit and vegetable processing industry in terms of both economic output and employment. In 2004, U.S. fruit and vegetable canneries generated over $18 billion in product shipments, roughly one half of the of the industry's total economic output (U.S. Census Bureau 2005b). Fruit and vegetable canneries in the United States employed nearly 48,000 people directly in 2004 (43% of total industry employment) at 764 different facilities (58% of total industry establishments) (U.S. Census Bureau 2005a).

In the canning process, fruits and vegetables are sterilized and preserved in hermetically sealed containers that prevent microbial spoilage. Common container materials include enamel-coated steel, tin-coated steel, aluminum, plastic, and glass (Luh and Kean 1988).

Fruit and vegetable canneries in the United States manufacture a wide variety of products, including canned tomato sauces, ketchup, fruit and vegetable juices, canned vegetables and fruits, fresh fruit juices, pickles, and fruit jellies and jams. However, canned tomatoes and tomato-based products (e.g., sauces, ketchup, tomato paste, salsas, and tomato juice) represent the most important products from this sub-sector from an economic perspective, accounting for over $5.5 billion in product shipments in 2002 (U.S. Census Bureau 2004b).

Other major sub-sector outputs from an economic perspective are canned orange juices, pickles and pickled products, canned jellies, jams, and preserves, fresh orange juices, canned corn, and canned beans. A summary of key products manufactured by U.S. fruit and vegetable canneries is provided in Appendix A.

Although fruit and vegetable canneries are located across the United States, the greatest number of canneries is found in California due to the state's large agricultural industry. According to the California League of Food Processors, California canneries produce 33% of the world's processed tomatoes (11 million tons per year), 100% of the U.S. supply of canned peaches and fruit cocktail, and 100% of the U.S. supply of black ripe olives (CLFP 2005). In 2002, nearly 16,000 people were directly employed in 145 fruit and vegetable canneries in California (U.S. Census Bureau 2004b).

After California, the states with the highest employment in fruit and vegetable canneries are Wisconsin (5,200 employees), Florida (4,660 employees, primarily in orange juice manufacture), and New York (3,750 employees).

Major U.S. based companies in this sub-sector include H.J. Heinz (Pittsburgh, Pennsylvania), Del Monte Foods (San Francisco, California), J.M. Smucker (Orrville, Ohio), ConAgra Foods (Omaha, Nebraska), Ocean Spray Cranberries (Lakeville-Middleboro, Massachusetts), and Seneca Foods (Marion, New York) (Hoover's Online 2006).

Frozen fruit, juice, and vegetable manufacturing (NAICS 311411) is the next largest sub-sector of the U.S. fruit and vegetable processing industry after canning. This sub-sector generated $8.7 billion in product shipments in 2004, or roughly one quarter of the industry's total economic output (U.S. Census Bureau 2005b). Frozen fruit, juice, and vegetable manufacturers in the United States employed over 35,000 people directly in 2004 at 247 different facilities (U.S. Census Bureau 2005a).

Freezing preserves fruits and vegetables by lowering their temperature to a point at which the growth of micro-organisms is severely limited (Luh and Lorenzo 1988). Key products manufactured by the frozen fruit, juice, and vegetable manufacturing sub-sector include frozen French fried potatoes, frozen concentrated orange juices, frozen potato patties and puffs, frozen sweet yellow corn, frozen onions (rings, diced, and chopped), and frozen strawberries. A summary of key products manufactured by this sub-sector is provided in Appendix A.

From an economic perspective, frozen French fried potatoes represent the most significant product manufactured by the frozen fruit, juice, and vegetable manufacturing sub-sector. In 2002, over $2.3 billion worth of frozen French fried potatoes (an estimated 6 billion to 7 billion pounds) were produced in the United States, representing roughly one quarter of total sub-sector economic output (U.S. Census Bureau 2004a). Frozen concentrated orange juice represents the next most significant product of this sub-sector with $1.5 billion in product shipments in 2002.

The three Pacific Coast states of California, Oregon, and Washington accounted for roughly 60% of the employment (19,500 employees) and one half of the establishments (95 facilities) in the frozen fruit, juice, and vegetable manufacturing sub-sector in 2002 (U.S. Census Bureau 2004a). Oregon and Washington are major producers of frozen fruits (notably cherries, berries, and apples) while California produces a wide range both frozen fruits (notably peaches and strawberries) and frozen vegetables (notably spinach, green beans, and broccoli) (USDA 2005b; IPM Centers 2005). Idaho, the leading U.S. producer of frozen processed potato products, and Florida, the leading U.S. producer of frozen concentrated orange juice, are also major employers in this sub-sector.

Major U.S. based companies in this sub-sector include Birds Eye Foods (Rochester, New York), ConAgra Foods (Omaha, Nebraska), McCain USA (Lisle, Illinois), NORPAC Foods (Lake Oswego, Oregon), Heinz Frozen Foods (Pittsburgh, Pennsylvania), J.R. Simplot (Boise, Idaho), and Dole Foods (Westlake Village, California) (Hoover's Online 2006).

The **specialty canning** sub-sector (NAICS 311422) generated nearly $7 billion in product shipments in 2004, or roughly 18% of the U.S. fruit and vegetable processing industry's 2004 economic output (U.S. Census Bureau 2005b). In 2004, this sub-sector employed nearly 14,000 people in 130 different facilities (U.S. Census Bureau 2005a). The primary products manufactured by this sub-sector that are of relevance to fruit and vegetable processing are canned soups and stews and canned baby foods, which often contain processed vegetables (e.g., carrots, beans, and tomatoes) as primary ingredients. Product shipments of canned soups and stews and canned baby foods in 2002 represented nearly 60% ($3.9 billion) of the total 2002 economic output of U.S. specialty canneries (U.S. Census Bureau 2004c).

Other major products manufactured by the specialty canning sub-sector include canned beans and chili (with and without meat) and canned nationality foods (including spaghetti, ravioli, Mexican rice, tortillas, and enchiladas). A summary of key products manufactured by this sub-sector is provided in Appendix A. Texas (1,214 employees) and California (1,151 employees) were the largest employers in U.S. specialty canneries in 2002 (U.S. Census Bureau 2004c).

Major U.S. based companies in this sub-sector include Campbell Soup Company (Camden, New Jersey), Gerber Products (Parsippany, New Jersey), and Goya (Bayamon, Puerto Rico) (Hoover's Online 2006).

Dried and dehydrated food manufacturing (NAICS 311423) is the smallest sub-sector of the U.S. fruit and vegetable processing industry in economic terms, generating just over $4 billion in product shipments in 2004 (U.S. Census Bureau 2005b). Dried and dehydrated food manufacturers employed around 14,300 people at 186 different facilities in 2004 (U.S. Census Bureau 2005a).

The drying and dehydration of foods is one of the oldest preservation techniques known to man, and relies on the removal of moisture from foods to retard or prevent the growth of micro-organisms. The term "dehydrated" generally refers to foods with moisture content reduced below the point at which micro-organisms can grow (8% to 18% moisture), while the term "dried" generally refers to foods with reduced moisture content in general (typically below 30% moisture) (U.S. EPA 1995a).

Key products manufactured by this sub-sector include dried and dehydrated soup mixes ($1 billion in product shipments in 2002), dried and dehydrated potatoes ($400 million in product shipments in 2002), dried and dehydrated onions ($242 million in product shipments in 2002), and dried and dehydrated raisins ($237 million in product shipments in 2002) (U.S. Census Bureau 2004d). A summary of key products manufactured by this sub-sector is provided in Appendix A.

In 2002, the leading states for employment in the dried and dehydrated food manufacturing sub-sector were California (5,511 employees), Idaho (1,995 employees), and Illinois (1,225 employees). Combined, these three states accounted for roughly two thirds of total sub-sector employment (U.S. Census Bureau 2004d). California produces nearly 100% of the nation's dried raisins, around 70% of the world's dried prunes, over 50% of the nation's dehydrated garlic, and is the nation's leading producer of dehydrated onions. Idaho is the nation's leading producer of dehydrated potato products (IPM 2005; USDA 2003).

Major U.S. based companies in this sub-sector include Sunsweet Growers (Yuba City, California), Sun-Maid Growers (Kingsburg, California), Basic American Foods (Walnut Creek, California), ConAgra Foods (Omaha, Nebraska), and J.R. Simplot (Boise, Idaho) (Hoover's Online 2006).

2.3 Fruit and Vegetable Processing Trends

In 2003, the U.S. fruit and vegetable processing industry processed nearly 33 billion pounds of fresh fruits and nearly 55 billion pounds of fresh vegetables into canned, frozen, and dried and dehydrated products (USDA 2005a). Figure 2.3 depicts the mass of fresh fruits processed by product category between 1981 and 2003. After growing steadily throughout the 1980s, the total mass of fruits processed in the United States has fluctuated between 35 and 40 million pounds per year since the early 1990s.[3] In 2003, over 17 billion pounds of fresh oranges were processed into orange juice in the United States, representing roughly one half of all fruits processed by the industry.

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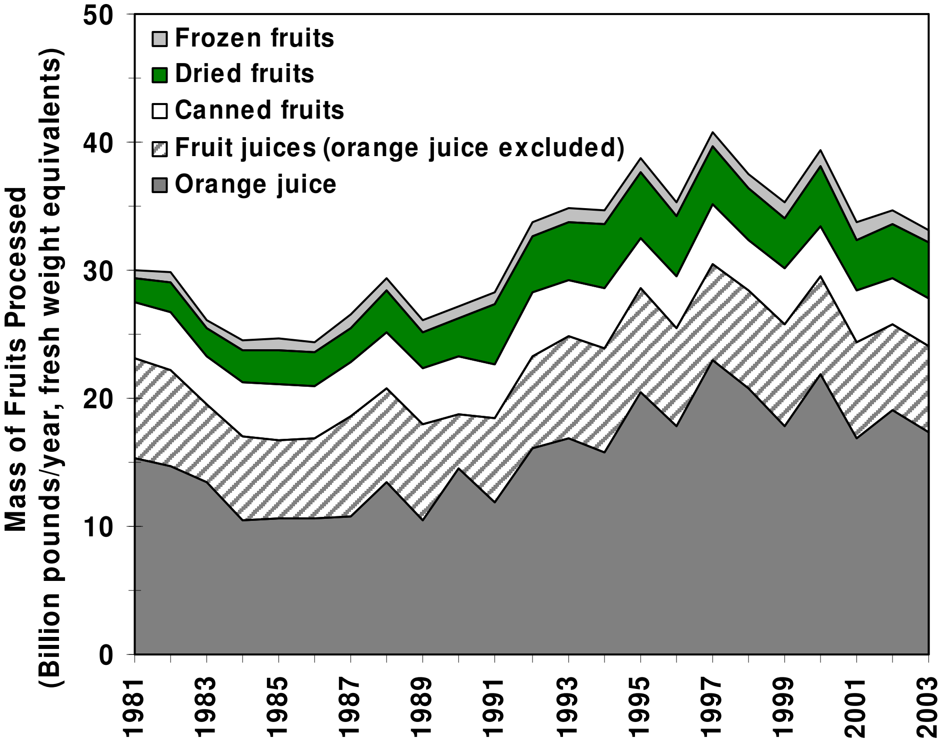
[3] The USDA calculates fresh weight equivalents by converting the weight of processed fruits into an equivalent weight of fresh produce.

Figure 2.3: Mass of fresh fruits processed by product category in the United States, 1981-2003



Source: USDA (2005a)

Figure 2.4 shows the mass of fresh vegetables processed by product category between 1981 and 2003 (U.S. Census Bureau 2005a).[4] The total mass of fresh vegetables processed in the United States rose steadily from around 37 billion pounds in 1981 to nearly 55 billion pounds in 2003.

Figure 2.4 also clearly shows the importance of two vegetable crops: tomatoes for canning (nearly 20 billion pounds processed in 2003) and potatoes for freezing (over 15 billion pounds processed in 2003). Together, these two vegetable crops accounted for nearly two thirds of the total mass of all vegetables processed by the industry in 2003. The large quantities of tomatoes and potatoes processed reflect the popularity of canned tomato products (pizza and spaghetti sauces, ketchup, salsa, tomato paste, etc.) and frozen potato products (French fried potatoes, potato patties and puffs, etc.) in U.S. consumer and commercial markets.

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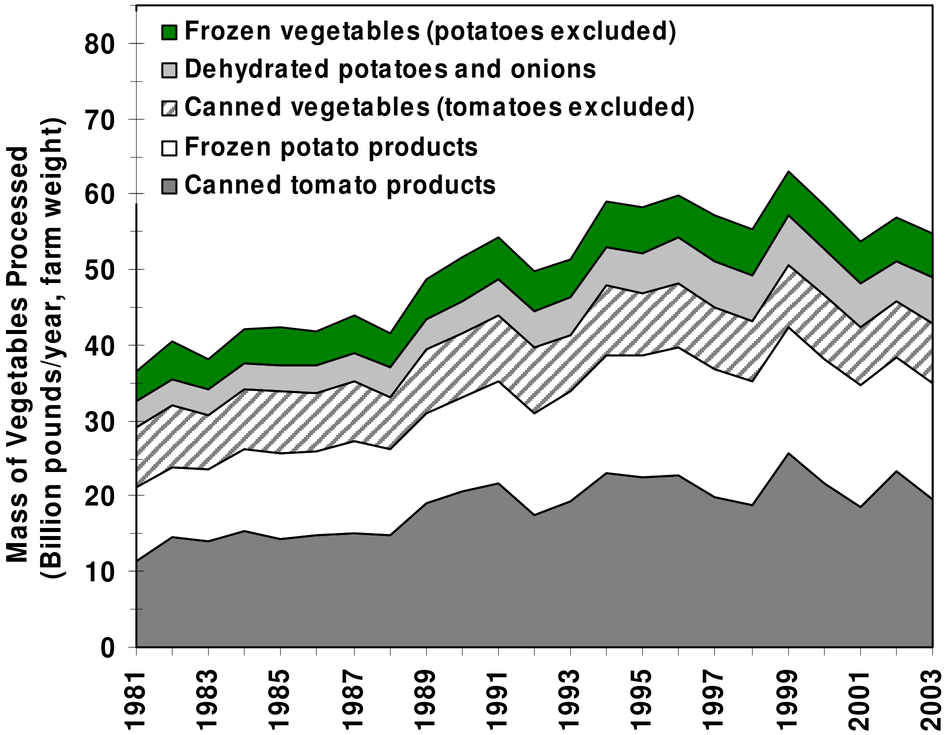
[4] The USDA defines farm weight as the weight of a commodity as measured on the farm before further conditioning and processing.

Figure 2.4: Mass of fresh vegetables processed by product category in the United States, 1981-2003



Source: USDA (2005a)

2.4 Imports and Exports

The U.S. fruit and vegetable processing industry has faced steadily increasing competition from foreign imports since the early 1980s. In 2003, imported processed fruit and vegetable products accounted for around 21% of the total mass consumed in the United States. This number is up from only around 10% in 1981 (USDA 2005a).

Import competition is most significant for fruit juices, for which around one third of all 2003 U.S. consumption was met by imports. In terms of sheer quantity, the most significant imports in 2003 were frozen potato products (3.3 billion pounds, farm weight), apple juice (450 million gallons), orange juice (290 million gallons), canned pineapples (1.3 billion pounds, fresh weight equivalent), canned Chile peppers (1.2 billion pounds, farm weight), and canned tomato products (1.2 billion pounds, farm weight). The top sources of imports in 2003 were Canada (23% of imports), the European Union (15% of imports), Mexico (14% of imports), and China (12% of imports).

Most of the products manufactured by the U.S. fruit and vegetable processing industry are consumed domestically. In 2003, exports by the industry totaled less than 8% of total industry economic output, or roughly $3 billion (U.S. Census Bureau 2005d). Of this, nearly one half ($1.4 billion) were exports from the fruit and vegetable canning sub-sector and nearly one third ($900 million) were exports from the frozen fruit, juice, and vegetable manufacturing sub-sector.

The top destinations for industry exports in 2003 were Canada (33% of exports), Japan (19% of exports), the European Union (14% of exports), and Mexico (7% of all exports).

2.5 Industry Structure and Characteristics

Table 2.2 illustrates the geographic concentration of the U.S. fruit and vegetable processing industry as of 2002. Listed are the top ten states for industry value of shipments in 2002, along with the number of employees and establishments in each state (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d).

California ranked first by a significant margin in all three categories, accounting for 21% of value of industry shipments, 25% of industry employment, and 20% of industry establishments. According to the California League of Food Processors, California accounted for more than 40% of the nation's total processed fruit and vegetable production in 2001 (CLFP 2001). The three Pacific Coast states of California, Oregon, and Washington together accounted for nearly 40% of all employment and one third of all facilities in 2002. These statistics clearly demonstrate the importance of the Pacific Coast region to the industry.

Table 2.2: Top ten states in the U.S. fruit and vegetable processing industry by value of industry shipments, 2002

State	2002 Value of Industry Shipments ($1,000)	Rank	Number of Employees in 2002	Rank	Number of Establishments in 2002	Rank
California	8,672,011	1	30,982	1	271	1
Florida	3,580,279	2	6,550	5	55	7
New York	2,417,026	3	5,328	7	75	2
Oregon	2,227,236	4	8,651	3	67	6
Washington	2,184,985	5	9,558	2	71	4
Wisconsin	1,686,960	6	8,486	4	75	2
Texas	1,355,892	7	4,004	8	69	5
Idaho	1,296,468	8	6,482	6	30	12
New Jersey	1,064,682	9	2,038	13	20	15
Illinois	846,987	10	3,612	9	49	9

Sources: USDA (2004a, 2004b, 2004c, 2004d)

Most manufacturing facilities in the U.S. fruit and vegetable processing industry are fairly small enterprises. In 2002, nearly two thirds of the industry's facilities employed fewer than 50 people, and nearly 80% of the industry's facilities employed fewer than 100 people (U.S. Census Bureau 2005a). Large processing facilities with 500 or more employees are somewhat of a rarity in the industry, accounting for only 3% of the facilities in 2002.

Table 2.3 summarizes the degree of industry consolidation within each sub-sector of the U.S fruit and vegetable processing industry as of 1997, the last year for which such data are available (U.S. Census Bureau 2001). The highest degree of industry consolidation can be seen in the specialty canning sub-sector, with only four companies accounting for around two thirds of the sub-sector's total 1997 economic output. Also highly consolidated are the frozen fruit, juice, and vegetable manufacturing sub-sector and the dried and dehydrated food sub-sector. The fruit and vegetable canning sub-sector is the least consolidated, with the 20 largest companies accounting for only 60% of industry shipments.

The operation of many facilities in the U.S. fruit and vegetable processing industry can be highly seasonal. Operations typically depend heavily on the harvesting schedules of the fruits and vegetables processed. For example, canned tomato processing in California typically only occurs between the months of July and October when tomatoes are harvested, and during this period tomato canneries normally run 24 hours per day (Wright 2005).

In order to minimize the time lapse between harvesting and processing so that freshness and optimal maturity are maintained, many facilities in the U.S. fruit and vegetable processing industry are located close to farming areas (Luh and Kean 1988). Locating close to farming areas also helps to reduce the costs of transporting fruits and vegetables from the field to the processing plant. Although many crops are processed immediately after harvest, some crops (such as onions, potatoes, and carrots) can be stored for weeks (or even months) after harvest in controlled temperature and humidity environments to suit the operating capacity of individual facilities (Luh and York 1988). The harvesting season for most fruits and vegetables in the United States runs from early spring until late fall; however, some facilities (e.g., fruit juicers) can be run year round by importing fruits and vegetables from overseas for processing.

Table 2.3: U.S. fruit and vegetable processing industry consolidation, 1997

Sector	**NAICS Code**	**Percentage of 1997 Value of Industry Shipments Accounted for by:**		
		4 Largest Companies	**8 Largest Companies**	**20 Largest Companies**
Frozen fruit, juice & vegetable manufacturing	311411	34%	47%	71%
Fruit and vegetable canning	311421	25%	38%	60%
Specialty canning	311422	67%	84%	96%
Dried & dehydrated food manufacturing	311423	30%	51%	80%

Source: U.S. Census Bureau (2001)

3 Overview of Fruit and Vegetable Processing Methods

The processing techniques that are employed by U.S. fruit and vegetable processors are as diverse as the variety of products that are manufactured by the industry. At any given facility, the choice of individual processes as well as the process sequences that are employed will depend heavily on the preservation method used (i.e., canning, freezing, or drying and dehydrating) and on the specific fruits and vegetables that are processed.

However, there are many unit processes (i.e., discrete processing steps) that are common across the industry. Unit processes such as washing, blanching, peeling, conveying, and size reduction can be found in nearly every type of fruit and vegetable processing facility in the United States. Furthermore, there are many unit processes that are common across individual sub-sectors (e.g., filling, exhausting, sealing, and heat sterilization in the canning sub-sector). Thus, while there is a diversity of processing techniques employed across the industry, a core group of unit processes exists that provides the basic building blocks for process sequences employed in nearly every U.S. fruit and vegetable processing facility.

Section 3.1 provides a brief overview of the most significant unit processes employed in the U.S. fruit and vegetable processing industry.[5] The unit process descriptions are grouped into six categories: (1) raw materials preparation, (2) canning, (3) thermal processes, (4) mechanical separation processes, (5) refrigeration and freezing, and (6) miscellaneous processes. Section 3.2 presents process flow diagrams for several key products manufactured by the U.S. fruit and vegetable processing industry, which illustrate how unit processes are typically sequenced within the various industry sub-sectors.

3.1 Unit Processes

3.1.1 Raw Materials Preparation

The unit processes associated with raw materials preparation are typically the first processes that raw fruits and vegetables are subjected to after harvest. In general, raw materials preparation processes are aimed at: (1) readying raw fruits and vegetables for preservation through cleaning, removal of unwanted items such as peels, husks, cores, pits, and stems, (2) transforming them into the proper size and shape, and, (3) inactivating microbial and enzymatic activity, where necessary.

Cleaning is done to remove dirt and other surface contaminants as well as foreign objects such as stones, insects, leaves, and stems prior to further processing. The two basic methods of cleaning are dry processes and wet processes (Gould 1996). Dry processes include the use of air classifiers (which remove foreign objects with blasts of air) de-stoners, and vibrating screens. Wet processes, which are sometimes referred to as **washing**, generally involve the use of high pressure water sprays, soaking, agitated tanks, and flumes to remove surface

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[5] Unless otherwise noted, the unit process descriptions in Section 3.1 are based broadly on information contained in the following sources, which can be consulted for more detailed information on fruit and vegetable processing methods: Luh and Woodroof (1988), Gould (1996), Fellows (2000), Maroulis and Saravacos (2003), Singh and Heldman (2001), and European Commission (2006).

contaminants. Washing is often done using hot water, which aids in contaminant removal, and can also involve the use of detergents.

Grading and **sorting** are terms that are often used interchangeably in practice, but in general refer to unit processes that are aimed at: (1) removing spoiled or damaged fruits and vegetables from the processing stream for quality control purposes, and (2) segregating fruits and vegetables based on their size, weight, and/or color for further processing (Fellows 2000). Grading and sorting can either be done manually, using skilled operators who separate products based on visual inspection, or by using specialized grading and sorting equipment. Such specialized equipment includes rotary screen size graders, belt and roller sorters, vibrating deck screens, and optical sorters that use pneumatic ejectors to separate products based on color.

Peeling is a particularly important unit process for many fruits and vegetables, such as tomatoes, potatoes, beets, carrots, onions, apples, and peaches. The goal of peeling is to remove peels with as little loss of usable product as possible. Common methods of peeling include (Fellows 2000; Woodroof 1988; Woodroof 1986):

- *Flash steam peeling*, in which products are exposed to high-pressure steam in a rotating vessel. The pressure is then instantly released, which causes the surface of the products to “flash off,” thereby removing the peels. The advantages of flash steam peeling are that product cooking is minimized and product texture and color are typically preserved.

- *Knife peeling*, in which stationary blades are pressed against the surface of rotating fruits and vegetables (or vice versa) to remove the skin.

- *Abrasion peeling*, in which products are introduced into a chamber lined with abrasive-coated rollers, which continuously rotate the product and grind away its surfaces. The advantages of abrasion peeling are its low energy costs, operation at ambient temperature, and low capital costs. Disadvantages include the generation of wastewater (from water used to wash away peels) and a higher product loss (around 25%) compared to flash steam peeling (around 8% to 18%) (Fellows 2000).

- *Caustic peeling*, in which products are exposed to a heated solution containing a caustic chemical (most commonly, lye), which softens the skin. Skins can then be removed through agitated baths, abrasion, steaming, and/or high pressure water sprays.

- *Flame peeling*, in which products are exposed to high temperatures in a furnace chamber to burn off their outer layers. Flame peeling is primarily used for onions and peppers, but is applicable to a limited extent to other thick-skinned vegetables such as squash and potatoes (Woodroof 1988).

For many fruits and vegetables, the removal of unwanted components such as husks, shells, pits, cores, and stems is necessary prior to preservation. **Husking** is a unit process used for corn, which generally involves rapidly revolving rubber or milled steel rolls that catch husks and remove them from the corn cob (Luh and Kean 1988). For peas and beans, the **shelling** process is used to thresh products from their pods using a series of beaters (Gould 1996).

The **pitting** process is common employed to remove the pits from cherries, peaches, apricots, olives, and plums. Generally, pitting processes center fruits in pockets or holes where the pit is quickly punched out using a plunger (Gould 1996). For some fruits, most notably peaches, pits can also be removed by mechanical systems that halve the product and shake out the pit. For products with cores, such as apples and pears, the **coring** process is often employed, in which a reamer is used to essentially bore out the product core.

Many fruits and vegetables undergo **size reduction** before preservation, which is done to transform products into shapes that are more amenable to further processing or that are more desirable or convenient for final consumption. One of the most common unit processes for size reduction is **cutting**, which typically uses a rotating blade and a series of cutting fixtures to obtain nearly any output shape desired (e.g., strips, cubes, or slices).

Blanching is the final step in raw materials preparation for nearly all processed vegetables and some processed fruits. The primary purposes of blanching are: (1) to inactivate enzymes, which can cause discoloration and undesirable changes in product flavor and aroma, and (2) to destroy any life processes, yeast, and mold that may be present in the product prior to further processing (Woodroof 1988). Blanching can also help shrink products for more efficient filling and shorten drying times (Rumsey 1986a).

The two most common methods of blanching involve passing products through an atmosphere of saturated steam or a bath of hot water. Common types of steam blanchers include tunnel-type units, in which products are carried on a meshed conveyor belt through a tunnel containing steam, screw-conveyor units, in which products are transported through a steam chamber using a screw-type conveyor, and fluidized bed units, in which a mixture of air and steam transport and heat the product simultaneously (Fellows 2000). Two common types of hot water blanchers are the reel blancher, in which products are moved through a hot water bath in a rotating drum with internal flights, and pipe blanchers, in which products are fed into and out of a pipe containing recirculated hot water.

3.1.2 Canning

In the canning process, fruits and vegetables are sterilized and preserved in hermetically sealed containers that prevent microbial spoilage. The basic canning process consists of five unit processes: (1) filling, (2) exhausting, (3) sealing, (4) heat sterilization, and (5) cooling.

After fruits and vegetables have been subjected to the applicable raw materials preparation processes, they are filled into containers typically made of glass or metal. Most **filling** is done by machine, but occasionally hand filling is also performed. Brush fillers are commonly used for solid products, while rotary piston fillers are commonly used for liquids, pastes, and powders. Containers are typically filled from 90% to 94% of full capacity, leaving a headspace that is necessary for forming a vacuum (Fellows 2000). Prior to filling, containers are typically cleaned using hot water, steam, or a blast of pressurized air.

After filling, it is common for containers to undergo **exhausting**, the purpose of which is to remove air from the container such that a vacuum is formed. The vacuum helps to keep the can ends drawn inward, reduces the strain on containers during processing, and minimizes the amount of oxygen remaining in the headspace (Luh and Kean 1988). Often, air is exhausted from the headspace using a blast of steam.

Immediately after the headspace is exhausted, the container is **sealed** mechanically through the application of a container lid. In most modern types of sealers, exhausting and sealing occur almost simultaneously on the same piece of equipment.

Once containers are sealed, the products are subjected to in-container **heat sterilization**, a process which destroys micro-organisms in the product via the application of heat. The temperature and duration of the heat sterilization process depend on both the product and the size of the container. The two most common types of heat sterilizers (also called "retorts") in use today are continuous rotary sterilizers and hydrostatic sterilizers (Luh and York 1988). In continuous rotary sterilizers, containers are fed into a rotating (and often pressurized) cylindrical heat chamber, which is typically heated by steam. A mechanism inside the chamber rotates the containers about their own axes as they are heated while also transporting them along the length of the chamber. In hydrostatic sterilizers, containers are fed continuously through a steam chamber that is isolated by water columns at the chamber entrance and exit.

After heat sterilization, the containers are quickly subjected to **cooling** in order to prevent overcooking. Many rotary sterilizers are equipped with a cooling stage that can use pressurized air or water as the cooling medium. Stand alone container cooling units that use water sprays at ambient pressure for evaporative cooling are also sometimes employed. In hydrostatic sterilizers, containers are cooled by passing through a long trough of cooling water before exiting the system.

Aseptic canning is an alternative method of canning that is applicable to liquid and semi-liquid products (e.g., baby foods, soups, and tomato pastes). In aseptic canning, foods are sterilized and cooled separately before being filled into sterilized containers in a sterilized environment. Continuous heat exchangers are used to sterilize and cool products as they flow into an enclosed filling chamber, which is kept in a sterile condition via ultraviolet light and filtered air. Because containers are not required to withstand high sterilization temperatures, alternative (and often more economical) container materials are commonly used, such as laminated cardboard and plastics (Luh and York 1988; Fellows 2000).

3.1.3 Thermal Processes

In addition to blanching and heat sterilization, there are several other important unit processes employed in fruit and vegetable processing that are based on the application of heat. Among the most common thermal processes are evaporation, pasteurization, drying and dehydration, and frying.

In **evaporation**, heat is used to remove water contained in fruit and vegetable pulps and juices to produce a more concentrated product. Evaporation—which is sometimes referred to as concentration by boiling—is used most notably in the production of tomato purees, juices, and pastes, and fruit and vegetable juice concentrates. While there are many different types of evaporators, the two most common types found in modern food processing operations are falling film evaporators and forced circulation evaporators (Maroulis and Saravacos 2003).

In falling film evaporators, liquids fall by gravity down the inside surfaces of tubes arranged in a shell-and-tube heat exchanger configuration, with steam as the primary heating medium (Luh and Kean 1988). In forced circulation evaporators, liquids are circulated by a centrifugal pump at high velocity through a heat exchanger, which is also typically heated by steam (Maroulis and Saravacos 2003).

A common approach to energy efficiency for evaporators is to use the hot vapors that boil out of the liquid in one evaporator (or “effect”) as the heating medium in another effect, which is operated at a lower pressure. This approach is called “multi-effect” evaporation; in practice, up to five effects are feasible in evaporators in food processing (Maroulis and Saravacos 2003).

Pasteurization is a mild thermal treatment process used for liquids, such as fruit and vegetable juices, in which the liquids are heated to below 100° C for a sufficient amount of time to destroy pathogenic micro-organisms. Unlike heat sterilization, which destroys all micro-organisms, the pasteurization process does not kill heat-resistant micro-organisms. Thus, pasteurized products have a shorter shelf life than heat sterilized products and, in the case of pasteurized fruit and vegetable juices, must be refrigerated and consumed in a timely manner. Continuous pasteurization processes are most commonly used in fruit and vegetable processing. In the basic process, liquids flow through a heat exchanger, which can use either hot water or steam as the heating medium, where they are heated for the required residence time to kill pathogens. Common heat exchanger configurations include plate heat exchangers, tubular heat exchangers, shell and tube heat exchangers, and spiral heat exchangers (Maroulis and Saravacos 2003). After heating, liquids typically flow through a regenerator (another heat exchanger in which pasteurized liquids are cooled by preheating incoming unpasteurized liquids) and then to a cooling stage.

Drying and dehydrating processes preserve fruits and vegetables by removing moisture to retard or prevent the growth of micro-organisms. The oldest and most basic method is sun drying, in which fruits are harvested and spread out on tarps or trays to dry in the sun. This process is still used throughout the world for such fruits as grapes and figs (Somogyi and Luh 1986).

However, most fruits and vegetables are currently dried using heated drying equipment. Continuous belt driers are among the most common driers used in fruit and vegetable processing. In a continuous belt drier, products are carried on a meshed conveyor through a tunnel in which hot air is circulated. The air can be heated directly (via fuel combustion) or indirectly (using steam via a heat exchanger) and is circulated in the tunnel using blowers. Other common driers include spray driers, drum driers, vacuum driers, fluidized-bed driers, and belt-trough driers (Somogyi and Luh 1986, 1988; Maroulis and Saravacos 2003).

Frying is used primarily in the production of frozen fried products, most notably in the production of frozen French fried potatoes. In the basic continuous frying process, products are conveyed on a stainless steel mesh through a bath of hot oil, which can be heated using electricity, steam, or the combustion of fuels (Maroulis and Saravacos 2003). Foods that float are held down by a second conveyor. As the food exits the hot oil bath, the conveyor is inclined to allow excess oil to drain back into the bath.

3.1.4 Mechanical Separation Processes

Mechanical separation processes for fruits and vegetables generally involve the separation of liquids from liquids or liquids from solids using mechanical means, primarily in the manufacture of juice products and concentrates.

Mechanical **expression** is a widely used process for extracting fruit juices, in which high pressures are applied to fruits using a pressing action to rupture cell walls and express juices. Expression is typically done using batch presses or continuous presses. Common types of batch presses include basket presses, hydraulic plate presses, and tank presses. Many continuous presses are of the screw type, in which fruits are fed into a barrel with a rotating helical screw that increases pressure on the fruits as they are fed along its length (Fellows 2000; Luh et al. 1986).

The **centrifugation** process is used for separating pulps and small particles from juices, and can also be used for separating citrus oils from citrus juices. The basic component of a centrifuge is a rapidly rotating mechanism that exerts centrifugal force, which separates different juice constituents (e.g., juices, pulps, and oils) based on their densities (Fellows 2000). Centrifugation can also be used in the freeze concentration process, which is discussed below.

Membrane concentration can be applied to concentrate fruit and vegetable juices in lieu of or as a precursor to traditional evaporation methods of concentration. In membrane concentration, water can be separated from juice solids using pressure as a driving force across a semi-permeable membrane (Fellows 2000). Because membrane concentration does not require a phase change (in contrast to traditional evaporation methods), it can offer a more energy-efficient option of juice concentration.

3.1.5 Refrigeration and Freezing

Refrigeration systems are used throughout the U.S. fruit and vegetable processing industry to produce chilled water for process cooling, for refrigerated storage, and in product freezing applications. Some of the most common unit processes related to refrigeration and freezing used in fruit and vegetable processing are discussed below.

Cold storage involves the storage of products in refrigerated rooms and can be used at several stages of fruit and vegetable processing. After harvest, some fruits and vegetables (such as onions, potatoes, and apples) are placed in cold storage to delay ripening and to maintain quality so that processing seasons can be extended (Luh and York 1988; Prussia and Woodroof 1986). Cold storage is also used extensively for finished frozen products to keep them at the desired temperature prior to shipping. Also, some facilities (e.g., soup canneries) can use cold storage to keep purchased ingredients fresh until required for further processing.

In **freezing**, the temperature of fruits and vegetables is reduced to a level sufficient to retard microbial activity. The three major types of freezing processes used in fruit and vegetable processing are: (1) individual quick freezing, (2) freezing in the container, and (3) immersion in a freezing solution (Luh and York 1988; Fellows 2000). Individual quick frozen products are frozen before packaging using fluidized-bed or air-blast freezers, both of which rely on the circulation of chilled air. Products frozen in the container can be frozen using plate freezers, in which containers are sandwiched between two refrigerated plates, or air-blast freezers. In immersion freezers, packaged products are passed through a bath of refrigerant (typically propylene glycol, brine, glycerol, or calcium chloride) on a submerged mesh conveyor (Fellows 2000).

Freeze drying is a process for dehydrating vegetables and fruits using a combination of freezing and low pressure. In the freeze drying process, products are first frozen and then placed in a chamber under high vacuum. In the vacuum chamber, the water in the products is transformed directly from ice into the vapor phase and is condensed on refrigerated coils (Luh and York 1988). While freeze drying can produce dried fruits and vegetables with better color, odor, and flavor retention than traditional drying methods, the cost of freeze drying can be up to four times greater than traditional methods (Fellows 2000).

In **freeze concentration**, fruit juices are concentrated using a combination of freezing and mechanical separation. First, fruit juices are frozen to produce a slurry of frozen fruit liquids and ice crystals. Next, a separation device (such as a centrifuge or filter press) is used to separate the ice crystals from the fruit liquids. Freeze concentration is said to produce fruit juice concentrates without appreciable loss in taste, aroma, color, or nutritive value (Luh et al. 1986). However, the high capital and refrigeration costs associated with freeze concentration might make it attractive for only high-value juices and extracts (Fellows 2000).

3.1.6 Miscellaneous Processes

In addition to the major unit processes discussed above, unit processes related to product conveying, mechanical mixing, and packaging are also ubiquitous across the fruit and vegetable processing industry.

The **conveying** of fruits and vegetables throughout a facility can be done either mechanically or hydraulically, depending on the product form. For solid products, common forms of conveying include belt conveyors, flight conveyors, screw conveyors, bucket elevators, and water flumes. For liquid and slurry products, pumps and piping networks are the most common form of transport throughout a facility. For both solid and liquid products, surge bins and tanks are commonly used as surge buffers in the production system (Gould 1996).

Mechanical mixing processes are typically employed to blend ingredients and to homogenize product consistency at various stages of fruit and vegetable processing. Although there are many different types of mixing equipment, the most commonly used varieties in fruit and vegetable processing include flat blade agitators, vaned disc impellers, and propeller agitators (Fellows 2000).

The unit processes related to **packaging** generally include automated operations for can labeling, shipping box assembly, shipping box packing, palletizing, and pallet shrink wrapping. Packaging processes are generally powered using a combination of electric motors, solenoids, and compressed air actuators.

3.2 Process Flow Diagrams

This section presents representative process flow diagrams for six key product categories produced by the U.S. fruit and vegetable processing industry: (1) canned fruits and vegetables (2) canned tomato products, (3) canned fruit juice, (4) frozen fruits and vegetables, (5) frozen concentrated fruit juice, and (6) dried and dehydrated fruits and vegetables. While not inclusive of all processes employed and all products manufactured by the industry, Figures 3.1 through 3.6 include the major process steps for many of the industry's most significant outputs from a value of product shipments perspective (see Appendix A). The process flows depicted in Figures 3.1 through 3.6 are meant to be representative of the process sequences employed at typical U.S. fruit and vegetable processing facilities, but might not be representative of the exact process flows at any individual plant.[6]

3.2.1 Fruit and Vegetable Canning

The typical processes employed in fruit and vegetable canning are depicted in Figure 3.1. For both fruits and vegetables, inspection, grading, and washing are generally the first processing steps. Vegetables are then typically peeled if needed, subjected to size reduction to obtain the proper form, and blanched to inactivate enzymes. Immediately after blanching, vegetables are typically cooled in a water bath to prevent overcooking. For some vegetables, a heated brine solution is added at the filling stage, which generally consists of salt, sugar, and water. After washing, fruits may be cored and/or peeled, depending on the variety, and washed again to remove peeling residues. Fruits are then subjected to size reduction to obtain the desired form. Some canned fruit products, such as applesauce, are then cooked. Heated syrup or fruit juice is often added to fruits at the filling stage. After filling, the canned fruits and vegetables are exhausted, sealed, sterilized, and cooled before proceeding to final packaging operations.

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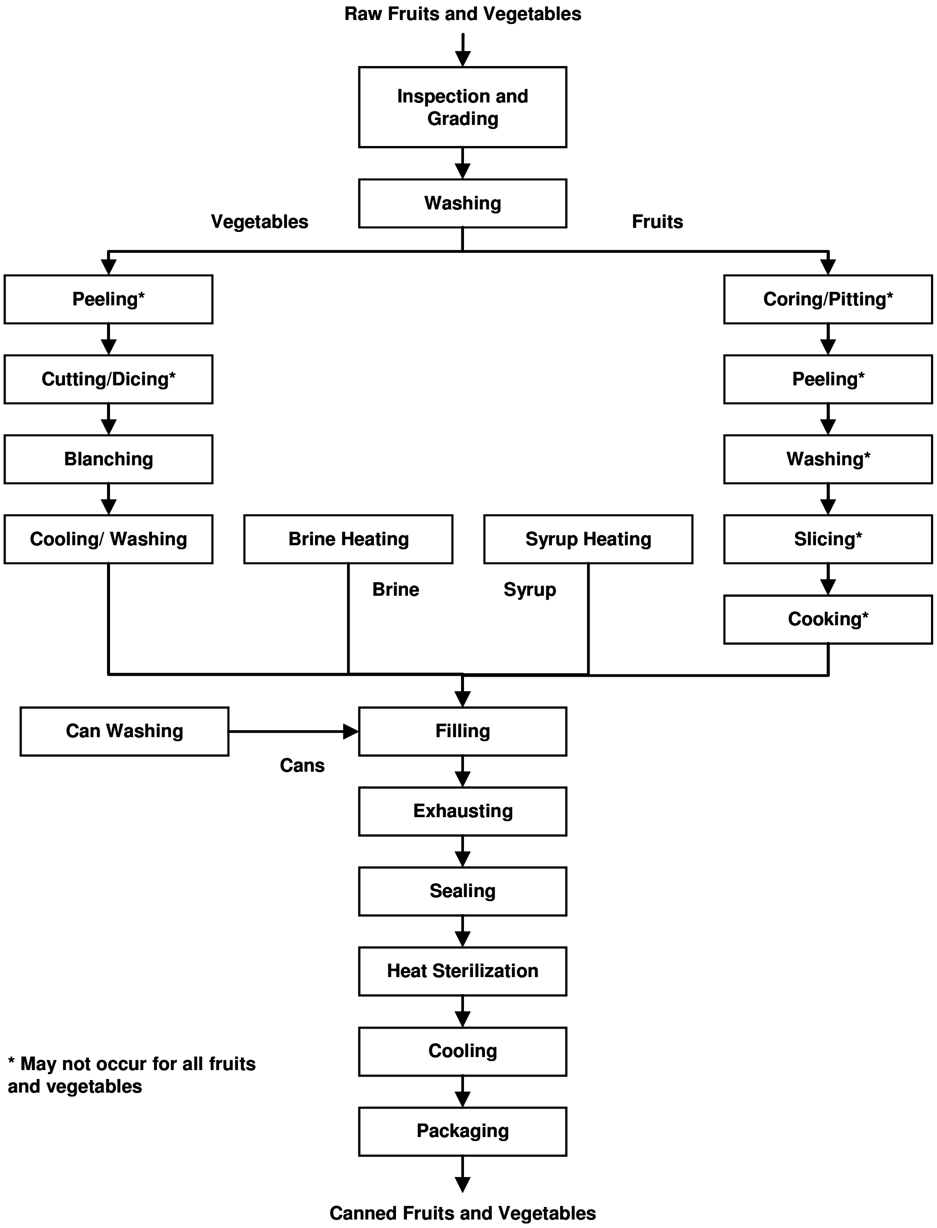
[6] The process flows depicted in Figures 3.1 through 3.6 were derived from information and process flow diagrams obtained from the following sources: Sikirica et al. (2003), U.S. EPA (1995a. 1995b), Brown et al. (1996), Singh (1986a, 1986b), Luh, Kean, and Woodroof (1986), Luh and Kean (1988), Luh et al. (1986), Kale and Adsule (1995), and Somogyi and Luh (1986, 1988).

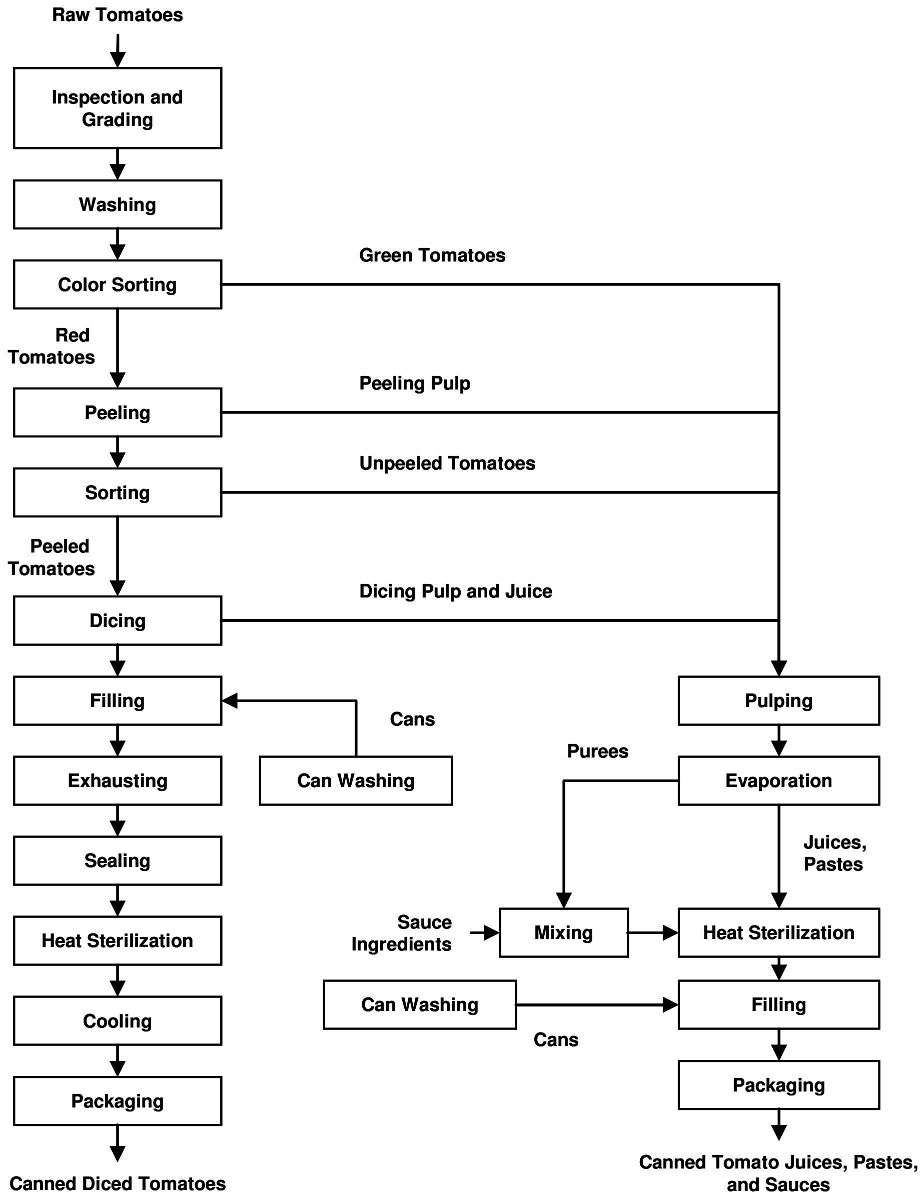
Figure 3.1: Process diagram for fruit and vegetable canning



3.2.2 Tomato Product Canning

Figure 3.2 depicts representative process flows for the combined manufacture of canned diced tomatoes and canned tomato juices, pastes, and sauces. After inspection and grading, tomatoes are typically washed in a series of agitated water flumes. Next, color sorting is done either manually or automatically to remove green tomatoes, which are subsequently sent to pulping. The red tomatoes are then subjected to steam peeling, followed by manual sorting to remove tomatoes that have not been sufficiently peeled, which are also sent to pulping. Peeled red tomatoes are then diced and filled into cans using rotary brush fillers.

Figure 3.2: Process diagram for tomato product canning

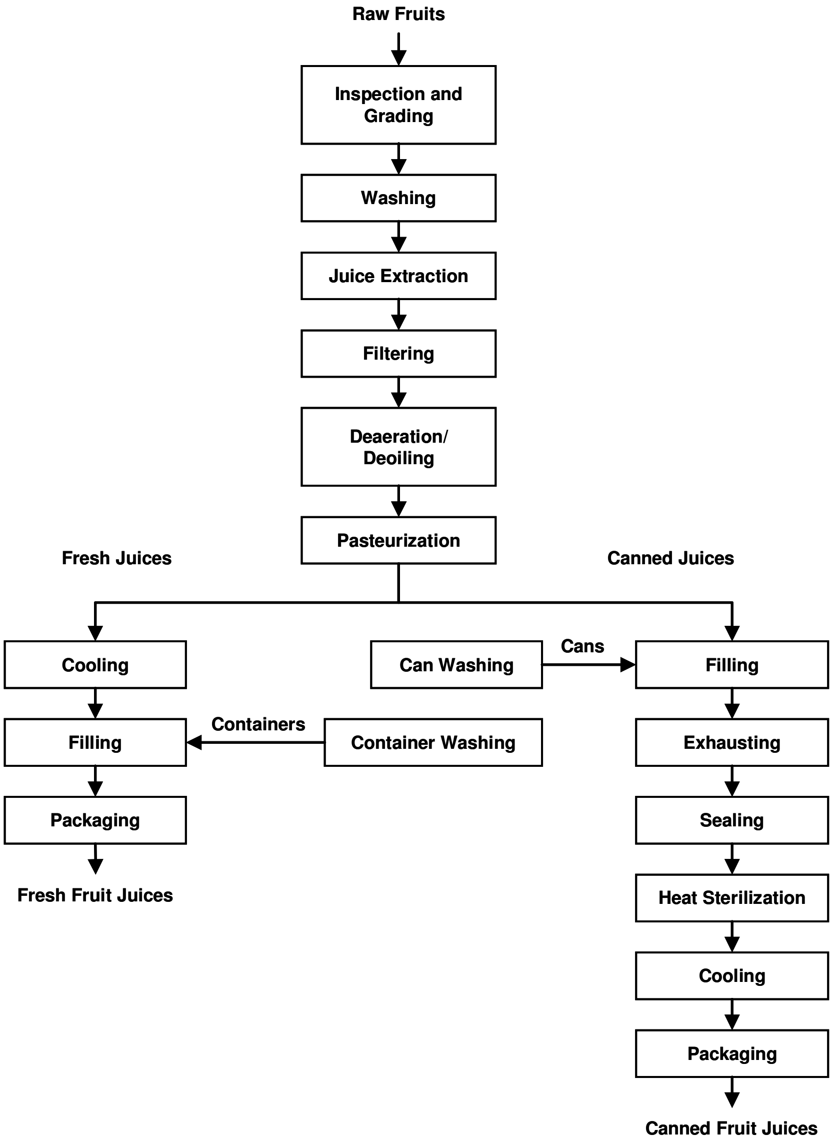


The canned diced tomatoes are then exhausted, sealed, sterilized, and cooled before proceeding to final packaging operations. The pulper is used to crush green and unpeeled tomatoes as well as pulping waste from the dicer. After pulping, the tomato slurry proceeds to the evaporator for concentration into juice, puree, and paste (the final product is solely dependent on the remaining moisture content after evaporation). Tomato purees are then typically mixed with other ingredients to create tomato sauce. Prior to filling, evaporated tomato products undergo continuous sterilization. Once filled the canned tomato juices, pastes, and sauces are sent to final packaging operations.

3.2.3 Fruit Juice Canning

The typical processing steps involved in fruit juice canning are depicted in Figure 3.3. After inspection, grading, and washing, juices are extracted from the fruits using mechanical expression or extraction methods. The juice is then often filtered to remove unwanted pulp, deaerated to remove excess oxygen, and deoiled. Next, the juice is pasteurized in a continuous fashion. For fresh juice manufacture, the pasteurized juice is immediately cooled and filled into a container before proceeding to final packaging operations. For canned juice manufacture, the pasteurized juice is hot filled into a container, which is subsequently exhausted, sealed, sterilized, and cooled before proceeding to final packaging operations.

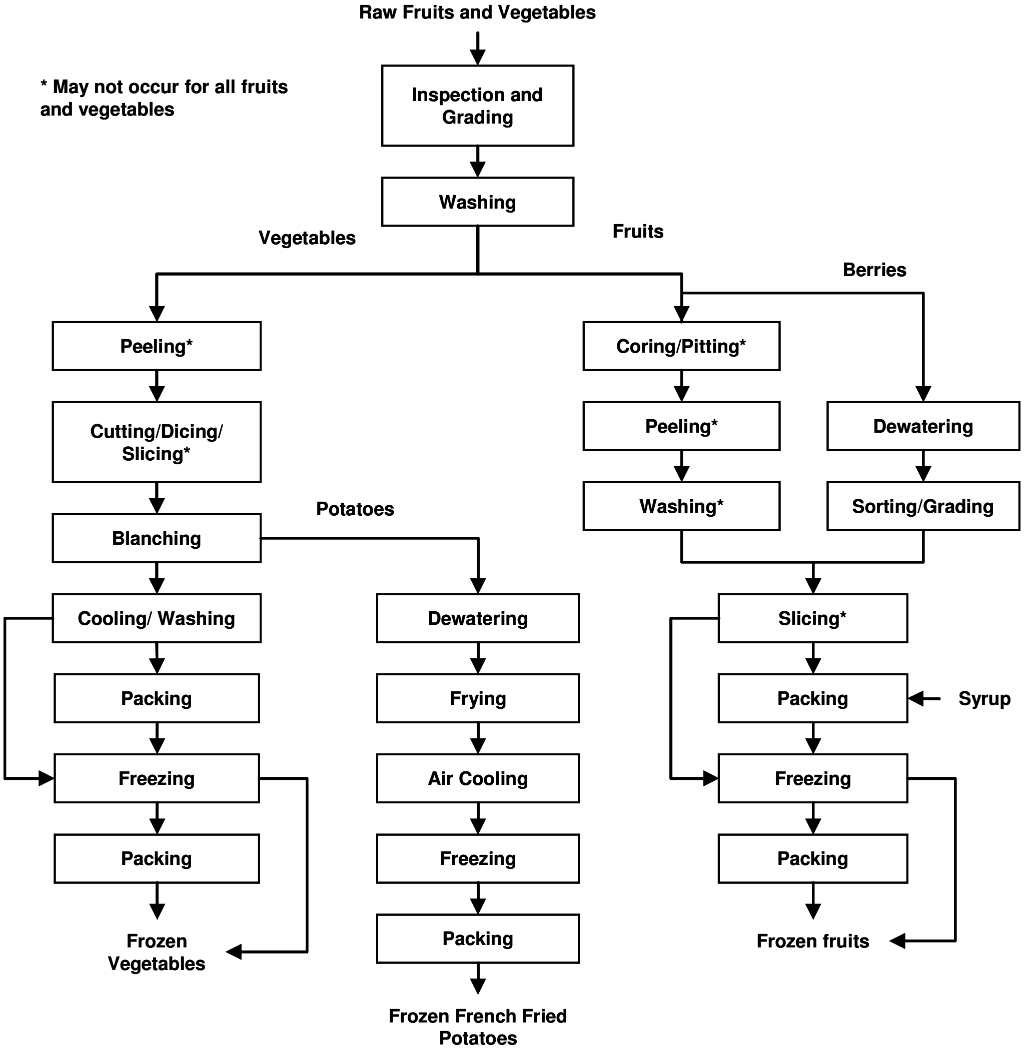
Figure 3.3: Process diagram for fruit juice canning



3.2.4 Fruit and Vegetable Freezing

Figure 3.4 depicts the typical process steps in the manufacture of frozen fruit and vegetable products, including frozen French fried potatoes. For vegetables, the process flow prior to freezing is similar to that for canned vegetables (see Figure 3.1). Vegetables can either be frozen prior to packaging, using fluidized-bed or air-blast freezers, or packed and frozen in the container. After blanching, potato strips are typically dewatered using screens and warm air blowers prior to frying. The fried potato strips are then air cooled as they proceed to the freezing tunnel. Once frozen, the fried potato strips are packed in plastic bags. For fruits besides berries, the process flow prior to freezing is similar to that for canned fruits. For berries, the next steps after washing are typically dewatering, sorting, and grading. Fruits and berries can either be frozen prior to packaging or after packaging.

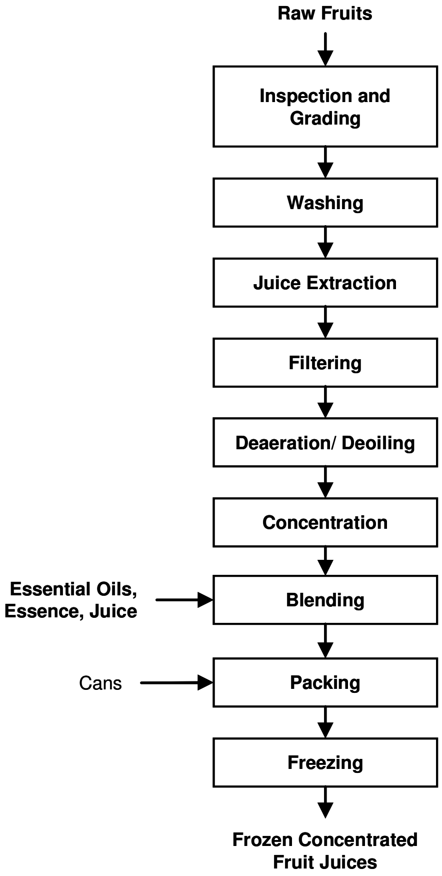
Figure 3.4: Process diagram for fruit and vegetable freezing



3.2.5 Frozen Concentrated Fruit Juice Manufacture

Figure 3.5 depicts the typical process flow for frozen concentrated juice manufacture. Processes prior to concentration are similar to that of fruit juice canning (see Figure 3.3). After deaeration and deoiling, fruit juices are concentrated, which can be done by using evaporation and/or membrane concentration or by using freeze concentration, depending on the facility. For evaporated concentrates, essential oils and/or fresh juice are then blended in to enhance flavor. The concentrates are then packed into containers, sealed, and frozen.

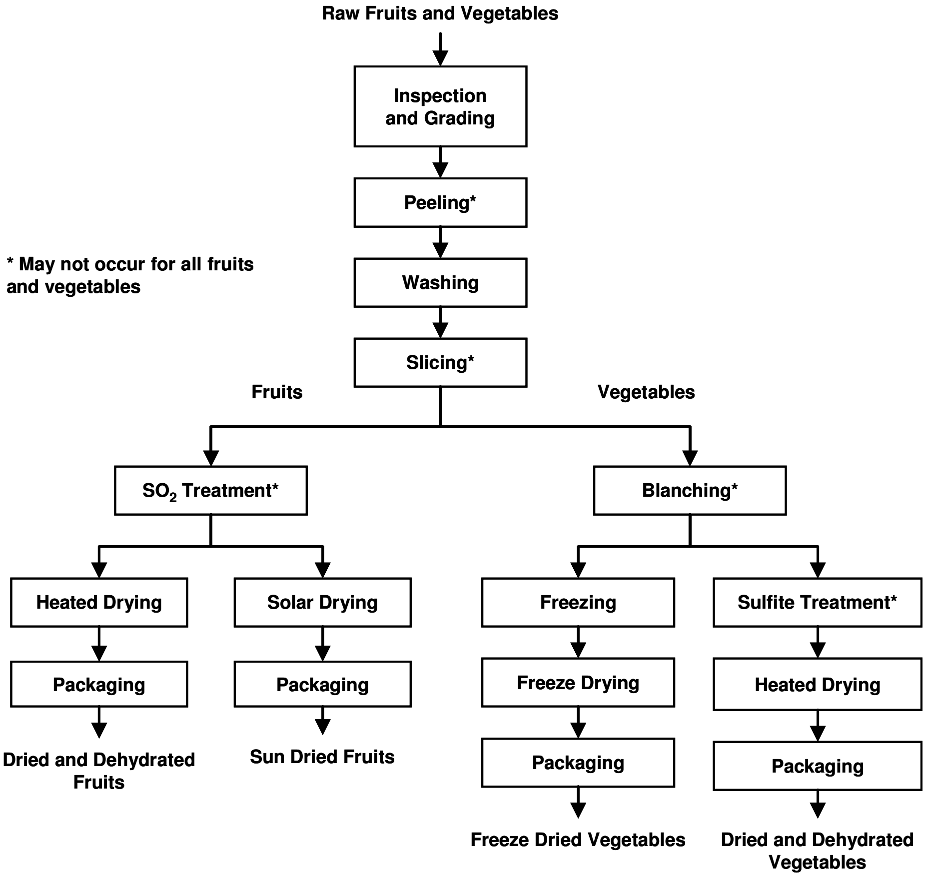
Figure 3.5: Process diagram for frozen concentrated fruit juice manufacture



3.2.6 Dried and Dehydrated Fruit and Vegetable Manufacture

The typical processing steps involved in dried and dehydrated fruit and vegetable manufacture are depicted in Figure 3.6. Incoming fruits and vegetables are generally inspected, graded, and washed. Depending on the desired final form, some fruits and vegetables are also sliced subsequent to washing. Fruits are then typically subjected to fumes of sulfur dioxide (SO_2), which helps to retard browning. For fruits that undergo solar drying, such as raisins, prunes, and figs, fruits are laid out on trays or tarps in the sunlight until the desired moisture content is reached. Other fruits undergo heated drying treatments as discussed in Section 3.1. Most vegetables are blanched prior to drying to inactive enzymatic activity. Freeze dried vegetables are then frozen and subjected to vacuum until the desired moisture content is reached. For vegetables that are dried using heated dryers, they are often subjected to a sulfite solution to retard browning.

Figure 3.6: Process diagram for dried and dehydrated fruit and vegetable manufacture



4 Energy Use in the U.S. Fruit and Vegetable Processing Industry

Energy represents a significant operating cost to the U.S. fruit and vegetable processing industry. In 2002, the industry spent nearly $810 million on purchased fuels and electricity, or roughly 4.5% of the industry's total cost of materials (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d).[7] Of this, $370 million was spent on purchased electricity and $440 million was spent on purchased fuels (primarily natural gas).

Electricity is used throughout the typical fruit and vegetable processing facility to power motors, conveyors, compressed air systems, and pumps, as well as building lighting and heating, ventilation, and air conditioning (HVAC) systems (Singh and Heldman 2001). Another major end use of electricity in the industry is refrigeration, which is used for process cooling, cold storage, and freezing applications. For all end uses, the U.S. fruit and vegetable processing industry consumed a total of 6.7 terawatt-hours (TWh) of electricity in 2002, or nearly 10% of the electricity consumed by the entire U.S. food industry (NAICS 311) (U.S. Census Bureau 2005e).

The major end use of fuels in the typical fruit and vegetable processing facility is in boiler systems for the generation of steam, which can be used in a wide variety of process heating, water heating, and cleaning applications (Singh and Heldman 2001). Fuels can also be used for direct-fired process heating as well as for air heating in building HVAC systems. Although coal, residual oil, and distillate oils are sometimes used as fuels (primarily in boilers), currently natural gas accounts for over 90% of all fuels consumed by the U.S. fruit and vegetable processing industry (U.S. DOE 1997a, 2005). Thus, in discussions of both the end uses of fuels and the energy efficiency opportunities available for fuels in U.S. facilities, the remainder of this Energy Guide focuses exclusively on natural gas.

4.1 Energy Expenditures

Figure 4.1 plots the costs of purchased electricity and fuels in the U.S. fruit and vegetable processing industry from 1997-2002 (U.S. Census Bureau 2003, 2004a, 2004b, 2004c, 2004d).[8] Energy expenditures remained fairly steady until 2001, when expenditures on purchased fuels rose dramatically due to the well-documented winter 2001 spike in natural gas prices across the United States (CEC 2003). Due in part to a combination of strong winter demand for natural gas and constrained national supply, the price for natural gas more than doubled in many parts of the United States for the first half of 2001 (CEC 2002a). As a direct result, between 2000 and 2001 the costs of fuels purchased by the U.S. fruit and

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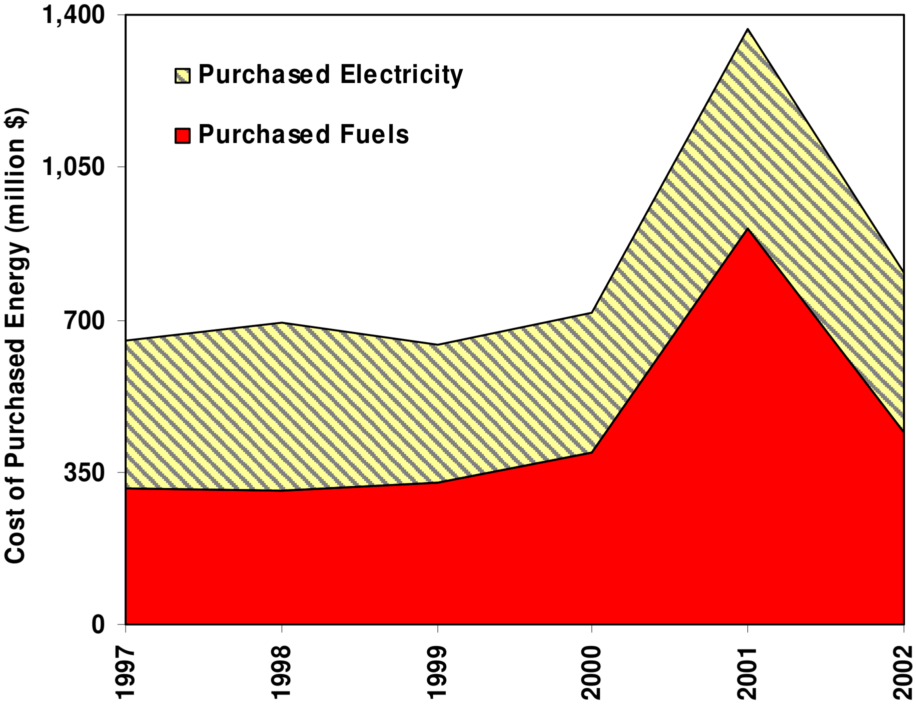
[7] Due to changes in the way sector-level data are reported by the U.S. Census Bureau in its 2003 and 2004 Annual Survey of Manufactures, 2002 is the most recent year for which energy purchase data are available for the U.S. fruit and vegetable processing industry sub-sectors considered in this Energy Guide.

[8] Prior to 1997, U.S. industry energy expenditure data were reported by Standard Industry Classification (SIC) code in the U.S. Census Bureau's Annual Survey of Manufactures. From 1997 onward, however, U.S. industry energy expenditure data are being reported by NAICS code. Because there are disagreements in the products included in the SIC and NAICS codes of the U.S. fruit and vegetable processing industry sub-sectors considered in this Energy Guide, it is not possible to construct a reliable time series of industry energy expenditures prior to 1997.

vegetable processing industry increased by over 130% (from $393 million to $907 million). Over the same period, the cost of electricity purchased by the industry also rose by nearly 45% (from $323 million to $462 million) due to the widespread use of natural gas in U.S. electricity generation. The data in Figure 4.1 demonstrate the negative economic impacts that energy price volatility can have on the U.S. fruit and vegetable processing industry. These data also underscore the importance of energy efficiency as a means of reducing the industry's susceptibility to volatile and rising energy prices.

Figure 4.1: Cost of purchased fuels and electricity in the U.S. fruit and vegetable processing industry, 1997-2002

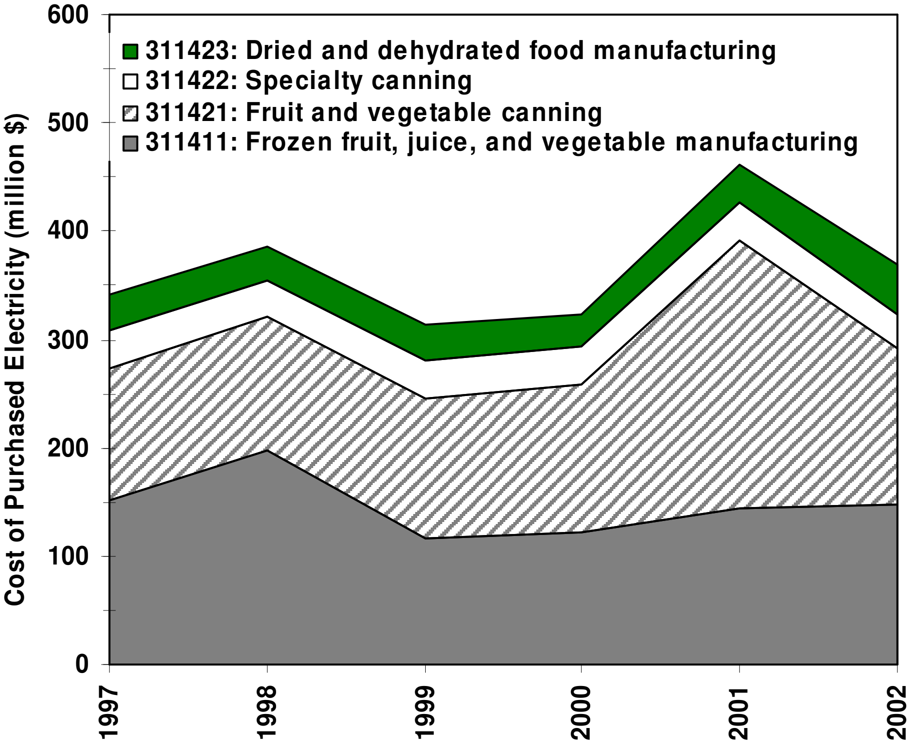


Sources: U.S. Census Bureau (2003, 2004a, 2004b, 2004c, 2004d)

Figures 4.2 and 4.3 provide breakdowns of expenditures on electricity and fuels, respectively, by industry sub-sector between 1997 and 2002 (U.S. Census Bureau 2003, 2004a, 2004b, 2004c, 2004d). The largest purchasers of electricity in the industry are the frozen fruit, juice, and vegetable manufacturing sub-sector and the fruit and vegetable canning sub-sector. These two sub-sectors accounted for nearly 80% of all purchased electricity in 2002.

The fruit and vegetable canning sub-sector is the largest purchaser of fuel in the industry, accounting for nearly 45% of all fuel purchases in 2002. The frozen fruit, juice, and vegetable manufacturing sub-sector accounted for roughly 30% of all fuel purchases in 2002.

Figure 4.2: Cost of purchased electricity by U.S. fruit and vegetable processing industry sub-sector, 1997-2002



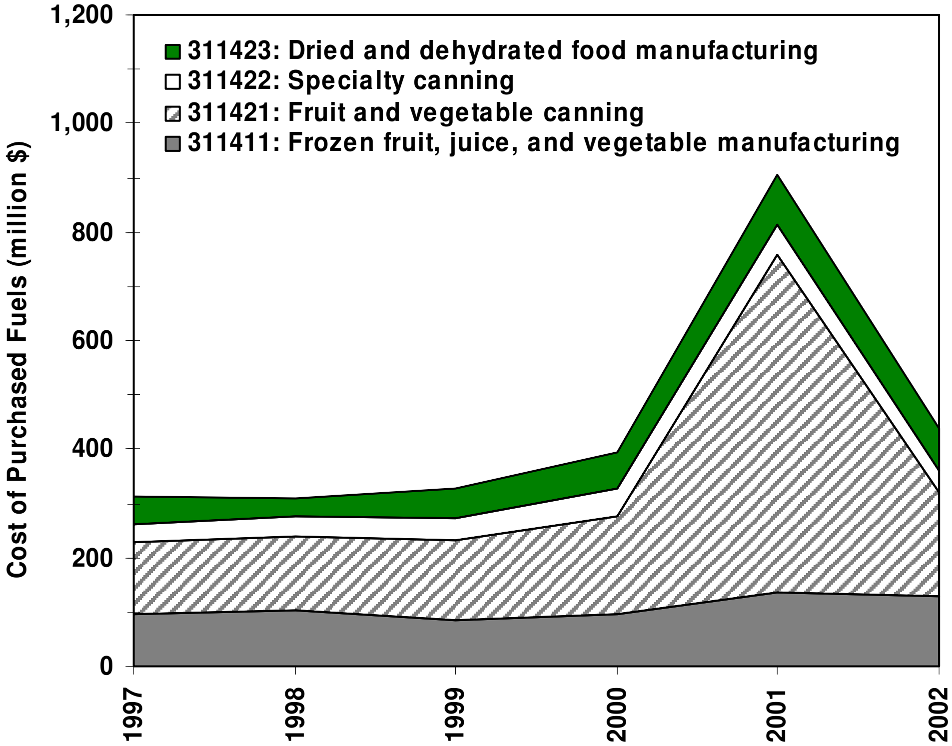
Sources: U.S. Census Bureau (2003, 2004a, 2004b, 2004c, 2004d)

Figures 4.2 and 4.3 also show that the 2001 spike in both electricity and fuel expenditures occurred mostly in the fruit and vegetable canning sub-sector. This phenomenon is likely attributable to the particularly sharp rise in 2001 natural gas and electricity costs in the Pacific Coast states where many canneries are located. For example, in California—a state with one fifth of the nation's fruit and vegetable canneries (U.S. Census 2004b)—the price of industrial natural gas rose from around $4 per thousand cubic feet in late 1999 to as high as $11 per thousand cubic feet in 2001 (CEC 2002a).

Since 2002, the costs of industrial natural gas and electricity have continued to rise across the United States, adding to the economic pressures on the U.S. fruit and vegetable processing industry. Nationwide, the average industrial price for natural rose from around $4.00 per thousand cubic feet in 2002 to nearly $8.50 per thousand cubic feet in 2005 (U.S. DOE 2006a). In California, the average industrial natural gas price was even higher in 2005 at $9.89 per thousand cubic feet.

Similarly, the average industrial price for electricity rose from 4.91 cents per kilowatt-hour (kWh) in 2002 to 5.57 cents per kWh in 2005; in California, the 2005 price for industrial electricity averaged 7.62 cents per kWh (U.S. DOE 2006b). Given the increases in industrial natural gas and electricity prices in the United States since 2002, the need for improved energy management and energy efficiency in the U.S. fruit and vegetable processing industry is perhaps stronger now than ever.

Figure 4.3: Cost of purchased fuels by U.S. fruit and vegetable processing industry sub-sector, 1997-2002



Sources: U.S. Census Bureau (2003, 2004a, 2004b, 2004c, 2004d)

4.2 Energy Consumption and End Uses

In 2002, the U.S. fruit and vegetable processing industry consumed around 6.7 TWh of electricity, which equates to roughly 23 trillion Btu (TBtu) of final (i.e., site) energy (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d).[9] The frozen fruit, juice, and vegetable manufacturing sub-sector was the industry's largest consumer of electricity—due in large part to its extensive use of electricity for refrigeration—accounting for roughly 45% (9.9 TBtu) of the total electricity consumed by the industry in 2002. The fruit and vegetable canning sub-sector was the next largest user of electricity (8.5 TBtu), followed by the dried and dehydrated food sub-sector (2.4 TBtu) and the specialty canning sub-sector (2.1 TBtu). At least half of the industry's electricity was expected to be consumed in the Western United States (primarily in California, Oregon, Washington, and Idaho) (U.S. DOE 1997a).[10]

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[9] A standard conversion factor of 3,412 Btu/kWh was used. Final energy, also called site or point-of-use energy, does not include the energy losses associated with electricity generation and distribution.

[10] As of 1994, the latest year for which such data are available, around 60% of the electricity consumption in the frozen fruit, juice, and vegetable manufacturing and fruit and vegetable canning sub-sectors occurred in the U.S. West Census Region (U.S. DOE 1997).

The use of on-site electricity generation appears to be quite limited in the U.S. fruit and vegetable processing industry. In 2002, only 5% of the industry's electricity was generated at individual facilities (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d). The use of on-site generation was confined almost exclusively to the fruit and vegetable canning sub-sector, where the extensive use of steam in blanching, evaporating, pasteurizing, and sterilizing applications makes combined heat and power (CHP) systems particularly attractive.

The U.S. fruit and vegetable processing industry consumed an estimated 78 TBtu of natural gas in 2002.[11] The fruit and vegetable canning sub-sector was the industry's largest consumer of natural gas, accounting for nearly one half (36 TBtu) of all industry natural gas consumption in 2002 (U.S. DOE 2005a). The frozen fruit, juice, and vegetable manufacturing sub-sector was the next largest user of natural gas, consuming an estimated 21 TBtu of natural gas in 2002, followed by the dried and dehydrated foods manufacturing sub-sector (13 TBtu) and the specialty canning sub-sector (8 TBtu).[12] At least one half of the industry's natural gas was expected to be consumed in the Western United States (primarily in California, Oregon, Washington, and Idaho) (U.S. DOE 1997a).[13]

Table 4.1 summarizes the electricity and natural gas use of the U.S. fruit and vegetable processing industry. In total, the industry consumed an estimated 101 TBtu of final (i.e., site) energy in 2002. Combined, the fruit and vegetable canning sub-sector and frozen fruit, juice, and vegetable manufacturing sub-sector accounted for around 75% of the industry's total final energy use. Figures 4.4 and 4.5 depict the end uses of energy in these two important sub-sectors.

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[11] Publicly-available data are scarce on the annual natural gas consumption, in physical units, of the four U.S. fruit and vegetable processing industry sub-sectors considered in this Energy Guide. Therefore, this consumption figure is an estimate, which was derived using the following procedure: First, it was assumed that 90% ($395 million) of the industry's 2002 total fuel expenditures ($440 million) was attributable to natural gas purchases, based on natural gas expenditure data from the U.S. DOE's 2002 Manufacturing Energy Consumption Survey (U.S. DOE 2005a). Next, a weighted average 2002 U.S. industrial natural gas price of $5.13 per MBtu was assumed. This weighted average was derived by multiplying the average 2002 industrial natural gas price for each U.S. state (U.S. DOE 2006a) by each state's share of total 2002 value added for the industry (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d) and summing the results. Finally, the estimated 2002 natural gas expenditures ($395 million) were divided by the estimated average U.S. natural gas price ($5.13 per MBtu) to arrive at the estimate of 77 TBtu of natural gas consumed by the industry in 2002. While only an approximation, this estimate is expected to be reasonably accurate for the purposes of the general discussion of energy use presented in this Energy Guide.

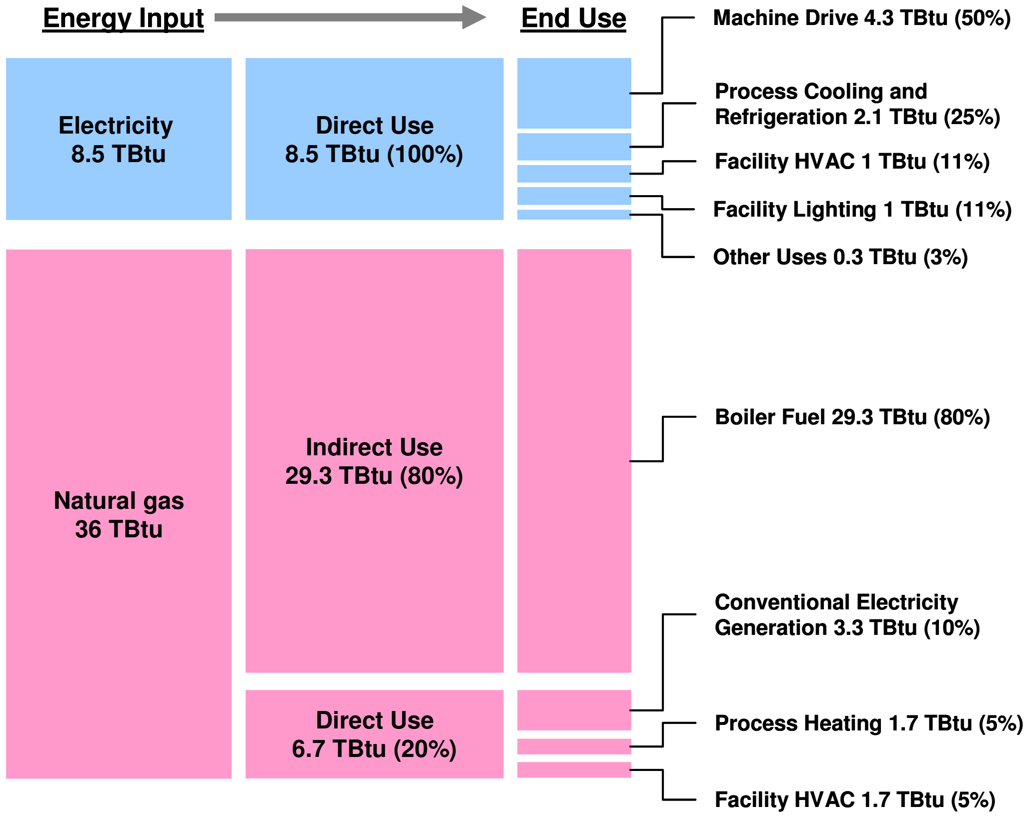
[12] These three figures are also estimates, derived using the calculation procedure outlined in footnote 8.

[13] As of 1994, the latest year for which such data are available, around 60% of the natural gas consumption in the frozen fruit, juice, and vegetable manufacturing and fruit and vegetable canning sub-sectors occurred in the U.S. West Census Region (U.S. DOE 1997).

Table 4.1: Energy use of the U.S. fruit and vegetable processing industry, 2002

Sub-Sector	NAICS Code	Electricity Use (TBtu)	Natural Gas Use (TBtu)	Total (TBtu)	% of Industry Total
Frozen fruit, juice & vegetable manufacturing	311411	9.9	21	30.9	31%
Fruit and vegetable canning	311421	8.5	36	44.5	44%
Specialty canning	311422	2.1	8	10.1	10%
Dried & dehydrated food manufacturing	311423	2.4	13	15.4	15%
Industry Total		22.9	78	100.9	

Figure 4.4: Estimated energy consumption and end uses in the fruit and vegetable canning sub-sector, 2002

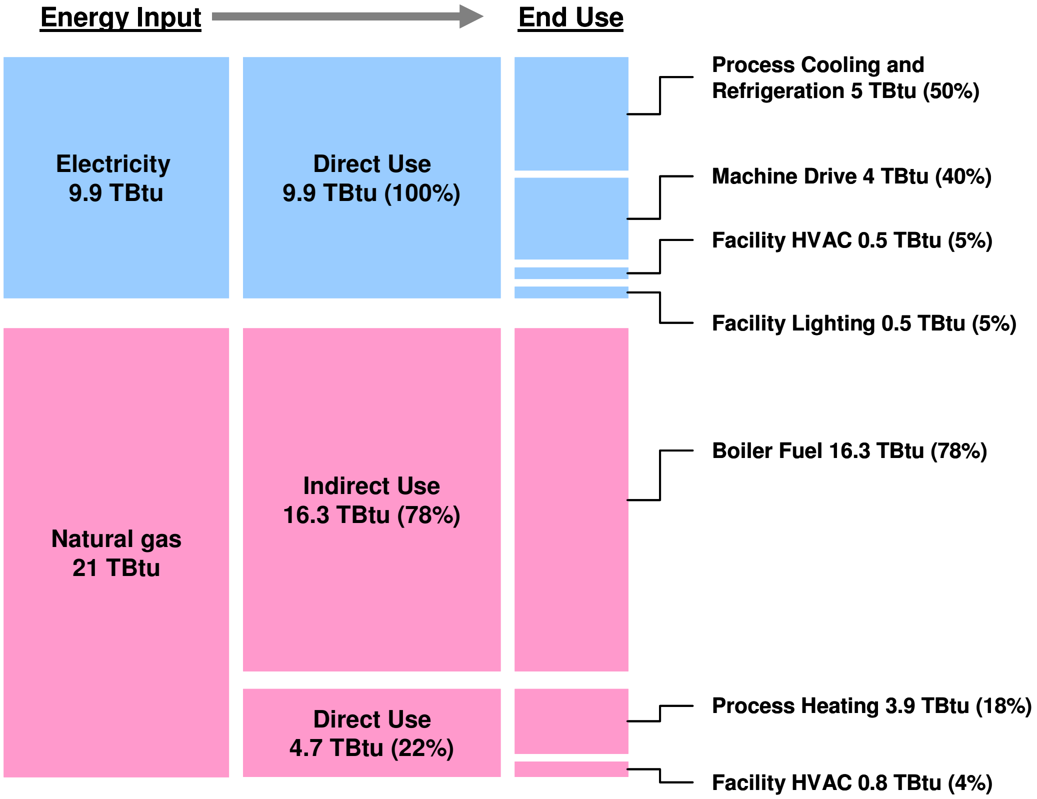


Sources: Estimated using data in U.S. DOE (1997, 2005, 2006a) and U.S. Census Bureau (2004b)

Figure 4.4 provides an illustrated breakdown of energy sources and end uses in the fruit and vegetable canning sub-sector in 2002, based on energy end use data for U.S. fruit and vegetable canneries obtained from the U.S. DOE's Manufacturing Energy Consumption

Survey (MECS) (U.S. DOE 1997a, 2005).[14] Natural gas represented the most significant form of energy used in fruit and vegetable canneries. Most of the natural gas (80%) was used indirectly as boiler fuel to generate steam for use in blanchers, evaporators, sterilizers, and other steam-based applications. Electricity represented roughly 20% of all site energy use in the sub-sector. Around one half of all electricity use was for machine drives, while one quarter of electricity use was for process cooling and refrigeration.

Figure 4.5: Estimated energy consumption and end uses in the frozen fruit, juice, and vegetable manufacturing sub-sector, 2002



Sources: Estimated using data in U.S. DOE (1997, 2006a) and U.S. Census Bureau (2004a)

Figure 4.5 provides an illustrated breakdown of energy sources and end uses in the frozen fruit, juice, and vegetable manufacturing sub-sector in 2002, based on MECS sub-sector energy end use data (U.S. DOE 1997a).[15] As in canneries, natural gas represented the most significant use of energy in frozen fruit, juice, and vegetable manufacturing plants. Most of the natural gas (78%) was used indirectly as boiler fuel. Electricity represented roughly one third of all site energy consumed in the sub-sector. Around one half of all electricity use was for process cooling and refrigeration.

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[14] The energy end use breakdown in Figure 4.4 is estimated using data from both the 1994 MECS (SIC 2033 basis) and 2002 MECS (NAICS 311421 basis).

[15] The energy end use breakdown in Figure 4.5 is estimated using data from the 1994 MECS (SIC 2037 basis).

4.3 Process Energy Intensities

Tables 4.2 through 4.7 provide process energy intensity data for several key types of products manufactured by the U.S. fruit and vegetable processing industry. These data are meant to provide a representative breakdown of processing steps and process energy use in typical U.S. facilities; however, they might not be representative of operating conditions at any single facility. Where applicable, each figure provides process energy intensity data (in Btu/lb of product output) for steam, hot water, electricity, and direct fuel as well as total process energy intensity.[16] For ease of data interpretation, the relative magnitudes of the total process energy intensities in each figure are illustrated graphically via a bar graph (not to scale) in the rightmost column.

Table 4.2 provides process energy intensity data for key processes used in fruit and vegetable canning. Steam accounts for the majority of energy use in the typical fruit and vegetable cannery. Most steam use can be attributed to a few key processes (most significantly heat sterilization, blanching, and cooking). Thus, the most fruitful energy efficiency efforts at canneries are likely to be directed at these key steam-based processes.

Table 4.2: Representative process energy intensities in fruit and vegetable canning

Process	Process Energy Intensity (Btu/lb)			
	Steam	Hot Water	Electricity	Total
Inspection and grading			5	5
Washing		217	7	224
Cutting and slicing			12	12
Blanching	200			200
Peeling			7	7
Pulping			7	7
Cooking	200			200
Brine heating	100			100
Cooling and washing			7	7
Can washing		43		43
Can filling			10	10
Can exhausting	100			100
Can sealing	33		10	43
Heat sterilization (retort)	217			217
Cooling			7	7
Packaging			15	15

Source: Singh (1986b)

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[16] Electricity energy intensity data are expressed in units of final (i.e., site) energy.

The energy consumed by steam-based processes at individual canneries depends heavily on the type of equipment employed, the product(s) manufactured, and equipment configurations. For example, steam blanchers have been reported to consume anywhere from 0.37 kg steam/kg product (for efficient models with hydrostatic seals) to 0.94 kg steam/kg product (for conveyor blanchers without end seals). Water blanchers have been reported to consume anywhere from 0.22 kg steam/kg product (for tubular blanchers) to 0.52 kg steam/kg product (for tank blanchers) (Rumsey 1986a).

Another major consumer of energy is the washing of incoming fruits and vegetables, which, depending on the facility, can use either hot water or ambient water and generally involves a high degree of mechanical agitation. For washing systems that use hot water, water efficiency measures and measures for recovering energy from hot water can be key strategies for reducing process energy consumption. For further details on water efficiency, see Chapter 15 of this Energy Guide.

Table 4.3 shows energy intensity data for key processes used in juice canning. The two washing operations—incoming product washing and container washing—are seen to be the most energy-intensive processes involved, together consuming 434 Btu/lb of hot water. Thus, as for fruit and vegetable canning, water efficiency and heat recovery are likely to be key energy saving strategies in juice canning. The pasteurization process is the most significant consumer of steam, followed by the heat sterilization process.

Tables 4.2 and 4.3 suggest that for most canneries, steam and hot water represent by far the most dominant uses of process energy in the facility, while process electricity use (although critical in many processes) is generally of lesser significance.

Table 4.3: Representative process energy intensities in juice canning

Process	Process Energy Intensity (Btu/lb)			
	Steam	Hot Water	Electricity	Total
Inspection and grading			7	7
Washing		217	7	224
Pulping/extraction			12	12
Vacuum deaeration			13	13
Pasteurization	133			133
Can washing		217		217
Hot can filling			7	7
Can sealing	33		8	41
Heat sterilization (retort)	100			100
Cooling			7	7
Packaging			13	13

Source: Brown et al (1996)

Representative process energy intensities for frozen fruit manufacture are provided in Table 4.4. As for canneries, the processes of washing and blanching are likely to be the largest consumers of steam in a typical fruit freezing facility. However, unlike canneries, it can be seen that electricity use is as significant as steam use in the facility, primarily due to the electricity intensity of the freezing process. While the energy intensity of freezing at individual plants can vary widely based on the technology employed—typical energy intensity values for freezing technologies range from 250 Btu/lb to 1,750 Btu/lb (Sikirica et al. 2003)—in general, freezing will be the most energy intensive operation in fruit freezing facilities by a significant margin.

Table 4.4: Representative process energy intensities in frozen fruit manufacture

Process	Process Energy Intensity (Btu/lb)		
	Steam	Electricity	Total
Inspection and grading		7	7
Washing	183	7	190
Peeling	70	7	77
Washing	183	7	190
Slicing		12	12
Blanching	159		159
Packing		3	3
Freezing		586	586
Packaging		15	15

Source: Sikirica et al. (2003)

Similarly, the freezing process is the most energy intensive operation in the manufacture of frozen French fried potatoes, as can be seen in Table 4.5. After freezing, the next largest consumer of energy in frozen French fried potato manufacture is typically the frying process, which consumes a significant amount of direct fuel (primarily natural gas) to heat the frying oil.

Table 4.6 provides representative process energy intensity data for the manufacture of frozen concentrated citrus juice, one of the most significant product outputs of the U.S. fruit and vegetable processing industry (see Appendix A). As in fruit freezing facilities, the freezing process accounts for the largest share of electricity use in frozen concentrated juice manufacturing facilities. However, the concentration process is the most energy intensive process by a significant margin, consuming an estimated 900 Btu of steam per pound of citrus juice concentrate. Thus, in addition to freezing, the concentration process is likely to be one of the most attractive opportunities for energy efficiency in the typical frozen concentrated juice facility.

Table 4.5: Representative process energy intensities in frozen potato manufacture

Process	Process Energy Intensity (Btu/lb)			
	Steam	Fuel	Electricity	Total
Grading			5	5
Washing	173		6	179
Peeling			6	6
Slicing			11	11
Blanching	160			160
Frying		325		325
Cooling			6	6
Freezing			586	586
Packaging			15	15

Source: Sikirica et al. (2003)

Table 4.6: Representative process energy intensities in frozen concentrated citrus juice manufacture

Process	Process Energy Intensity (Btu/lb)		
	Steam	Electricity	Total
Sorting		54	54
Washing	183	54	237
Extraction		16	16
Deaeration		52	52
Concentration	900		900
Blending		33	217
Can filling		35	7
Blast freezing		565	565

Sources: Estimated using data from Sikirica et al. (2003) and Singh (1986b)

Lastly, representative process energy intensity data for dehydrated mashed potato manufacture are provided in Table 4.7. Peeling, precooking, and cooking are estimated to be very energy intensive processes. However, the most energy intensive process by far is the drum drying process, which consumes an estimated 6,000 Btu of steam per pound of dehydrated mashed potatoes. In fact, the drying process is one of the most energy intensive processes employed in the entire U.S. food processing industry, with typical energy intensity values ranging from around 1,500 Btu per pound of water in the product to over 28,000 Btu per pound of water in the product (Sikirica et al. 2003).

Table 4.7: Representative process energy intensities in dehydrated mashed potato flake manufacture

Process	Process Energy Intensity (Btu/lb)			
	Steam	Hot Water	Electricity	Total
Washing, grading			175	175
Peeling	900		200	1100
Precooking		1300		1300
Cook tunnel	1300			1300
Mashing			300	300
Drum drying	6000		350	6350

Source: Singh (1986b)

5 Energy Efficiency Improvement Opportunities

Many opportunities exist within U.S. fruit and vegetable processing facilities to reduce energy consumption while maintaining or enhancing productivity. Ideally, energy efficiency opportunities should be pursued in a coordinated fashion at multiple levels within a facility. At the component and equipment level, energy efficiency can be improved through regular preventative maintenance, proper loading and operation, and replacement of older components and equipment with higher efficiency models (e.g., high efficiency motors) whenever feasible. At the process level, process control and optimization can be pursued to ensure that production operations are running at maximum efficiency. At the facility level, the efficiency of space lighting, cooling, and heating can be improved while total facility energy inputs can be minimized through process integration and combined heat and power systems, where feasible. Lastly, at the level of the organization, energy management systems can be implemented to ensure a strong corporate framework exists for energy monitoring, target setting, employee involvement, and continuous improvement.

The remaining chapters in this Energy Guide discuss some of the most significant energy efficiency measures applicable to fruit and vegetable processing at the component, process, facility, and organizational levels. This focus of this Energy Guide is on energy efficiency measures that are proven, cost effective, and available for implementation today. Whenever possible, measure descriptions include case studies of fruit and vegetable processing plants that have successfully implemented the measure, both in the United States and abroad. Many case studies include specific energy and cost savings data as well as typical investment payback periods. For measures where data are not available for fruit and vegetable processing facilities, this Energy Guide presents case study data from other sub-sectors of the food industry (e.g., dairies, breweries, and wineries) and occasionally from non-food industries to illustrate typical measure savings. Lastly, for most measures references to the technical literature and online resources are provided, which can be consulted for further information.

For individual fruit and vegetable processing facilities, the actual payback period and savings associated with a given measure will vary depending on facility activities, configuration, size, location, and operating characteristics. Thus, the values presented in this Energy Guide are offered as guidelines. Further research on the economics of all measures—as well on as their applicability to different production practices—is needed to assess their cost effectiveness at individual plants.

This Energy Guide also presents a brief overview of selected emerging energy-efficient technologies, which have recently been developed or commercialized and hold promise for reducing energy use in the U.S. fruit and vegetable processing industry in the near future.

While the focus of this Energy Guide is on energy efficiency improvement measures, a chapter on basic, proven measures for plant-level water efficiency is also provided in recognition of the importance and rising costs of water as a resource in the U.S. fruit and vegetable processing industry. Water savings can also lead to energy savings through reduced demand for water heating, treatment, and pumping.

To enable easy access to information, this Energy Guide is organized into chapters that focus on specific areas of opportunity for energy and water efficiency.

Chapters 6 through 12 are focused on cross-cutting energy efficiency measures, which are defined as energy efficiency measures that are applicable across all manufacturing industries. Table 5.1 summarizes the cross-cutting energy efficiency measures presented in this Energy Guide and the respective chapters in which the measure descriptions appear. After a brief overview of corporate energy management programs in Chapter 6, this Energy Guide focuses on the following cross-cutting industrial systems, which are of particular importance to the U.S. fruit and vegetable processing industry: steam systems, motors and pumps, compressed air systems, refrigeration systems, building systems (HVAC and lighting) and self generation.

Table 5.1: Summary of cross-cutting energy efficiency measures presented in this Energy Guide

Energy Management Programs and Systems (Chapter 6)	
Energy management programs	Energy teams
Energy monitoring and control systems	
Steam Systems: (Chapter 7)	
Boilers	
Boiler process control	Flue gas heat recovery
Reduction of flue gas quantities	Condensate return
Reduction of excess air	Blow down steam recovery
Properly sized boiler systems	Boiler replacement
Improved boiler insulation	Direct contact water heating
Boiler maintenance	
Steam Distribution Systems	
Improved distribution system insulation	Steam trap monitoring
Insulation maintenance	Leak repair
Steam trap improvement	Flash steam recovery
Steam trap maintenance	
Process Integration	
Process integration	Pinch analysis
Motor Systems and Pumps (Chapter 8)	
Motor Systems	
Motor management plan	Strategic motor selection
Maintenance	Properly sized motors
Adjustable-speed drives	Power factor correction
Minimizing voltage unbalances	
Pumps	
Pump system maintenance	Multiple pumps for variable loads
Pump system monitoring	Impeller trimming
Pump demand reduction	Avoiding throttling valves
Controls	Replacement of belt drives
High-efficiency pumps	Proper pipe sizing
Properly sized pumps	Adjustable-speed drives

Table 5.1 (Continued)

Refrigeration Systems (Chapter 9)	
Refrigeration System Management	
Good housekeeping	Refrigeration system controls
Monitoring system performance	Checking for refrigerant contamination
Ensuring proper refrigerant charge	Efficient piping design
Cooling Load Reduction	
Piping insulation	Properly sized motors
Minimizing heat sources in cold storage areas	Hydrocooling
Reducing heat infiltration in cold storage areas	Geothermal cooling
Reducing building heat loads	Removal of excess surface water
Free cooling	
Compressors	
Compressor control systems and scheduling	Adjustable-speed drives
Floating head pressure control	Compressor heat recovery
Indirect lubricant cooling	Dedicating a compressor to defrosting
Raising system suction pressure	
Condensers and Evaporators	
Keeping condensers clean	Adjustable-speed drives on condenser fans
Automatic purging of condensers	Cycling of evaporator fans in cold storage
Reducing condenser fan use	Adjustable-speed drives on evaporator fans
Reducing condensing pressure	Demand defrost
Use of axial condenser fans	Water defrosting
Compressed Air Systems (Chapter 10)	
System improvements	Improved load management
Maintenance	Pressure drop minimization
Monitoring	Inlet air temperature reduction
Leak reduction	Controls
Turning off unnecessary compressed air	Properly sized pipe diameters
Modification of system in lieu of increased pressure	Heat recovery
Replacement of compressed air by other sources	Natural gas engine-driven compressors
Building Energy Efficiency Measures (Chapter 11)	
HVAC Systems	
Energy-efficient system design	Fan modification
Recomissioning	Efficient exhaust fans
Energy monitoring and control systems	Use of ventilation fans
Non-production hours set-back temperatures	Cooling water recovery
Duct leakage repair	Solar air heating
Variable-air-volume systems	Building reflection
Adjustable-speed drives	Low-emittance windows
Heat recovery systems	
Lighting	
Turning off lights in unoccupied areas	Replacement of mercury lights
Lighting controls	High-intensity discharge voltage reduction
Exit signs	High-intensity fluorescent lights
Electronic ballasts	Daylighting
Replacement of T-12 tubes with T-8 tubes	
Self Generation (Chapter 12)	
Backpressure turbines	Tri-generation
Combined heat and power	Photovoltaic panels

Chapter 13 presents a variety of energy efficiency measures that are applicable to specific processes employed in fruit and vegetable processing, such as blanching, evaporation, frying, and dehydration. These process-specific energy efficiency measures are summarized in Table 5.2.

Table 5.2: Summary of process-specific energy efficiency measures presented in this Energy Guide

Process-Specific Energy Efficiency Measures (Chapter 13)	
Blanching	
Upgrading of steam blanchers	Heat recovery from blancher water or condensate
Heat and hold techniques	Steam recirculation
Drying and Dehydrating	
Maintenance	Exhaust air heat recovery
Insulation	Using dry air
Mechanical dewatering	Heat recovery from the product
Direct fired dryers	Process controls
Evaporation	
Maintenance	Mechanical vapor recompression
Multiple effect evaporators	Concentration using membrane filtration
Thermal vapor recompression	Freeze concentration
Frying	
Heat recovery from fryer exhaust gases	Heat recovery via adsorption cooling
Heat recovery via exhaust gas combustion	Using spent fryer oil as fuel
Pasteurization and Sterilization	
Sterilizer insulation	Helical heat exchangers
Compact immersion tube heat exchangers	Induction heating of liquids
Peeling	
Heat recovery from discharge steam	Dry caustic peeling
Multi-stage abrasive peeling	

Chapter 14 provides an overview of selected, promising emerging energy-efficient technologies applicable to fruit and vegetable processing. An emerging technology is defined as a technology that was recently developed or commercialized with little or no market penetration in the food processing industry at the time of this writing. Table 5.3 summarizes the emerging energy-efficient technologies discussed in this Energy Guide.

Table 5.3: Summary of emerging energy-efficient technologies discussed in this Energy Guide

Emerging Energy-efficient Technologies (Chapter 14)	
Heat pump drying	Carbon dioxide as a refrigerant
Ohmic heating	Geothermal heat pumps for HVAC
Condition-based motor monitoring	Pulsed electric field pasteurization
Infrared drying	Advanced rotary burners
Pulsed fluid-bed drying	Magnetically-coupled adjustable-speed drives

Chapter 15 provides an overview of basic, proven measures for water efficiency in the fruit and vegetable processing industry. While this Energy Guide is primarily focused on energy efficiency measures, water is a critical resource throughout all industry sub-sectors that should be used wisely in the face of increasing water prices and scarcity. Thus, a variety water efficiency measures are also presented in this Energy Guide, which are summarized in Table 5.4.

Table 5.4: Summary of water efficiency measures presented in this Energy Guide

Basic Water Efficiency Measures (Chapter 15)	
General Water Efficiency Measures	
Strategic water management program	Use of small diameter hoses
Good housekeeping	Air cooling
Recycling of product waste as animal feed	Use of automated start/stop controls
Use of water efficient building fixtures	Reducing demand for steam and hot water
Dry conveyors	Reducing cooling tower bleed-off
Cleaning and Sanitation	
Dry cleaning of equipment and surfaces	Pigging
High pressure low volume sprays	Low pressure foam cleaning
Clean equipment immediately after use	Control of volume in clean-in-place processes
Optimization of clean-in-place performance	Pre-soaking of floors and equipment
Water Recovery and Recycling	
Reuse of washing water	Membrane filtration
Cooling towers	Hydrocyclones
Counter-current washing	Recycling of can cooling water
Recycling of final rinse water	Recycling of blanching and cooking water
Recycling of evaporator condensate	Reuse of flume water
Segregation of wastewater streams	Reuse of compressor cooling water

6 Energy Management Programs and Systems

6.1 A Strategic Energy Management Program

Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy efficiency improvements.

Continuous improvements to energy efficiency typically only occur when a strong organizational commitment exits. A sound energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.

The U.S. EPA, through the ENERGY STAR program, works with leading industrial manufacturers to identify the basic aspects of effective energy management programs.[17] The major elements in a strategic energy management program are depicted in Figure 6.1.

Other environmental management frameworks, such as ISO 14001, can be used to complement energy management programs to ensure optimal organizational management of energy. One ENERGY STAR partner noted that using energy management programs in combination with the ISO 14001 program has had a greater impact on conserving energy at its plants than any other strategy.

A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team (see the Section 6.2). Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

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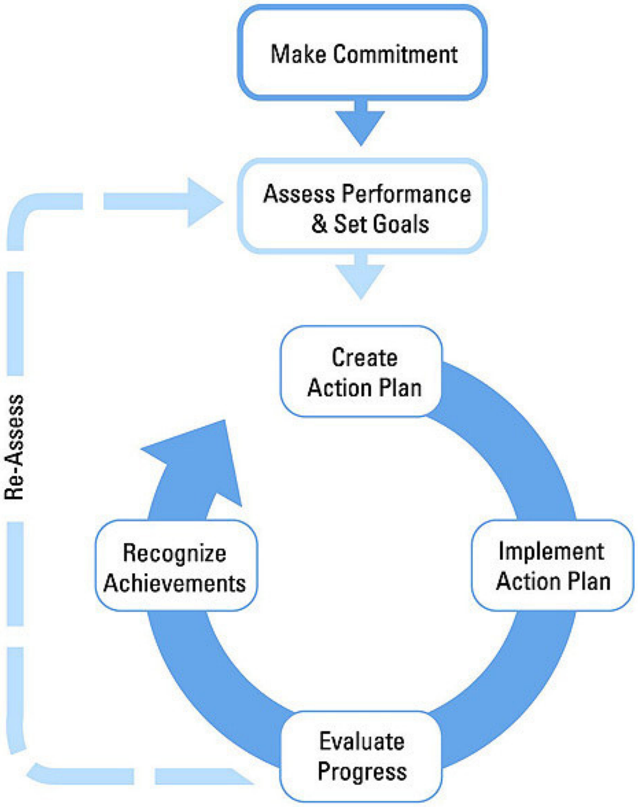
[17] Read more about strategic energy management at http://www.energystar.gov/industry.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. Some examples of simple tasks employees can do are outlined in Appendix B. In addition, performance results should be regularly evaluated and communicated to all personnel and high achievement should be rewarded and recognized.

Figure 6.1: Main elements of a strategic energy management program



For example, ConAgra Foods has recognized outstanding employee contributions to energy efficiency as part of its corporate Sustainable Development program since 1993. Each year, several ConAgra production facilities are given a monetary award for outstanding plant-initiated projects that led to energy savings and other environmental improvements. The monetary awards are used by the production facilities as charitable donations to their communities for local sustainability projects. In addition to providing its employees with recognition and incentives for continuous improvement, ConAgra's Sustainable Development program has also reduced facility operating expenses by over $60 million since 2000 (Pehanich 2005; Halberstadt 2006).

Evaluating progress on the action plan involves a regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans, and in revealing best practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communication program and seeking recognition for accomplishments are also critical steps, as both areas help to build support and momentum for future activities.

A quick assessment of an organization's efforts to manage energy can be made by comparing its current energy management program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix C.

Frito-Lay, a manufacturer of snack foods headquartered in Plano, Texas, implemented a comprehensive corporate energy management program in 1999 that has led to energy savings of 21% across its 34 U.S. facilities and saved the company more than $40 million in energy costs to date (Frito-Lay 2006). Key components of this plan include: (1) the designation of three tiers of energy management personnel (energy and utility managers with corporate-level responsibilities, resource conservation captains with regional responsibilities, and champions with site-level responsibilities), (2) capital budgets that are designated exclusively for energy efficiency improvements, (3) annual energy budget target setting for each site with weekly performance tracking, and (4) an annual energy summit for continuing education, sharing of success stories between facilities, and awards for top performers (ASE 2005).

Internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Some utility companies work together with industrial clients to achieve energy savings in both existing facilities and in the design of new facilities. Recently, Mission Foods, a California manufacturer of specialty Mexican foods, worked with Southern California Edison (its local utility company) to design its new production facility in Rancho Cucamonga to be as energy efficient as possible. By employing energy-efficient technologies for motors, HVAC systems, compressors, and lighting throughout the facility, Mission Foods was able to reduce the electricity consumption of its new facility by roughly 18% compared to its existing facilities. Annual energy savings of over $300,000 per year were achieved (EDR 2005).

Facility audits can be another particularly effective form of outside support. In a recent audit carried out by U.S. DOE Industrial Assessment Center (IAC) staff at an Odwalla Juice Company facility in Dinuva, California, energy efficiency opportunities were identified that would reduce annual energy costs by $268,000 and annual energy usage by 15% with an average payback period of just 20 months (U.S. DOE 2002a).

6.2 Energy Teams

The establishment of an energy team is an important step toward solidifying a commitment to continuous energy efficiency improvement.[18] The energy team should primarily be responsible for planning, implementing, benchmarking, monitoring, and evaluating the organizational energy management program. However, its duties can also include delivering training, communicating results, and providing employee recognition (U.S. EPA 2006).

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[18] For a comprehensive overview of establishing, operating, and sustaining an effective energy management team, please consult the U.S. EPA's *Teaming Up to Save Energy* guide available at http://www.energystar.gov/ (U.S. EPA 2006).

In forming an energy team, it is necessary to establish the organizational structure, designate team members, and specify roles and responsibilities. Senior management needs to perceive energy management as part of the organization's core business activities, so ideally the energy team leader will be someone at the corporate level who is empowered by support from senior-level management. The energy team should also include members from each key operational area within an organization and be as multi-disciplinary as possible to ensure a diversity of perspectives. It is crucial to ensure adequate organizational funding for the energy team's activities, preferably as a line item in the normal budget cycle as opposed to a special project.

Prior to the launch of an energy team, a series of team strategy meetings should be held to consider the key initiatives to pursue as well as potential pilot projects that could be showcased at the program's kickoff. The energy team should then perform facility audits with key plant personnel at each facility to identify opportunities for energy efficiency improvements. As part of the facility audits, the energy team should also look for best practices in action to help highlight success stories and identify areas for inter-plant knowledge transfer.

A key function of the energy team is to develop mechanisms and tools for tracking and communicating progress and for transferring the knowledge gained through facility audits across an organization. Examples of such mechanisms and data tools include best practice databases, facility benchmarking tools, intranet sites, performance tracking scorecards, and case studies of successful projects. Corporate energy summits and employee energy fairs are also effective means of information exchange and technology transfer.

To sustain the energy team and build momentum for continuous improvement, it is important that progress results and lessons learned are communicated regularly to managers and employees and that a recognition and rewards program is put in place.

A checklist of key steps for forming, operating, and sustaining an effective energy management team is offered in Appendix D.

6.3 Energy Monitoring Systems

Energy monitoring systems are key tools that play an important role in energy management. Energy monitoring systems may include energy sub-metering at the component, equipment, or process level and can be used to track various end uses of energy over time for energy efficiency improvement analysis. These systems can play a key role in alerting energy teams to problem areas and in assigning accountability for energy use within a facility. Furthermore, energy monitoring systems can provide useful data for corporate greenhouse gas accounting initiatives.

Energy monitoring and metering systems can also help companies participate in emergency demand response programs, in which utility companies provide financial incentives to customers who reduce their energy loads during peak demand times. S. Martinelli and Company, an apple juice manufacturer based in Watsonville, California, installed an energy monitoring system that provided it with real-time data on peak demand and energy consumption. This system allowed them to participate in a demand response program of their local utility. S. Martinelli also uses their system to verify electric and natural gas bills against their actual measured use as a cost control measure, as well as to track facility performance in system optimization efforts (Flex Your Power 2006a).

7 Steam Systems

As discussed in Chapter 4, steam systems are by far the most significant end use of energy in the U.S. fruit and vegetable processing industry. Energy efficiency improvements to steam systems therefore represent one of the most significant opportunities for energy savings in the industry. Furthermore, since the vast majority of steam systems in the U.S. fruit and vegetable processing industry use natural gas as a boiler fuel (U.S. DOE 1997a, 2005), improving steam system efficiency is also an important strategy for controlling energy costs in the face of sharp increases in industrial natural gas prices. According to the U.S. DOE, a typical industrial facility that conducts a steam system assessment will identify potential steam system energy use and cost savings that range from 10% to 15% per year (U.S. DOE 2006c).

Steam is used in many important applications throughout the typical fruit and vegetable processing facility, such as blanching, peeling, heat sterilization, evaporation, pasteurization, indirect drying, container washing, and equipment cleaning. Representative steam intensity values for different processes employed in the manufacture of several key industry products have been provided in Tables 4.2 through 4.7.

This chapter describes some of the most significant opportunities available for improving steam system efficiency in a typical industrial plant.[19] First, energy efficiency measures applicable to boilers—the heart of the steam system—are presented. Next, measures that are applicable to a facility's steam distribution network are discussed. Finally, this chapter provides a brief discussion of pinch technology and process integration as applied to steam systems.

In analyzing the opportunities for improving the energy efficiency of steam systems, a systems approach, in which both steam demand (i.e., end uses) and steam supply systems are optimized, is essential. Demand-side (i.e., process-specific) energy efficiency opportunities are discussed in greater detail in Chapter 13.

7.1 Boiler Energy Efficiency Measures

The boiler energy efficiency measures presented below focus primarily on improved process control, reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that when new boiler systems are needed, ideally they should be designed and installed in a custom configuration that meets the needs of a particular plant. Often, pre-designed boilers cannot be fine tuned to meet the steam generation and distribution system requirements unique to any given plant in the most efficient manner (Ganapathy 1994).

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[19] The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving industrial steam system efficiency, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE's *Improving Steam System Performance, A Sourcebook for Industry* (U.S. DOE 2004a) is a particularly helpful resource. Also, many tips, tools, and industrial case studies on steam system efficiency can be found at the Industrial Technologies Program's *BestPractices* steam systems website: http://www1.eere.energy.gov/industry/bestpractices/steam.html.

Boiler process control. Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration. By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and lower air pollutant emissions.

Typically, this measure is financially attractive only for large boilers, because smaller boilers often will not make up the initial capital cost as easily. Several case studies indicate that the average payback period for this measure is around 1.7 years (IAC 2005). At Glanbia Foods, a dairy product manufacturer in Lockerbie, Scotland, the installation of a boiler control system reduced annual boiler fuel consumption by 5% (CADDET 2003).

At the J.R. Simplot Company potato processing facility in Caldwell, Idaho, the installation of new burners equipped with process controls and a flue gas trim system led to significant annual savings in natural gas consumption. The Caldwell facility produces approximately 270 million pounds of frozen French fries each year and uses steam in its potato peeling, blanching, and frying operations. In 2003, new burners, flue gas oxygen analyzers, flue gas recirculation ducts, and boiler controls were installed on two boilers during plant outages. Natural gas consumption was reduced by 7.5%, resulting in cost savings of $279,000 per year and a payback period of around 14 months (U.S. DOE 2005c).

Reduction of flue gas quantities. Often excessive flue gas results from leaks in the boiler and/or in the flue. These leaks can reduce the heat transferred to the steam and increase pumping requirements. However, such leaks are often easily repaired, saving 2% to 5% of the energy formerly used by the boiler (Galitsky et al. 2005a). This measure differs from flue gas monitoring in that it consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses.

Reduction of excess air. When too much excess air is used to burn fuel, energy is wasted because excessive heat is transferred to the air rather than to the steam. Air slightly in excess of the ideal stochiometric fuel/-to-air ratio is required for safety and to reduce emissions of nitrogen oxides (NO_x), but approximately 15% excess air is generally adequate (U.S. DOE 2004a; Ganapathy 1994). Most industrial boilers already operate at 15% excess air or lower, and thus this measure may not be widely applicable (Zeitz 1997). However, if a boiler is using too much excess air, numerous industrial case studies indicate that the payback period for this measure is less than 1 year (IAC 2005).

For example, at a U.S. DOE sponsored energy audit of a Land O'Lakes dairy facility in Tulare, California, it was estimated that by reducing excess oxygen from 4.5% to 3.0%, the facility would reduce its natural gas costs by $113,000 per year while still meeting stringent NO_X emissions limits (U.S. DOE 2005b). As a rule of thumb, the Canadian Industry

Program for Energy Conservation (CIPEC) estimates that for every 1% reduction in flue gas oxygen, boiler efficiency is increased by 2.5% (CIPEC 2001).

Properly sized boiler systems. Designing the boiler system to operate at the proper steam pressure can save energy by reducing stack temperature, reducing piping radiation losses, and reducing leaks in steam traps. This measure is particularly important in fruit and vegetable processing facilities, where due to the seasonality of production, large boilers can often be run at low capacity during the off season, which can result in significant energy losses.

In a study done in Canada on 30 boiler plants, savings from this measure ranged from 3% to 8% of total boiler fuel consumption (Griffin 2000). Savings were greatest when steam pressures were reduced below 70 pounds per square inch (psi) (gauge). One industrial case study has shown that correct boiler sizing led to savings of $150,000 at a payback period of only 2.4 months (IAC 2005). However, costs and savings will depend heavily on the current boiler system utilization at individual plants.

Improved boiler insulation. It is possible to use new materials, such as ceramic fibers, that both insulate better and have a lower heat capacity (thus allowing for more rapid heating). Savings of 6% to 26% can be achieved if improved insulation is combined with improved heater circuit controls. Due to the lower heat capacity of new materials, the output temperature of boilers can be more vulnerable to temperature fluctuations in the heating elements (Caffal 1995). Improved boiler process control is therefore often required in tandem with new insulation to maintain the desired output temperature range.

At a U.S. DOE sponsored assessment of a Land O'Lakes dairy facility in Tulare, California, it was found that by improving insulation on the facility's steam header, boiler economizer, and process hot water tank, the company could save nearly $35,000 per year in reduced boiler fuel costs (U.S. DOE 2005b).

Boiler maintenance. A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 30% of initial efficiency over two to three years (Galitsky et al. 2005a). On average, the energy savings associated with improved boiler maintenance are estimated at 10%. Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling on the fire side of boiler tubes or scaling on the water side of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed boilers (boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do). Tests reported by CIPEC show that a fire side soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) soot layer reduces heat transfer by 69% (CIPEC 2001). For water side scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC 2001).

Flue gas heat recovery. Heat recovery from flue gas is often the best opportunity for heat recovery in steam systems (CIPEC 2001). Heat from flue gas can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels). Traditionally, this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on feed water temperature than on flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat feed water to close to the acid dew point before it enters the economizer. This approach allows the economizer to be designed so that exiting flue gas is just above the acid dew point. Typically, one percent of fuel use is saved for every 45°F (25°C) reduction in exhaust gas temperature (Ganapathy 1994).

At the Odwalla Juice Company's facility in Dinuva, California, the installation of an economizer was expected to save over $21,000 per year in energy costs and over 4,000 MBtu of boiler fuel per year (U.S. DOE 2002a). Odwalla's expected payback period for the economizer was just 10 months.

McCain Foods, a major producer of frozen French fried potatoes, installed an economizer at its Scarborough, England, facility as part of a plant-level heat recovery project in 1995. The new economizer saved the facility 67 therms of natural gas per hour, leading to energy savings of £67,000 per year ($107,000 in 1995 U.S. dollars) with a simple payback period of 2.5 years (CADDET 1995). Similar results were expected at Schneider Foods, a packaged and frozen meats company in Ontario, Canada. In 2005, the company installed a dual-stage economizer, which heats both boiler feed water and boiler makeup water with heat recovered from flue gas, leading to savings of about $225,000 (U.S. dollars) per year and a payback period of less than two years (NRC 2005).

Condensate return. Reusing hot condensate in boilers saves energy, reduces the need for treated boiler feed water, and reclaims water at up to 100°C (212°F) of sensible heat. Typically, fresh feed water must be treated to remove solids that might accumulate in the boiler; however, returning condensate to a boiler can substantially reduce the amount of purchased chemical required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs often makes building a return piping system attractive. A 2005 study of seven different fresh fruit and vegetable processing plants in California estimated a payback period for this measure ranging from approximately two to three years (Hackett et al. 2005).

Blow down steam recovery. When water is blown from a high-pressure boiler tank, the pressure reduction often produces substantial amounts of steam. This steam is typically low grade, but can be used for space heating and feed water preheating. The recovery of blowdown steam can save around 1% of boiler fuel use in small boilers (Galitsky et al. 2005a). In addition to energy savings, blow down steam recovery may reduce the potential for corrosion damage in steam system piping.

Green Giant of Canada, a manufacturer of frozen and canned vegetables, installed a shell and tube heat exchanger to recover heat from boiler blow down. This measure led to annual energy savings of roughly $1,500 with a payback of approximately 2 years (AAFC 1984).

Boiler replacement. Substantial efficiency gains can often be realized by replacing old boilers with new, higher efficiency models. In particular, the replacement of inefficient coal-fired boilers with natural gas-fired boilers is a sound strategy for reducing boiler fuel costs while also reducing emissions of air pollutants.

Valley Fig, a manufacturer of fig pastes and concentrates in Fresno, California, replaced their old and inefficient 300 boiler horsepower (bhp) fire tube boiler in 2004 in order to meet stringent NO_X emissions limits. The 300 bhp boiler was replaced with two smaller and more efficient 100 bhp boilers, which not only allowed them to meet the facility's steam demands while lowering NO_X emissions, but also reduced their natural gas costs by 8% to 10% (PM Engineer 2004). Additionally, Valley Fig received a $16,000 rebate check from Pacific Gas & Electric (their local utility company) for improved fuel efficiency.

Direct contact water heating. In direct contact water heaters, water is sprayed downward through a vertical chamber that serves as a flue for combustion gases. Because the hot combustion gases heat the water directly, this water heating system is more efficient than traditional boilers. Hot water is collected in a storage tank while the combustion gases exit the system at near-ambient temperatures. Since water does not contact the burner flames, complete combustion occurs before the gases heat the water. Thus, water quality is maintained to a level that is appropriate for food processing operations (FIRE 2005a). Additionally, direct-contact water heaters can operate at atmospheric pressure, which avoids the safety hazards and insurance premiums that can come with pressurized boiler operation.

One commercially-available direct-contact water heater by Kemco Systems, Inc., offers water heating efficiencies of up to 99.7%, which is a significant improvement compared to the 60% to 75% efficiencies achievable with traditional water heating technologies (U.S. DOE 2001a). Approximately 3,000 Kemco direct-contact water heaters are said to be in operation worldwide, with average payback periods ranging from one to two years.

Another commercially-available direct-contact water heating system by QuickWater was installed at Golden Temple, a natural foods manufacturing company based in Oregon, in 2003. Golden Temple's annual energy savings for water heating were estimated at 22%, with annual energy cost savings totaling around $2,300 (FIRE 2005a). Additionally, the direct-contact water heater was said to offer a smaller footprint than traditional systems as well as a longer life (estimated at 20 to 25 years).

7.2 Steam Distribution System Energy Efficiency Measures

Steam and hot water distribution systems are often quite extensive and can be major contributors to energy losses within a fruit and vegetable processing plant. Energy efficiency improvements to steam distribution systems are primarily focused on reducing heat losses throughout the system and recovering useful heat from the system wherever feasible. The following measures are some of the most significant opportunities for saving energy in industrial steam distribution systems.

Improved distribution system insulation. Using more insulating material or using the best insulation material for the application can save energy in steam systems. Crucial factors in choosing insulating material include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application, such as tolerance of large temperature variations, tolerance of system vibrations, and adequate compressive strength where the insulation is load bearing (Baen and Barth 1994). Industrial case studies indicate that the payback period for improved insulation is typically about one year (IAC 2005).

The S. Martinelli Company, an apple juice manufacturer in Watsonville, California, found that insulating steam distribution lines not only led to energy savings, but also reduced the amount of heat inadvertently released to interior spaces (Flex Your Power 2006a).

Insulation maintenance. It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can also save energy (Zeitz 1997).

Steam trap improvement. Using modern thermostatic element steam traps can reduce energy use while also improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures (Alesson 1995).

Steam trap maintenance. A simple program of checking steam traps to ensure that they are operating properly can save significant amounts of energy for very little money. In the absence of a steam trap maintenance program, it is common to find up to 15% to 20% of steam traps malfunctioning in a steam distribution system (Jaber 2005). Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% (Jones 1997; Bloss et al. 1997).

One industrial case study indicates a payback period of less than four months (IAC 2005). Although this measure offers a quick payback period, it is often not implemented because maintenance and energy costs are generally separately budgeted. In addition to energy and cost savings, proper functioning of steam traps will reduce the risk of corrosion in the steam distribution system. At a Land O'Lakes dairy facility in Tulare, California, a U.S. DOE sponsored energy assessment estimated that implementing a steam trap maintenance program would save nearly 20,000 MBtu of natural gas per year and lead to annual energy savings of around $278,000 (U.S. DOE 2005b).

Steam trap monitoring. Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy without significant added cost. This measure is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap failure and can detect when a steam trap is not performing at peak efficiency. Employing steam trap monitoring has been estimated to provide an additional 5% in energy savings compared to steam trap maintenance alone, at a payback period of around one year (Galitsky et al. 2005a). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring.

Leak repair. As with steam traps, steam distribution piping networks often have leaks that can go undetected without a program of regular inspection and maintenance. The U.S. DOE estimates that repairing leaks in an industrial steam distribution system will lead to energy savings of around 5% to 10% (U.S. DOE 2006d). At a Land O'Lakes dairy facility in Tulare, California, the U.S. DOE estimated that natural gas savings of $18,000 per year could be realized by implementing a steam leak maintenance program (U.S. DOE 2005b). Additionally, regular inspection and leak repair can reduce the likelihood of major system leaks, which can be very costly to repair.

Flash steam recovery. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blow down, steam trap flash steam can be recovered and used for low grade facility applications, such as space heating or feed water preheating (Johnston 1995).

The potential for this measure is site dependent, as its cost effectiveness depends on whether or not areas where low-grade heat is useful are located close to steam traps. Where feasible, this measure can be easy to implement and can save considerable energy. For example, an analysis of a U.S. based food processing facility predicted that the installation of a flash steam recovery system used for feed water preheating would save the plant around $29,000 in fuel costs annually at a payback period of less than 1.8 years (Iordanova et al. 2000). Based on the reduction in boiler fuel use, it was further estimated that the plant's carbon emissions would be reduced by 173 tons per year.

7.3 Process Integration

Process integration. Process integration refers to the exploitation of potential synergies that might exist in systems that consist of multiple components working simultaneously. In facilities that have multiple heating and cooling demands, like those in the fruit and vegetable processing industry, the use of process integration techniques may significantly improve facility energy efficiency by linking hot and cold process streams in a thermodynamically optimal manner. For example, the heat rejected in a facility's cooling process can be recovered and used in process heating applications (Das 2000). Developed in the early

1970s, process integration is now an established methodology for improving the energy efficiency of continuous industrial processes (Linnhoff et al. 1992; CADDET 1993).

At Elite Salads and Snacks, a Dutch producer of pre-cooked foods for the catering industry, continuous demand for both heating and cooling provided an attractive opportunity to integrate both functions into one common system. The company used rejected heat from its cooling system in combination with recovered heat from its flue gas condenser to pre-heat process water. The rejected heat from the cooling system was also raised to a higher temperature via the addition of a heat pump. The process integration initiative led to natural gas savings of approximately 120,000 cubic meters (approximately 4,320 MBtu) per year with a payback period of around 2.5 years (Das 2000).

McCain Foods, a major producer of frozen French fried potatoes, installed an integrated heat recovery system in its Scarborough, England, facility in 1995. Heat was recovered from fat-laden fryer exhaust gases via a vapor condenser and from boiler flue gases via economizers. The recovered heat was used to pre-heat air for potato chip dryers, to provide hot water for potato blanching, and to provide hot water for miscellaneous processes around the facility. The project led to annual energy savings of £176,000 ($280,000 in 1995 U.S. dollars) and a simple payback period of 3.6 years (CADDET 1995).

Pinch analysis. Pinch analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process system. It was developed originally in response to the “energy crisis” and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch analysis approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water, or a specific chemical species such as hydrogen.

The critical innovation in applying pinch analysis was the development of “composite curves” for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When these two curves are drawn on a temperature-enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements. These are called the energy targets. The pinch analysis methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing capital and energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs and retrofits of existing plants.

The analytical approach to pinch analysis has been well documented in the literature (Smith 1995; Shenoy 1994). Energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation, and steam trap management.

At the Nestle Svenska food processing facility in Bjuv, Sweden, a pinch analysis study was performed in 1993 to optimize facility-level energy consumption. The pinch analysis identified improvements to the facility’s steam system—specifically, heat recovery opportunities in the facilities soup, baby foods, and vegetable departments—that would reduce the facility’s annual energy consumption by 10% with an expected payback period of around three years (CADDET 1994). The expected annual savings in energy costs were estimated at around 300,000 Swedish Kronor ($40,000 in 1994 U.S. dollars).

8 Motor Systems and Pump Systems

Motors are used throughout a typical fruit and vegetable processing facility to drive process equipment (e.g., for mixing, peeling, cutting, pulping, filling, and packaging), conveyors, ventilation fans, compressors, and pumps. According to the U.S. DOE, the typical industrial plant in the United States can reduce its electricity use by around 5% to 15% by improving the efficiency of its motor-driven systems (U.S. DOE 2006e).

Pumps are particularly important pieces of motor-driven equipment in many fruit and vegetable processing plants. Pumps are used extensively to pressurize and transport water in cleaning, water fluming, and wastewater handling operations, for transporting liquid food streams (e.g., fruit and vegetable juices) between processes, and for circulating liquid foods streams within the processes themselves (e.g., pasteurization and evaporation). Studies have shown that as much as 20% of the energy consumed by pumping systems could be saved through changes to pumping equipment and/or pump control systems (U.S. DOE 2002g).

This chapter presents some of the most significant energy efficiency measures available for motors and pumps in industrial applications.[20]

8.1 Energy Efficiency Measures for Motor Systems

When considering energy efficiency improvements to a facility's motor systems, it is important to take a "systems approach." A systems approach strives to optimize the energy efficiency of entire motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as individual components. A systems approach analyzes both the energy supply and energy demand sides of motor systems as well as how these sides interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach typically involves the following steps. First, all applications of motors in a facility should be located and identified. Second, the conditions and specifications of each motor should be documented to provide a current systems inventory. Third, the needs and the actual use of the motor systems should be assessed to determine whether or not motors are properly sized and also how well each motor meets the needs of its driven equipment. Fourth, information on potential repairs and upgrades to the motor systems should be collected, including the economic costs and benefits of implementing repairs and upgrades to enable the energy efficiency improvement decision-making process. Finally, if upgrades are pursued, the performance of the upgraded motor systems should be monitored to determine the actual costs savings (SCE 2003).

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[20] The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial motor systems and pumps, which can be consulted for more detailed information on many of the measures presented in this chapter. For pumps, the U.S. DOE's *Improving Pumping System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE 2006f). For a collection of tips, tools, and industrial case studies on motor and pump efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: http://www1.eere.energy.gov/industry/bestpractices/systems.html. The Motor Decisions Matter^{SM} Campaign also provides a number of excellent resources for improving motor system efficiency (http://www.motorsmatter.org/).

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components.

Motor management plan. A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter^{SM} Campaign suggests the following key elements for a sound motor management plan (MDM 2007):

1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification.
5. Development of a repair specification.
6. Development and implementation of a predictive and preventive maintenance program.

The Motor Decisions Matter^{SM} Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM 2007).

Strategic motor selection. Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM 2007). Life cycle costing (LCC) is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al. 2001), which also provides an introduction to LCC for motor systems.

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). The Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE 2007):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term "energy efficient" in the marketplace for motors. NEMA Standards Publication No. MG-1 (Revision 3), Table 12-11 defines efficiency levels for a range of different motors (NEMA 2002).

- The Energy Policy Act of 1992 (EPACT) required that many commonly used motors comply with NEMA "energy efficient" ratings if offered for sale in the United States.

- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPACT required, for the same classes of motors covered by EPACT. The CEE efficiency levels specified were generally two NEMA efficiency bands (Table 12-10, NEMA MG-1 Revision 3) above those required by EPACT.

- In 2001, the NEMA Premium® Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium® also denotes a brand name for motors which meet this specification. Specifically, this specification covers motors with the following attributes:

    - Speed: 2, 4, and 6 pole
    - Size: 1-500 horsepower (hp)
    - Design: NEMA A and B
    - Enclosure type: open and closed
    - Voltage: low and medium voltage
    - Class: general, definite, and special purpose

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix E) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA 2001). Payback times will vary based on size, load factor, running time, local energy costs, and available rebates and/or incentives (see Appendix E). Given the quick payback time, it usually makes sense to by the most efficient motor available (U.S. DOE and CAC 2003).

NEMA and other organizations have created the Motor Decisions Matter^{SM} campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium® motors and "best practice" repair, and support the development of motor management plans before motors fail.

At the Odwalla Juice Company's facility in Dinuva, California, an IAC energy assessment found that the installation of more energy efficient motors would lead to $6,300 in annual cost savings with a simple payback period of only eight months (U.S. DOE 2002a). Similarly, in energy audits of seven fresh fruit and vegetable processing facilities in California, the installation of premium efficiency motors as motors wear out was expected to yield simple payback periods ranging from 0.7 to 1.6 years (Hackett et al. 2005).

Stahlbush Island Farms, a grower, canner, and freezer of fruits and vegetables in Corvalis, Oregon, also replaced targeted motors with higher efficiency models as motors wore out. The expected average payback period was estimated at 2.7 years (ODEQ 1996). When all targeted motors are replaced over a 12-year period, the company expects to save 50,000 kWh of electricity per year and to cut their electricity bill by around $2,300 per year.

In some cases, it may be cost-effective to rewind an existing energy efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM 2007). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5% to 1% (EASA 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA 2006).

Maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al. 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use (Efficiency Partnership 2004).

Properly sized motors. Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (Xenergy 1998). Higher savings can often be realized for smaller motors and individual motor systems.

To determine the proper motor size, the following data are needed: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE's BestPractices program provides a fact sheet that can assist in decisions regarding replacement of oversized and under loaded motors (U.S. DOE 1996). Additionally, software packages such as MotorMaster+ (see Appendix E) can aid in proper motor selection.

Adjustable speed drives (ASDs).[21] Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7% and 60%. Energy audits carried out at seven fresh fruit and vegetable processing plants in California estimated simple payback periods for ASDs ranging from 0.8 to 2.8 years (Hackett et al. 2005).

Two published case studies on applications of ASDs in the U.S. fruit and vegetable processing industry report similar benefits. At Odwalla Juice Company's Dinuva, California, facility, an energy audit estimated that the installation of ASDs on the facility's glycol pump motors (used in the juice pasteurization process) would save the company $31,500 in electricity costs per year with a payback period of six months (U.S. DOE 2002a). In a three-year study of the application of ASDs to ventilation fans in storage units for potatoes, electricity savings of 40% were reported, with two companies citing payback periods of less than two years (Cascade 2003).

Power factor correction. Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

Minimizing voltage unbalances. A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

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[21] Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Energy Guide for consistency.

For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh (U.S. DOE 2005e).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE 2005e). The typical payback period for voltage controller installation on lightly loaded motors in the United States is 2.6 years (IAC 2005).

8.2 Energy Efficiency Measures for Pump Systems

As with motors, it is important to take a systems approach when assessing pump energy efficiency improvement opportunities within a facility. For example, although an individual pump might be operating efficiently, it could be generating more flow than the system requires for a given application and therefore wasting energy. Thus, it is important to not only assess individual pump efficiencies, but also to assess how well the various end uses in a facility's pump system are being served by its pumps (U.S. DOE 2006f).

It is also important to consider that the initial capital cost of a pump is typically only a small fraction of its total life cycle costs. In general, maintenance costs and energy costs represent by far the most significant fraction of a pump's total life cycle costs. In some cases, energy costs can account for up to 90% of the total cost of owning a pump (U.S. DOE 2001b). Thus, the decision to make a capital investment in pumping equipment should be made based on projected energy and maintenance costs rather than on initial capital costs alone.

The basic components in a pump system are pumps, drive motors, piping networks, valves, and system controls. Some of the most significant energy efficiency measures applicable to these components and to pump systems as a whole are described below.

Pump system maintenance. Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase pumping energy costs. The implementation of a pump system maintenance program will help to avoid these problems by keeping pumps running optimally. Furthermore, improved pump system maintenance can lead to pump system energy savings of anywhere from 2% to 7% (Xenergy 1998). A solid pump system maintenance program will generally include the following tasks (U.S. DOE 2006f; Xenergy 1998):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, on an annual or semiannual basis.

- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2 to 60 drops per minute.

- Inspection and replacement of mechanical seals. Allowable leakage is typically 1 to 4 drops per minute.

- Wear ring and impeller replacement. Pump efficiency degrades by 1% to 6% for impellers less than the maximum diameter and with increased wear ring clearances.

- Checking of pump/motor alignment.

- Inspection of motor condition, including the motor winding insulation.

Pump system monitoring. Monitoring can be used in conjunction with a proper maintenance program to detect pump system problems before they escalate into major performance issues or equipment repairs. Monitoring can be done manually on a periodic basis (e.g., performing regular bearing oil analyses to detect bearing wear or using infrared scanning to detect excessive pump heat) or can be performed continuously using sensor networks and data analysis software (e.g., using accelerometers to detect abnormal system vibrations) (U.S. DOE 2006f). Monitoring can help keep pump systems running efficiently by detecting system blockages, impeller damage, inadequate suction, clogged or gas-filled pumps or pipes, pump wear, and if pump clearances need to be adjusted. In general, a good pump monitoring program should include the following aspects:

- Wear monitoring.

- Vibration analysis.

- Pressure and flow monitoring.

- Current or power monitoring.

- Monitoring of differential head and temperature rise across pumps (also known as thermodynamic monitoring).

- Distribution system inspection for scaling or contaminant build-up.

Pump demand reduction. An important component of the systems approach is to minimize pump demand by better matching pump requirements to end use loads. Two effective strategies for reducing pump demand are the use of holding tanks and the elimination of bypass loops. Holding tanks can be used to equalize pump flows over a production cycle, which can allow for more efficient operation of pumps at reduced speeds and lead to energy savings of 10% to 20% (Xenergy 1998). Holding tanks and can also reduce the need to add pump capacity. The elimination of bypass loops and other unnecessary flows can also lead to energy savings of 10% to 20% (Xenergy 1998). Other effective strategies for reducing pump demand include lowering process static pressures, minimizing elevation rises in the piping system, and lowering spray nozzle velocities.

Controls. Control systems can increase the energy efficiency of a pump system by shutting off pumps automatically when demand is reduced, or, alternatively, by putting pumps on standby at reduced loads until demand increases.

In 2000, Cisco Systems upgraded the controls on its fountain pumps so that pumps would be turned off automatically during periods of peak electrical system demand. A wireless control system was able to control all pumps simultaneously from one location. The project saved $32,000 and 400,000 kWh annually, representing a savings of 61.5% in the total energy consumption of the fountain pumps (CEC 2002b). With a total cost of $29,000, the simple payback period was 11 months. In addition to energy savings, the project reduced maintenance costs and increased the pump system's equipment life.

High-efficiency pumps. It has been estimated that up to 16% of pumps in use in U.S. industry are more than 20 years old (Xenergy 1998). Considering that a pump's efficiency may degrade by 10% to 25% over the course of its life, the replacement of aging pumps can lead to significant energy savings. The installation of newer, higher-efficiency pumps typically leads to pump system energy savings of 2% to 10% (Elliott 1994).

A number of high-efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating costs and capital costs. For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost (U.S. DOE 2001b).

Properly sized pumps. Pumps that are oversized for a particular application consume more energy than is truly necessary. Replacing oversized pumps with pumps that are properly sized can often reduce the electricity use of a pumping system by 15% to 25% (Xenergy 1998). Where peak loads can be reduced through improvements to pump system design or operation (e.g., via the use of holding tanks), pump size can also be reduced. If a pump is dramatically oversized, often its speed can be reduced with gear or belt drives or a slower speed motor. The typical payback period for the above strategies can be less than one year (Galitsky et al. 2005a).

The Welches Point Pump Station (a medium-sized water treatment plant located in Milford, Connecticut) replaced one of their system's four identical pumps with a smaller model (ITT Flygt 2002). They found that the smaller pump could more efficiently handle typical system flows and the remaining three larger pumps could be reserved for peak flows. While the smaller pump needed to run longer to handle the same total volume, its slower pace and reduced pressure resulted in less friction-related losses and less wear and tear. Installing the smaller pump has reduced the pump system's annual electricity use by more than 20%. Furthermore, it was estimated that using this approach at each of the city's 36 stations would result in annual energy savings of over $100,000. In addition to the energy savings projected, less wear on the system was expected to result in less maintenance, less downtime, and longer life for the equipment. Additionally, the station noise was significantly reduced with the smaller pump.

Multiple pumps for variable loads. The use of multiple pumps installed in parallel can be a cost-effective and energy-efficient solution for pump systems with variable loads. Parallel pumps offer redundancy and increased reliability, and can often reduce pump system electricity use by 10% to 50% for highly variable loads (Xenergy 1998). Parallel pump arrangements often consist of a large pump, which operates during periods of peak demand, and a small pump (or "pony" pump), which operates under normal, more steady-state conditions (U.S. DOE 2006f). Because the pony pump is sized for normal system operation, this configuration operates more efficiently than a system that relies on a large pump to handle loads far below its optimum capacity.

For example, one case study of a Finnish pulp and paper plant indicated that by installing a pony pump in parallel with an existing larger pump to circulate water from a paper machine into two tanks, electricity cost savings of $36,500 per year were realized with a simple payback period of just 6 months (U.S. DOE 2001b).

Impeller trimming. Impeller trimming refers to the process of reducing an impeller's diameter via machining, which will reduce the energy added by the pump to the system fluid. According to the U.S. DOE (2006f), one should consider trimming an impeller when any of the following conditions occur:

- Many system bypass valves are open, indicating that excess flow is available to system equipment.
- Excessive throttling is needed to control flow through the system or process.
- High levels of noise or vibration indicate excessive flow.
- A pump is operating far from its design point.

Trimming an impeller is slightly less effective than buying a smaller impeller from the pump manufacturer, but can be useful when an impeller at the next smaller available size would be too small for the given pump load. The energy savings associated with impeller trimming are dependent upon pump power, system flow, and system head, but are roughly proportional to the cube of the diameter reduction (U.S. DOE 2006f). An additional benefit of impeller trimming is a decrease in pump operating and maintenance costs.

To reduce energy consumption and improve the performance of its beer cooling process, the Stroh Brewery Company analyzed the glycol circulation system used for batch cooling of beer products at its G. Heileman Division brewing facility in La Crosse, Wisconsin. By simply trimming down the diameter of the pump impeller and fully opening the discharge gate valve, cooling circulation system energy use was reduced by 50%, resulting in savings of $19,000 in the first year. With a cost of $1,500, the simple payback period for this measure was about one month (U.S. DOE 2001c).

Avoiding throttling valves. Throttling valves and bypass loops are indications of oversized pumps as well as the inability of the pump system design to accommodate load variations efficiently, and should always be avoided (Tutterow et al. 2000). Pump demand reduction, controls, impeller trimming, and multiple pump strategies (all previously discussed in this section) should always be more energy-efficient flow management strategies than throttling valves.

Replacement of belt drives. According to inventory data of U.S. industrial pumps, up to 4% of pumps are equipped with V-belt drives (Xenergy 1998). Many of these V-belt drives can be replaced with direct couplings, which are estimated to lead to energy savings of around 1%.

Proper pipe sizing. Pipes that are too small for the required flow velocity can significantly increase the amount of energy required for pumping, in much the same way that drinking a beverage through a small straw requires a greater amount of suction. Where possible, pipe diameters can be increased to reduce pumping energy requirements, but the energy savings due to increased pipe diameters must be balanced with increased costs for piping system components. Increasing pipe diameters will likely only be cost effective during greater pump system retrofit projects. Xenergy (1998) estimate typical industrial energy savings in the 5% to 20% range for this measure.

Adjustable-speed drives (ASDs). Pumps that experience highly variable demand conditions are often good candidates for ASDs. As pump system demand changes, ASDs adjust the pump speed to meet this demand, thereby saving energy that would otherwise be lost to throttling or bypassing. The resulting energy and maintenance cost savings can often justify the investment costs for the ASD. However, ASDs are not practical for all pump system applications—for example, pump systems that operate at high static head and those that operate for extended periods under low-flow conditions (U.S. DOE 2006f).

9 Refrigeration Systems

Refrigeration systems are a significant consumer of electrical energy in the U.S. fruit and vegetable processing industry, particularly in the frozen fruit, juice, and vegetable manufacturing sub-sector (as evidenced in Figure 4.5). The most significant applications of refrigeration systems in the industry are in the generation of chilled water for various process cooling applications (e.g., the cooling stage in the juice pasteurization process) and the in generation of cold air for cold storage and fruit, vegetable, and juice concentrate freezing.

There are four primary components to the typical refrigeration system: (1) the compressor, (2) the condenser, (3) the expansion valve, and (4) the evaporator. In the first stage of the refrigeration cycle, refrigerant enters the compressor as a low pressure gas and is pressurized by the compressor into a hot, high pressure gas. The high pressure gas leaves the compressor and is circulated to the condenser. In the condenser, the high pressure gas is cooled via a heat exchanger with a cooling medium (typically ambient air), which causes it to condense into a hot liquid. The hot liquid refrigerant then proceeds through an expansion valve, which decreases the pressure of the refrigerant, causing it to cool. The cool refrigerant is then circulated to an evaporator. In the evaporator, the refrigerant accepts heat from its surroundings, causing it to vaporize into a low pressure gaseous state. In direct expansion evaporators, the evaporator coils are in direct contact with the object or fluid that is being refrigerated. In indirect expansion evaporators, the evaporator coils are in contact with a carrier medium, such as water or brine, which is then pumped to the object that is being refrigerated. From the evaporator, the low pressure gas is fed back to the compressor, completing the cycle.

Most refrigeration systems in the U.S. fruit and vegetables processing industry use ammonia as a refrigerant. Some favorable properties that make ammonia the refrigerant of choice include its high latent heat of vaporization, its classification as a non ozone-depleting substance, the fact that it is non-corrosive to iron and steel, and because ammonia leaks can often be easily detected by smell (Singh and Heldman 2001).

Because many fruit and vegetable processing operations are concentrated in the warmest months of the year, refrigeration systems must often be operated under heavy loads during daytime hours when electrical costs and outdoor temperatures are at their highest. Energy efficiency improvements to refrigeration systems can therefore lead to significant cost and energy savings in many fruit and vegetable processing facilities.

This chapter discusses some of the most significant energy efficiency measures available for industrial refrigeration systems. Measure descriptions are grouped under the following four major categories, based on their applicability: (1) refrigeration system management, (2) cooling load reduction, (3) compressors, and (4) condensers and evaporators.

9.1 Refrigeration System Management

Good housekeeping. Good housekeeping refers to simple steps that can be taken by all facility personnel on a regular basis to help keep refrigeration systems running properly and efficiently. Such actions include the following (EEBPP 2000a):

- Reporting and repairing any pipes that are vibrating.
- Making sure the control settings for the refrigeration system are easy to find and interpret for ease of system tuning and adjustment.
- Keeping the doors to cold storage areas closed whenever possible.
- Making sure that cold storage areas are not cooled to a lower temperature than is truly needed (refrigeration system energy use will increase by 1% to 3% for every degree (Fahrenheit) of additional cooling).
- Making sure that products are not stacked directly under or in front of evaporators in cold storage units.
- Minimizing other heat sources (such as lights and forklifts) in cold storage areas, which produce heat that will have to be removed by the refrigeration system.
- Reporting the formation of ice on cold storage area floors and walls. Ice indicates that a lot of air is entering the cold storage area, which carries moisture that gives off heat as it freezes, adding to the refrigeration load.
- Switching off system pumps and fans (such as those used for circulating cold air, chilled water, or anti-freeze) when not required. Pumps and fans can add significant heat loads to the refrigeration system during operation.
- Reporting and repairing damage to refrigeration system pipe insulation.
- Regularly checking compressor oil levels to ensure proper lubrication.
- Reporting and repairing any refrigerant leaks.

Monitoring system performance. Monitoring systems can help detect refrigeration system performance issues before they become major problems, helping to avoid major repair costs and keeping the system running at optimal efficiency. Monitoring involves the installation of sensors at key points in the refrigeration system, which can be as simple as visual gauges or as advanced as computer-based sensor and control networks. A basic monitoring system should include ongoing measurement and logging of compressor suction and discharge pressures; a drop in suction pressure typically indicates a refrigerant leak, while a rise in discharge pressure can indicate a blocked condenser (EEBPP 2000a). Ideally, monitoring systems should also have the ability to provide system and component level information to operating and maintenance staff as well as high-level performance summaries for management. In a review of energy efficiency opportunities for refrigeration systems in wineries, the energy savings associated with the installation of monitoring systems were estimated at 3% (Galitsky et al. 2005b).

Ensuring proper refrigerant charge. Low refrigerant charge affects many small direct expansion systems, and, if left unchecked, can lead to significant deteriorations in system performance and energy efficiency over time. Additionally, too much refrigerant charge (i.e., over-charging) can also reduce energy efficiency. Galitsky et al. (2005b) report that a low refrigerant charge or over-charging can increase the energy use of direct expansion systems by as much as 20%. Regular monitoring and maintaining of refrigerant charge is therefore critical for ensuring optimal system performance. The refrigerant sight glass should be checked periodically for bubbles (when the system is operating at steady state), which can indicate that refrigerant is leaking somewhere in the system (EEBPP 2000a).

Refrigeration system controls. Control systems can help improve the energy efficiency of refrigeration systems by ensuring optimal matching of cooling demand and component loads. Optimal matching is usually done by monitoring the temperature of the space, object, or media that is being cooled and adjusting the operation of key system components to maintain the desired temperature in the most efficient manner.

For example, Doble Quality Foods, a frozen food manufacturer in Cornwall, England, installed electronic controls on the expansion valves of its refrigeration system, which allowed for more precise evaporator temperature control. The control system saved the company £2,150 ($3,225 in 1993 U.S. dollars) in annual refrigeration system energy costs with a payback period of just 1.4 years (EEBPP 2001).

Fetzer Vineyards, a winery in Hopland, California, experienced even more impressive savings with the installation of an advanced refrigeration control system in 2001. Programmable logic controls and sensors were used to monitor return glycol temperature and pressure, allowing for efficient cycling of the system’s compressors to maintain the desired glycol conditions. The controls installation lowered the winery’s annual electricity use by over 168,000 kWh, saving the company $21,250 per year with a simple payback period of roughly three years (CEC 2002c).

Another important application of control systems is to ramp down or turn off system components during periods of non-use. For example, automatic switches or ASDs can be used to turn down or off system fans and pumps where feasible, with typical payback periods of one year or less (EEBPP 2000a).

The International Institute of Refrigeration recommends avoiding the following control strategies that may compromise system energy efficiency (Pearson 2003):

- Slide valve unloading of oversized screw compressors.

- Hot gas bypass of compressors.

- Throttling valves between evaporators and compressors.
- Evaporator control by starving refrigerant supply.
- Too frequent defrosts.
- Condenser head pressure controls, except when necessary.

Checking for refrigerant contamination. Refrigerants should be periodically checked for contamination such as oil, water, or debris, which can be an indication of system operating and maintenance problems. Galitsky et al. (2005b) estimate energy savings attributable to this measure at around 2%.

Efficient piping design. Interconnecting pipes should be designed such that their size and routing minimizes friction and pressure drops (e.g., using the largest diameter pipe that is economical for the system and avoiding excessive bends and fittings), thereby reducing energy losses in the system (Pearson 2003). This measure might only be economical in large retrofit or new system installation projects.

9.2 Cooling Load Reduction

Piping insulation. Pipes containing cold refrigerant (i.e., pipes between the expansion valve and evaporator) should be properly insulated to minimize heat infiltration. Piping insulation should be checked regularly for cracks or decay and repaired promptly as needed. Galitsky et al. (2005b) estimate the typical energy savings attributable to improved piping insulation at 3% with a payback period of less than two years.

Minimizing heat sources in cold storage areas. Sources of heat within cold storage areas such as lights, forklifts, motors, and even personnel, should be minimized because the refrigeration system must remove the additional heat that they produce. For example, it has been estimated that up to 15% of the refrigeration load in cold storage is due to heat from evaporator fans, and that lighting heat can add an additional 10% to the refrigeration load (Carbon Trust 2006). Thus, heat generating equipment should be switched off when not needed. Also, where feasible, product entering the cold storage area should be as close to the desired cold storage temperature as possible (EEBPP 2000b).

Reducing heat infiltration in cold storage areas. The infiltration of warm outside air can be reduced through proper door management and the use of tight sealing doors. Door seals should be inspected regularly, as faulty door seals can increase refrigeration system energy consumption by up to 11% (Carbon Trust 2006). Where strip/walk-in curtains are used, they should be periodically checked to ensure that they are intact and positioned properly. Additionally, doors should always be closed immediately after personnel or forklifts enter and leave the cold storage area; where feasible, doors that close automatically should be considered. In total, the energy losses associated with improper door management in cold storage areas have been estimated at 10% to 20% of the total cooling load (Galitsky et al. 2005b).

Reducing building heat loads. Refrigeration system compressors in poorly ventilated areas surrounded by warm air will run hotter than necessary, which will reduce compressor reliability and energy efficiency. Compressor areas should be adequately ventilated so that cool air is allowed to circulate around the compressor. Similarly, for air-cooled condensers, an ample supply of cool ambient air is necessary to keep condenser temperatures low. Energy efficiency measures aimed at the building structure, such as the use of adequate insulation and reflective roofing materials, can help reduce the heat load on compressors and condensers, helping them to run efficiently. These building energy efficiency measures and others are discussed further in Chapter 11.

Free cooling. Free cooling makes use of outside air for process and building cooling applications when outdoor air conditions are appropriate, which can reduce the load on refrigeration systems. According to Schepp and Nicol (2005), free cooling is suited for locations where many hours are below 40 degree Fahrenheit, and has led to energy savings of up to 15% in some Canadian facilities. Although not expected to be widely applicable in the U.S. fruit and vegetable processing industry, given that most operations are concentrated in warm weather months, this measure might be applicable for plants operating year-round in cold weather climates. The payback can be immediate where outdoor air makeup ducts and ventilation control systems already exist, but can range from two to four years when building retrofits are required (Schepp and Nicol 2005).

Nighttime air cooling is a form of free cooling, in which cooler outside air is allowed into facility and office areas at night to reduce daytime building heat loads.

Properly sized motors. Oversized motors on pumps and fans in refrigeration systems can result in unnecessary energy losses. It has been estimated that correcting for motor oversizing can save 1.2% of motor electricity consumption (Xenergy, 1998).

Hydrocooling. In hydrocooling, fruits and vegetables are cooled using chilled water just prior to freezing to reduce the cooling demand on freezers. Chilled water is typically produced using a heat exchanger and put into direct contact with the fruits and vegetables, either in shower-type units or immersion-type units. Hackett et al. (2005) report that using hydrocooling to cool fruits and vegetables down to just above freezing is much more energy efficient than using the evaporators in freezers to perform the same service.

Removal of surface water before freezing. Excess water on the surfaces of fruits and vegetables prior to freezing (typically due to product washing or hydrocooling) leads to unnecessary energy consumption in the freezing tunnel because water must be frozen along with the product. The removal of residual water on products prior to freezing can be accomplished by using a vibrating mesh or a perforated belt to convey products into freezing chambers (European Commission 2006).

Geothermal cooling. Geothermal cooling takes advantage of underground temperatures that stay cool and constant throughout the year. Geothermal cooling systems circulate water below ground through a series of pipes where it is cooled by the surrounding earth and subsequently pumped back to the surface. Where feasible, such systems can replace or augment existing refrigeration systems, leading to significant energy savings.

In 2005, Aohata Corporation, a jam manufacturer in Japan, began operating a new geothermal cooling system that provided its facility with 260 kW of additional cooling capacity. Water is circulated below ground through a series of pipes placed in 37 holes that are drilled to a depth of 100 meters. The company reported that the geothermal cooling system uses only about 25% of the electricity required by a traditional refrigeration system (Japan for Sustainability 2006).

9.3 Compressors

Compressor control systems and scheduling. The compressor is the workhorse of the refrigeration system, and the use of control systems to effectively match compressor loads to cooling demands is often a sound strategy for energy efficiency. Control systems can help compressors operate at optimal efficiency by monitoring and adjusting to system flow conditions and by scheduling the operation of multiple compressors to minimize part-load operation (e.g., running one compressor at 100% rather than two compressors at 50%) (EEBPP 2000b). Compressor control systems are discussed in further detail in Chapter 10.

Rainier Cold Storage, a cold storage warehouse and frozen seafood products company located in Seattle, Washington, used to run its seven refrigeration plant compressors manually before a computer control upgrade in the early 1990s. The company installed controls consisting of sensors and computer software, which automatically modulated compressor discharge and suction pressures to improve the coefficient of performance and to better adjust compressor operation to changes in refrigeration system cooling demand. The upgrade led to annual energy savings of 367,000 kWh as well as reduced operations and maintenance costs through more efficient system operation (CADDET 2004b). The reported payback period, which included both electricity bill savings and reduced operations and maintenance costs, was around 2.6 years.

Floating head pressure control. Floating head pressure control can be a particularly effective control strategy for reducing compressor energy consumption. Floating head pressure control allows compressor head pressures to move up or down with variations in ambient wet-bulb temperature, saving energy compared to fixed head pressure operation. However, additional energy is required for the condenser fan, which must be balanced with compressor energy savings. It is also important not to allow head pressure to go too low, as certain system demands (e.g., liquid injection oil cooling or defrosting) might require minimum head pressures (Galitsky et al. 2005b). Hackett et al. (2005) estimate a typical payback period of less than one year for floating head pressure control systems.

A U.S. DOE sponsored energy audit at the Odwalla Juice Company's facility in Dinuva, California, estimated that the use of floating head pressure control on the facility's seven ammonia compressors would save the company nearly $108,000 per year in energy costs (U.S. DOE 2002a). Total estimated electricity savings were around 1 million kWh per year at a payback period of only six months.

Birds Eye Walls, a UK based manufacturer of frozen foods, implemented refrigeration controls that allowed for floating head pressure in its Gloucester, England, facility in 1994. The controls led to a 30% lower head pressure on average, allowing the company to save around £150,000 ($225,000 in 1994 U.S. dollars) in refrigeration costs annually (CADDET 2000a). At an initial investment cost of less that £30,000 ($45,000 in 1994 U.S. dollars), the payback period was less than three months.

Indirect lubricant cooling. Direct injection of refrigerant is an inefficient method for compressor cooling that can decrease the overall efficiency of screw-type compressors by as much as 5% to 10% (ISU 2005). An indirect system is a more efficient option for lubricating and cooling screw-type compressors, in which a heat exchanger is used in conjunction with cooling tower water, a section of an evaporative condenser, or a thermosyphon system to cool compressor lubricant.

Raising system suction pressure. In two-stage compressor systems, a simple way to save energy is to raise the suction pressure and temperature of the low-stage compressor when ambient temperatures decrease. It has been estimated that energy savings of about 8% can be realized in two-stage systems when suction temperatures are raised from -30 °F to -20 °F (ISU 2005).

Adjustable-speed drives (ASDs) on compressor motors. Adjustable-speed drives can be used in conjunction with control systems to better match compressor loads to system cooling requirements. The Industrial Refrigeration Consortium (2004a) reports that ASDs used on compressors below a part-load ratio of about 95% will deliver performance equal to a fixed speed compressor but with lower electricity requirements. However, at near full (i.e., 100%) load, ASDs are approximately 3% less efficient than fixed speed drives due to electrical power losses associated with the ASD controller. Adjustable-speed drives are thus most beneficial for refrigeration systems with large differences between required and installed condenser capacities (ISU 2005). Galitsky et al. (2005b) have estimated average refrigeration system energy savings of 10% from the use of ASDs on compressors.

Naumes, Inc., an Oregon based company specializing in fruit growing, processing, storage, and juice production, recently upgraded their ammonia-based refrigeration system with computer controls and ASD compressors for more efficient matching of cooling demand and system load. The new system saved the company a reported 741,000 kWh per year, with total annual energy savings of around $37,000 (CADDET 2004a). The simple payback period was estimated at just over two years.

As part of a planned expansion for its dairy facility in Portland, Oregon, WestFarm Foods installed a new compressor with a 350 hp ASD, which allowed the remaining system compressors to either be off or working efficiently at 100% load. Other upgrades included new refrigeration system controls and ASDs on the system's evaporator fans. The total system upgrade reduced annual refrigeration system energy consumption by nearly 40% and annual operating costs by around $75,000 (Cascade Energy Engineering 2005). At an investment cost of $310,000, the payback period was estimated at roughly four years; however, energy efficiency investment incentives from Portland General Electric (the local utility company) as well as a 35% tax credit from the Oregon Department of Energy helped reduce the final payback to around one year.

In 2003, Oregon Freeze Dry, a manufacturer of freeze-dried fruits, vegetables, and other specialty foods, installed ASDs on its refrigeration system screw compressors at its Albany, Oregon, facility. The company also decided to replace an undersized eight inch suction line with a new 12 inch line. The energy savings of the ASD and suction line installations amounted to nearly 2 million kWh per year (a 66% reduction), while energy cost savings amounted to $77,700 per year (FIRE 2005b).

Compressor heat recovery. Where economically feasible, rejected heat can be recovered from compressors and used in other facility applications, such as space heating or water heating. Further details on this measure are provided in Chapter 10.

Dedicating a compressor to defrosting. It has been reported that if one compressor of a large system can be dedicated to running at the pressure needed for the defrost cycle, while the other compressors can be run at lower system pressures, that the resulting energy savings (due to reduced condensing pressure) can often justify the cost of the dedicated compressor (ISU 2005).

9.4 Condensers and Evaporators

Keeping condensers clean. Condensers should be checked regularly for dirt, ice buildup, or plugged nozzles, which can reduce heat transfer rates and thus raise the condensing temperature. Furthermore, water-cooled and evaporative condensers should be kept free of hard water or bacterial buildup, which can cause fouling, scaling, and clogging that can also lead to increased condensing temperatures. In general, a one degree Celsius (1.8 degrees Fahrenheit) increase in condensing temperature will increase operating costs by 2% to 4% (EEBPP 2000a). Badly corroded condensers should be replaced as soon as possible.

Automatic purging of condensers. Periodic purging of evaporative condensers is needed to remove non-condensable gases (such as air), which can reduce refrigeration system efficiency by increasing system head pressure and impeding condenser heat transfer (CADDET 1996). Automatic purging systems can help refrigeration systems operate efficiently by ensuring purging occurs on a regular basis. Automatic purging systems can also reduce the refrigerant loss and labor costs associated with manual purging.

Excel Logistics Ltd., an operator of cold storage facilities in the United Kingdom, installed a five-point automatic refrigeration purging system at their Glasgow, Scotland, facility in 1989. Previously, the company purged its system manually on a weekly basis, which was time consuming and often led to refrigerant loss. The automatic purging system featured computer controls and five different refrigeration system purge points: one at each end of the receiver, one on each of the two condenser outlets, and one on the hot gas line. The company reported that the automatic purging system led to a 15% reduction in compressor energy use and £8,800 ($15,400 in 1991 U.S. dollars) in annual energy savings (CADDET 1996). The simple payback period, including both energy and maintenance cost savings, was 10 months.

Reducing condenser fan use. Sometimes condenser fans are operated continuously, even when the refrigeration system's compressor isn't running. This practice wastes energy. Wherever possible, the operation of condenser fans should be coupled to the operation of the system's compressors to ensure that the fans are only run when needed.

Reducing condensing pressure. This measure is similar to floating head pressure control for compressors (discussed above). To reduce the energy required to compress refrigerant, condensing pressures and temperatures should be set as low as possible. Computer controls can be installed on condensing systems to minimize condensing temperatures and pressures based on ambient wet-bulb temperatures, as well as to optimize the use of condenser fans and water (ISU 2005). Lowering the condensing temperature can reduce compressor energy use by around 2% to 3% for every degree Celsius (1.8 degrees Fahrenheit) of temperature reduction (SenterNovem 2003).

Use of axial condenser fans. Air-cooled or evaporative condensers generally do not need high-pressure air, and thus axial fans are well suited for this application. Axial fans can reduce compressor fan energy use by up to 50% compared to centrifugal fans (ISU 2005).

Adjustable-speed drives (ASDs) on condenser fans. For refrigeration systems with large differences between installed and operating condensing capacity, the use of ASDs on condenser fans can lead to significant energy savings compared to fixed-speed condenser fans. Prior to installing ASDs, however, it is important to establish the extent to which the condensing pressure can be floated. On systems where floating head operation is stable, ASDs can lower condenser fan energy consumption by up to 40% compared to operating a fixed-speed condenser fan in on/off fashion (IRC 2004b).

Cycling of evaporator fans in cold storage. It is often possible to maintain adequate temperature in cold storage areas without continuously running evaporator fans. Where feasible, evaporator fans can be turned off or ramped down periodically using timers or variable-speed control systems to save electricity while still maintaining proper cold storage temperatures. The cycling of evaporator fans should be managed carefully, however, to avoid stratification (i.e., warm and cool layers of air in the cold storage space) and to ensure that solenoids are cycled properly (for flooded and recirculated evaporators) (Galitsky et al. 2005b).

In 1996, Stahlbush Island Farms, a grower, canner, and freezer of fruits and vegetables in Corvalis, Oregon, installed timers to cycle the evaporator fans of its cold storage unit. Prior to the installation of the timers, evaporator fans were run close to 24 hours per day. By cycling the evaporator fans, the company was able to save around 133,000 kWh of electricity per year because the fans ran for fewer hours and the fan motors released less heat into the cold storage unit (ODEQ 1996). The annual savings were estimated at $4,500 and, with a one-time implementation cost of $1,000, the simple payback period was around three months.

Adjustable-speed drives (ASDs) on evaporator fans. Similar to ASDs on condenser fans, for refrigeration systems with excess evaporator capacity, the installation of ASDs can lead to significant energy savings compared to fixed-speed fans. The cost effectiveness of ASDs, however, depends on the number of hours the evaporator fans can be run under part-load conditions. In an analysis of a -20° Fahrenheit freezer with seven evaporators, the use of ASDs on evaporator fans at a load ratio of 50% required 20% lower power than fixed-speed fans under the same operating conditions (IRC 2004c).

The U.S. DOE has supported the development of a simple evaporator fan controller for medium temperature (28° F to 40° F) walk-in refrigeration units, which is capable of varying fan speed is reported to reduce evaporator and compressor energy consumption by 30% to 50% (U.S. DOE 2001e). The controller regulates the speed of evaporator fan motors to better match cooling demands in the refrigeration cycle. The U.S. DOE estimates typical payback periods of one to two years. As of 2000, the controller had been installed in 300 refrigeration units and had led to cumulative energy savings of around $80,000. According to BC Hydro (2004), evaporator fan controllers are not good candidates for freezers that run under 28° Fahrenheit, have compressors that run continuously, have evaporator fans that run on poly-phase power, and have evaporator fans of types other than shaded-pole and permanent-split-capacitor.

Demand defrost. Evaporators should be defrosted only when necessary, as opposed to on timed schedules where defrosting occurs regardless of need. Defrosting cycles should ideally be based on coil pressure readings, where an increase in pressure drop indicates that frost is present on the coils (which reduces system efficiency) and that defrosting is necessary (ISU 2005).

Water defrosting. Water defrosting is said to be more efficient than hot gas defrosting (a common method of defrosting in which hot refrigerant gas is cycled through the system) (ISU 2005). In water defrosting, water is sprayed manually over the evaporator coils to remove frost. However, water defrosting must be managed properly to ensure that the water does not freeze on the evaporator coils.

10 Compressed Air Systems

Compressed air generally represents one of the most inefficient uses of energy in U.S. industry due to poor system efficiency. Typically, the efficiency of a compressed air system—from compressed air generation to end use—is only around 10% (U.S. DOE and CAC 2003). Because of this inefficiency, if compressed air is used, it should be of minimum quantity for the shortest possible time; it should also be constantly monitored and weighed against potential alternatives.

Many opportunities to reduce energy consumption in compressed air systems are not prohibitively expensive; payback periods for some options can be extremely short. Energy savings from compressed air system improvements can range from 20% to 50% of total system electricity consumption (McKane et al. 1999). Common energy efficiency measures for industrial compressed air systems are discussed below. Additionally, a number of measures that are applicable to refrigeration system compressors (Chapter 9) and motors (Chapter 8) are also applicable to compressed air systems.

10.1 Energy Efficiency Measures for Compressed Air Systems

System improvements. Adding additional compressors should be considered only after a complete system evaluation. In many cases, compressed air system efficiency can be managed and reconfigured to operate more efficiently without purchasing additional compressors. System improvements utilize many of the energy efficiency measures for compressors discussed below. Compressed air system service providers offer integrated services both for system assessments and for ongoing system maintenance needs, alleviating the need to contact several separate firms. The Compressed Air Challenge® (http://www.compressedairchallenge.org) offers extensive training on the systems approach, technical publications, and free web-based guidance for selecting the right integrated service provider. Also provided are guidelines for walk-through evaluations, system assessments, and fully instrumented system audits (CAC 2002).

Maintenance. Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes the following (U.S. DOE and CAC 2003; Scales and McCulloch 2007):

- *Ongoing filter inspection and maintenance.* Blocked filters increase the pressure drop across the filter, which wastes system energy. By inspecting and periodically cleaning filters, filter pressure drops may be minimized. Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear. Generally, when pressure drops exceed 2 psi to 3 psi, particulate and lubricant removal elements should be replaced. Regular filter cleaning and replacement has been projected to reduce compressed air system energy consumption by around 2% (Radgen and Blaustein 2001).

- *Keeping compressor motors properly lubricated and cleaned*. Poor motor cooling can increase motor temperature and winding resistance, shortening motor life and increasing energy consumption. Compressor lubricant should be changed every 2 to 18 months and periodically checked to make sure that it is at the proper level. In addition, proper compressor motor lubrication will reduce corrosion and degradation of the system.

- *Inspection of fans and water pumps* for peak performance.

- *Inspection of drain traps* to ensure that they are not stuck in either the open or closed position and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and should never be undertaken. Instead, simple pressure driven valves should be employed. Malfunctioning traps should be cleaned and repaired instead of left open. Some auto drains, such as float switch or electronic drains, do not waste air. Inspecting and maintaining drains typically has a payback of less than two years (U.S. DOE 2004b).

- *Maintaining the coolers* on the compressor to ensure that the dryer gets the lowest possible inlet temperature (U.S. DOE and CAC 2003).

- *Compressor belt inspection.* Where belt-driven compressors are used, belts should be checked regularly for wear and adjusted. A good rule of thumb is to adjust them after every 400 hours of operation.

- *Replacing air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2 psi to 3 psi pressure drop at full load. When the pressure drop increases to 10 psi, the separator should be changed (U.S. DOE and CAC 2003).

- *Checking water-cooling systems* regularly for water quality (pH and total dissolved solids), flow, and temperature. Water-cooling system filters and heat exchangers should be cleaned and replaced per the manufacturer's specifications.

- *Minimizing compressed air leak throughout the systems.*

- Applications requiring compressed air should be *checked for excessive pressure, duration, or volume*. Applications not requiring maximum system pressure should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Using more pressure than required wastes energy and can also result in shorter equipment life and higher maintenance costs. Case studies have demonstrated that the payback period for this measure can be shorter than half a year (IAC 2005).

Monitoring. In addition to proper maintenance, a continuous monitoring system can save significant energy and operating costs in compressed air systems. Effective monitoring systems typically include the following (CADDET 1997a):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.
- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.
- Flow meters to measure the quantity of air used.
- Dew point temperature gauges to monitor the effectiveness of air dryers.
- Kilowatt-hour meters and hours run meters on the compressor drive.
- Checking of compressed air distribution systems after equipment has been reconfigured to be sure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.
- Checking for flow restrictions of any type in a system, such as an obstruction or roughness, which can unnecessarily raise system operating pressures. As a rule of thumb, every 2 psi pressure rise resulting from resistance to flow can increase compressor energy use by 1% (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, after-coolers, moisture separators, dryers and filters.
- Checking for compressed air use outside production hours.

Leak reduction. Air leaks can be a significant source of wasted energy. A typical industrial facility that has not been well maintained will likely have a leak rate ranging from 20% to 30% of total compressed air production capacity (U.S. DOE and CAC 2003). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein 2001).

The magnitude of the energy loss associated with a leak varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 87 psi with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250 kWh per year (CADDET 1997a). Several industrial case studies suggest that the payback period for leak reduction efforts is generally shorter than two months (IAC 2005).

In addition to increased energy consumption, leaks can make air-powered equipment less efficient, shorten equipment life, and lead to additional maintenance costs and increased unscheduled downtime. Leaks also cause an increase in compressor energy and maintenance costs.

The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects, and thread sealants. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. Leak detection and repair programs should be ongoing efforts.

In 1994, Mead-Johnson Nutritionals, a manufacturer of infant formula and adult nutritional supplements, implemented a compressed air system improvement project at its plant in Evansville, Indiana. Energy efficiency measures included the introduction of a monitoring system, the installation of new compressors, and the repair of leaks. The improved compressed air system of this plant functioned so efficiently that only two-thirds of the compressed air capacity had to be kept online. The company saved $102,000 per year in compressed air system energy costs (4% of the total power costs of the plant) with a payback period of just over 2.5 years. Additionally, the project helped the plant avoid the purchase of a new ($900,000) compressor (DOE 2001d).

Turning off unnecessary compressed air. Equipment that is no longer using compressed air should have the air turned off completely. This can be done using a simple solenoid valve. Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

Modification of system in lieu of increased pressure. For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, such as employing a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

Replacement of compressed air by alternative sources. Many operations can be accomplished more economically and efficiently using energy sources other than compressed air (U.S. DOE 2004c, 2004d). Various options exist to replace compressed air use, including:

- Cooling electrical cabinets: air conditioning fans should be used instead of using compressed air vortex tubes.

- Flowing high-pressure air past an orifice to create a vacuum: a vacuum pump system should be applied instead of compressed air venturi methods.

- Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air.

- Cleaning parts or removing debris: brushes, blowers, or vacuum pump systems should be used instead of compressed air.

- Moving parts: blowers, electric actuators, or hydraulics should be used instead of compressed air.

- Tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales 1995). However, it has been reported that motors can have less precision, shorter lives, and lack safety compared to compressed air. In these cases, using compressed air may be a better choice.

Based on numerous industrial case studies, the average payback period for replacing compressed air with other applications is estimated at 11 months (IAC 2005).

Improved load management. Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of two years or less (Ingersoll-Rand 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.2 years (IAC 2005).

In June 2004, the Canandaigua Wine Company upgraded the compressed air system at its winery in Lodi, California. Before the project began, the winery was served by two 125 hp rotary screw compressors that operated at full load only during the 3-month fall grape crushing season. During the rest of the year, however, the compressors were operated at part-load, which wasted energy. The company opted to install a 75 hp variable-speed compressor, which could be used to satisfy facility demand during the off-season while also providing supplemental power to the two 125 hp units during the fall crush season. Additionally, the company installed a new compressor control system, additional storage, and started a leak reduction campaign. The total energy savings attributable to the upgrade were estimated at 218,000 kWh per year, saving the company $27,000 annually (U.S. DOE 2005d). The simple payback period was estimated at 1.2 years.

Similarly impressive savings were realized with a compressor upgrade at a Sara Lee bakery in Sacramento, California, in 2004. Prior to the upgrade, the company used one 100 hp and two 150 hp rotary screw compressors in its compressed air system. After the upgrade, the company used the 100 hp fixed-speed unit as its base compressor and a new 100 hp ASD compressor for variable loads. The project reduced annual facility energy consumption by 471,000 kWh and annual energy costs by around $40,000, while also saving the company

$10,000 per year in avoided maintenance costs (U.S. DOE 2005e). The reported payback period was just 6.5 months.

Pressure drop minimization. An excessive pressure drop will result in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, results in higher operating pressures than is truly needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles, and lubricators (demand side), as well as air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized. Audits of industrial facilities found that the payback period is typically shorter than 3 months for this measure (IAC 2005).

Inlet air temperature reduction. If airflow is kept constant, reducing the inlet air temperature reduces the energy used by the compressor. In many plants, it is possible to reduce the inlet air temperature to the compressor by taking suction from outside the building. As a rule of thumb, each temperature reduction of 5°F (3°C) will save 1% compressor energy (CADDET 1997a; Parekh 2000). A payback period of two to five years has been reported for importing fresh air (CADDET 1997a). In addition to energy savings, compressor capacity is increased when cold air from outside is used. Industrial case studies have found an average payback period for importing outside air of less than 1.7 years (IAC 2005), but costs can vary significantly depending on facility layout.

Controls. The primary objectives of compressor control strategies are to shut off unneeded compressors and to delay bringing on additional compressors until needed. Energy savings for sophisticated compressor controls have been reported at around 12% annually (Radgen and Blaustein 2001). An excellent review of compressor controls can be found in Compressed Air Challenge® *Best Practices for Compressed Air Systems* (Second Edition) (Scales and McCulloch 2007). Common control strategies for compressed air systems include:

- *Start/stop (on/off) controls*, in which the compressor motor is turned on or off in response to the discharge pressure of the machine. Start/stop controls can be used for applications with very low duty cycles and are applicable to reciprocating or rotary screw compressors. The typical payback for start/stop controls is one to two years (CADDET 1997a).

- *Load/unload controls*, or constant speed controls, which allow the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003). Hence, load/unload controls can be inefficient.

- *Modulating or throttling controls*, which allow the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors.

  At the Truitt Brothers fruit, vegetable, and specialty foods cannery in Salem, Oregon, the installation of variable-speed controls in 2001 led to compressor energy savings of 9% (FIRE 2005c).

- *Single master sequencing system controls*, which take individual compressor capacities on-line and off-line in response to monitored system pressure demand and shut down any compressors running unnecessarily. System controls for multiple compressors typically offer a higher efficiency than individual compressor controls.

- *Multi-master controls*, which are the latest technology in compressed air system control. Multi-master controls are capable of handling four or more compressors and provide both individual compressor control and system regulation by means of a network of individual controllers (Martin et al. 2000). The controllers share information, allowing the system to respond more quickly and accurately to demand changes. One controller acts as the lead, regulating the whole operation. This strategy allows each compressor to function at a level that produces the most efficient overall operation. The result is a highly controlled system pressure that can be reduced close to the minimum level required (U.S. DOE and CAC 2003). According to Nadel et al. (2002), such advanced compressor controls are expected to deliver energy savings of about 3.5% where applied.

Yasama Corporation U.S.A., a manufacturer of soy sauce, installed new compressor system controls at its Salem, Oregon, facility in 2004. Previously, the company ran its three compressors using inefficient individual load/unload controls. Additionally, the company added two 2,200 gallon air storage receivers to help handle the facility's short-term peak loads. Under the new control strategy, the three compressors were sequenced to run most efficiently, leading to annual energy savings of 100,000 kWh and annual electricity savings of $5,100 (FIRE 2005d). Additionally, the new control system allowed the company to better manage the total operating hours of each compressor as well as the number of starts per unit per hour, helping to reduce compressor wear and tear.

In addition to energy savings, the application of controls can sometimes eliminate the need for some existing compressors, allowing extra compressors to be sold or kept for backup. Alternatively, capacity can be expanded without the purchase of additional compressors.

Reduced operating pressures will also help reduce system maintenance requirements (U.S. DOE and CAC 2003).

Properly sized pipe diameters. Increasing pipe diameters to the greatest size that is feasible and economical for a compressed air system can help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings. Increasing pipe diameters typically reduces compressed air system energy consumption by 3% (Radgen and Blaustein 2001). Further savings can be realized by ensuring other system components (e.g., filters, fittings, and hoses) are properly sized.

H.B. Reese, a subsidiary of the Hershey Foods Company, overhauled the compressed air system piping network at its Hershey, Pennsylvania, facility in 1996. The plant modified and replaced undersized components such as filters, lubricators, fittings, and hoses, which lowered the minimum system operating pressure from 85 psi to 75 psi (a 12% decrease) (U.S. DOE 2002d).

Heat recovery. As much as 90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50% to 90% of this available thermal energy and apply it to space heating, process heating, water heating, make-up air heating, boiler make-up water preheating, and heat pump applications (Parekh 2000). It has been estimated that approximately 50,000 Btu/hour of recoverable heat is available for each 100 cfm of compressor capacity (U.S. DOE and CAC 2003). Payback periods are typically less than one year (Galitsky et al. 2005a).

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is somewhat low. However, with large water-cooled compressors, recovery efficiencies of 50% to 60% are typical (U.S. DOE and CAC 2003).

Natural gas engine-driven air compressors. Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive and can have higher maintenance costs, but may have lower overall operating costs depending on the relative costs of electricity and gas. Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. However, gas engine-driven compressors have some drawbacks: they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime. According to Galitsky et al. (2005a), gas engine-driven compressors currently account for less than 1% of the total air compressor market.

Ultra Creative Corporation, a U.S. manufacturer of specialty plastic bags, installed gas engine-driven compressors in its plant in Brooklyn, New York. The initial costs were $85,000 each for two 220 hp units and $65,000 for one 95 hp unit. The company reported savings of $9,000 in monthly utilities (averaging $108,000 annually) (Audin 1996).

Nestlé Canada found that its gas engine-driven air compressor system was a cost effective option when it was operated properly. The company's projected payback period was estimated as low as 2.6 years with a 75% efficient heat recovery system, and as high as 4.2 years without heat recovery (Audin 1996).

11 Building Energy Efficiency Measures

This chapter summarizes significant energy efficiency measures related to building lighting and HVAC systems.

Lighting systems and HVAC systems are significant consumers of electricity at many fruit and vegetable processing facilities, together accounting for anywhere from 10% to 25% of total electricity use (see Figures 4.4 and 4.5). Additionally, HVAC systems are expected to consume around 5% of total facility natural gas use.

The energy efficiency measures discussed in the remainder of this chapter are applicable to most workspaces within a typical fruit and vegetable processing facility, including manufacturing areas, offices, laboratory spaces, and warehouses.

11.1 Energy Efficiency Measures for HVAC Systems

Energy-efficient system design. The greatest opportunities for energy efficiency exist at the design stage for HVAC systems in new industrial facilities. By sizing equipment properly and designing energy efficiency into a new facility, fruit and vegetable processors can minimize the energy consumption and operational costs of HVAC systems from the outset. This practice often saves money in the long run, as it is generally cheaper to install energy-efficient HVAC equipment at building construction than it is to upgrade an existing building with an energy-efficient HVAC system later on, especially if those upgrades lead to production downtime.

Recently, Mission Foods, a California manufacturer of specialty Mexican foods, worked with Southern California Edison (its local utility company) to design its new production facility in Rancho Cucamonga to be as energy efficient as possible. The new facility had 50,000 square feet of office space, 125,000 square feet of manufacturing space, and 134,000 square feet of warehouse space. Mission Foods chose to install energy-efficient technologies for its HVAC systems and lighting systems, room occupancy sensors that turned off lights automatically, low-emissivity windows that reduced building heat gain, and skylights that provided natural lighting. The total project (which also included refrigeration system measures) allowed the company to reduce the electricity consumption of its new facility by roughly 18% compared to its existing facilities, leading to annual energy savings of over $300,000 per year (EDR 2005).

Recommissioning. Before replacing HVAC system components to improve energy efficiency, the possibility of HVAC system recommissioning should be explored. Recommissioning is essentially the same process as commissioning, but applied to a building's existing HVAC, controls, and electrical systems (U.S. EPA 2004).

Commissioning is the process of verifying that a new building functions as intended and communicating the intended performance to the building management team. This usually occurs when a new building is turned over for occupancy. In practice, commissioning costs are not included in design fees and often compete with other activities. As a result, commissioning is seldom pursued properly. It is critical that the building is commissioned to ensure that energy performance and operational goals are met. To achieve this, ENERGY STAR recommends the following:

- Communicate your energy performance goals during commissioning to ensure that the design target is met. Encourage energy-use tracking that will allow performance comparisons to be made over time.

- Specify detailed commissioning activities in your project contracts. Seek separate funding for commissioning work to ensure that it is given the appropriate level of importance.

- Hire experts that specialize in building commissioning. Include the commissioning firm as part of the design team early in the project.

- Finalize and transfer a set of technical documents including manufacturers' literature for systems and components. Supplement technical literature with summaries of intended operation. Provide additional explanation for innovative design features.

Recommissioning involves a detailed assessment of existing equipment performance and maintenance procedures for comparison to intended or design performance and maintenance procedures to identify and fix problem areas that might be hampering building energy efficiency. Recommissioning can be a cost-effective retrofit in itself, sometimes generating more savings than the cost of the retrofit measure. For example, recommissioning may help avoid the need to install new or additional equipment, leading to savings in capital investments.

The U.S. EPA’s ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) recommends a stepwise approach to recommissioning, in which a series of strategically-ordered building “tune up” strategies are pursued in order. First, lighting and supplemental loads should be assessed, then the building envelope, then controls, then testing, adjusting and balancing, then heat exchange equipment, and finally heating and cooling systems. Most of these steps relate to HVAC system components or factors that will directly affect HVAC system energy consumption (such as building envelope and lighting). For more information, the U.S. EPA’s ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) should be consulted (see also http://www.energystar.gov).

Energy monitoring and control systems. An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC system problems. Several industrial case studies from the United States indicate that the average payback period for HVAC control systems is about 1.3 years (IAC 2005).

Non-production hours set-back temperatures. Setting back building temperatures (i.e., turning building temperatures down in winter or up in summer) during periods of non-use, such as weekends or non-production times, can lead to significant savings in HVAC energy consumption.

Duct leakage repair. Duct leakage can waste significant amounts of energy in HVAC systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. According to studies by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces could reduce HVAC energy consumption by up to 30% (Galitsky et al. 2005a).

One commercial building in Apple Valley, California, adopted a technique called the mobile aerosol-sealant injection system (MASIS) to reduce duct leakage. The application of MASIS resulted in a reduction in overall duct leakage from 582 cfm to 74 cfm, leading to a 34% increase in the overall efficiency of the building's HVAC system (Carrier Aeroseal 2002).

Variable-air-volume systems. Variable-air-volume systems adjust the rate of air flow into a room or space based on the current air flow requirements of that room or space. Variable-air-volume systems therefore work to more closely match HVAC load to heating and cooling demands, which reduces energy use.

Adjustable-speed drives (ASDs). Adjustable speed drives can be installed on variable-volume air handlers, as well as recirculation fans, to match the flow and pressure requirements of air handling systems precisely. Energy consumed by fans can be lowered considerably since they are not constantly running at full speed. Adjustable-speed drives can also be used on chiller pumps and water systems pumps to minimize power consumption based on system demand.

Heat recovery systems. Heat recovery systems reduce the energy required to heat or cool facility intake air by harnessing the thermal energy of the facility's exhaust air. Common heat recovery systems include heat recovery wheels, heat pipes, and run-around loops. The efficiency of heat pipes is in the 45% to 65% range (U.S. EPA/DOE 2003), while the efficiency of run-around loops can be slightly higher, in the 55% to 65% range (U.S. EPA/DOE 2001).

Fan modification. Changing the size or shape of the sheaves of a fan can help to optimize fan efficiency and airflow, thereby reducing energy consumption. In a case study from the automotive industry, a Toyota plant optimized the sheaves of its fans in lieu of installing ASDs on fans. Toyota found better savings and payback periods with sheave modification than they anticipated to experience from ASDs (Galitsky et al. 2005a).

Efficient exhaust fans. Exhaust fans are standard components in any HVAC system. Mixed flow impeller exhaust fans offer an efficient alternative to traditional centrifugal exhaust fans. Mixed flow impeller fans are typically 25% more efficient than centrifugal fans, and can also be cheaper to install and maintain. The expected payback period for this measure is around two years (Tetley 2001).

Use of ventilation fans. Ventilation fans installed in the ceilings of work areas can help de-stratify the workspace air, leading to better circulation of cool air in summer and warm air in winter, and more even distributions of temperature from floor to ceiling. Such fans can help to reduce the load on building heating systems by helping to "push down" warm air that rises to the ceiling during facility heating months.

Yasama Corporation U.S.A., a manufacturer of soy sauce, installed new high bay ceiling fans to improve air circulation at its Salem, Oregon, facility in 2004. Previously, to provide heat during the winter, the company operated ceiling-mounted heaters with 15 hp fans in its production area. However, the fans didn't de-stratify the air in the production area's tall ceilings, nor take advantage of the heat given off by process equipment. Furthermore, to provide ventilation in the summer, the company ran the heater fans in "fan only" mode in conjunction with six 3 hp exhaust fans to remove hot air. The new high-bay ceiling fans were operated using only 1.5 hp motors, which were expected to lead to electrical energy savings of 48,000 kWh per year and electricity cost savings of $2,500 (FIRE 2005d). Furthermore, the company expected to save significant amounts of natural gas in heating months through reduced operation of the heaters.

Cooling water recovery. If available, secondary cooling water from municipal sources can be leveraged to reduce chiller energy consumption. In Washington, Boeing partnered with Puget Sound Power and Light and the King County Department of Metropolitan Services to recycle secondary treated cooling water into its chiller system. By doing so, Boeing reduced its water consumption by 48 million gallons per year, leading to projected savings of 20% in its cooling energy consumption (Michaelson and Sparrow 1995). As an additional benefit, Boeing also expected to save on refrigerants and treatment chemicals for its cooling tower water.

Solar air heating. Solar air heating systems, such as Solarwall®, use conventional steel siding painted black to absorb solar radiation for insulation. Fresh air enters the bottom of the panels where it is heated as it passes over the warm absorber. Fans distribute the air. Using this technology, Ford Motor Company's Chicago Stamping plant turned the south wall of its plant into a huge solar collector (CREST 2001). Energy savings were estimated to be over $300,000 per year compared to conventional gas air systems. Capital costs were $863,000 ($14.90 per square foot, including installation) resulting in a payback period of less than three years. In addition to energy savings, the system was said to provide clean fresh air for employees, even out hot and cold spots in the plant, and reduce emissions. However, this measure is only of interest for buildings in cold climates, and the potential benefits should be analyzed based on the local conditions of each site.

Building reflection. Use of a reflective coating on the roof of buildings in sunny, hot climates can save on air conditioning costs inside. Two medical offices in Northern California used reflective roofs on their buildings; one reduced air conditioning demand by 8%, the other reduced air conditioning demand by 12% (Konopacki et al., 1998). For colder climates, heat lost due to cool roofs (in winter, for example) also needs to be taken into account, and often negates savings. In addition to location and weather, other primary factors influence energy savings, such as roof insulation, air conditioning efficiency, and building age. Reflective roof materials are available in different forms and colors.

Roof gardens on a flat roof improve the insulation of buildings against both hot and cold by providing both heat (in winter) and air conditioning (in summer). In winter, green roofs can freeze, so they carry a slight heating penalty but often still yield net energy savings (Holtcamp 2001). In addition, a roof garden can increase the lifetime of the roof, provide and reduce runoff, and reduce air pollution and dust. Today, Germany installs over 10 million ft^2 of green roofs a year, helped in part by economic incentives (Holtcamp 2001). The Gap Headquarters in San Bruno (California) installed green roofs in 1997 (Greenroofs.com 2001). In addition to saving energy and lasting longer than traditional roofs, a roof garden absorbs rain, slowing run-off to local storm drains.

Other simple options for decreasing building HVAC energy use exist for certain conditions. Shade trees reduce cooling for hot climates. Shade trees should be deciduous trees (providing shade in the summer and none in the winter) and planted on the west and southwest sides of the building (based on the path of the summer sun) (McPherson and Simpson 1995). Trees planted on the north side of the building in cold climates can reduce heating in winter by shielding the building from the wind. Vines can provide both shade and wind shielding.

Building insulation. Adding insulation to a facility will nearly always result in the reduction of utility bills. Older buildings are likely to use more energy than newer ones, leading to very high heating and air conditioning bills. Even for a new building, adding insulation may save enough through reduced utility bills to pay for itself within a few years (U.S. DOE 2002c).

Various states have regulations and guidelines for building insulation, for example, California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24) (CEC 2001). Going beyond regulated insulation levels may be economically beneficial and should be considered as part of the design of a new building, as well as for reconstruction of existing buildings. For refrigerated warehouses, much higher levels of insulation are preferred.

Low emittance (Low-E) windows. Low emittance windows are another effective strategy for improving building insulation. Low emittance windows can lower the heat transmitted into a building and therefore increase its insulating ability. There are two types of Low-E glass, high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills) (U.S. DOE 1997b). The U.S. DOE supports the development of new window and glazing technology, while ENERGY STAR provides a selection of rated Low-E windows. New window and glazing technology is being developed continuously around the world.[22]

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[22] For more information on Low-E windows see: http://www.efficientwindows.org/.

11.2 Energy Efficiency Measures for Lighting

Turning off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

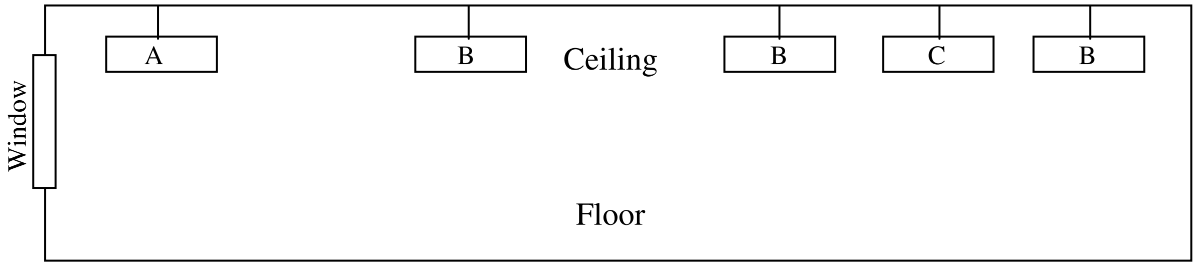
Lighting controls. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10% to 20% of facility lighting energy use (Galitsky et al. 2005a). Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2005).

In a case study from the pharmaceutical industry, at the Merck office and storage building in Rahway, New Jersey, lighting panels were programmed to turn off automatically during expected periods of building non-use (override switches in entrance hallways allowed lights to be turned on manually during these times, if needed). Annual savings amounted to 1,310 MBtu per year, which corresponded to avoided energy-related carbon dioxide (CO_2) emissions of nearly 260 tons per year (Merck 2005).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

An example of energy-efficient lighting control is illustrated by Figure 11.1, which depicts five rows of overhead lights in a workspace. During the brightest part of the day, ample daylight is provided by the window and thus only row C would need to be turned on. At times when daylight levels drop, all B rows would be turned on and row C would be turned off. Only at night or on very dark days would it be necessary to have both rows A and B turned on (Cayless and Marsden 1983). These methods can also be used as a control strategy on a retrofit by adapting the luminaries already present. (For example, turning on the lighting in rows farthest away from the windows during the brightest parts of the day, then turning on additional rows as needed later.)

Figure 11.1: Lighting placement and controls



Exit signs. Energy costs can be reduced by switching from incandescent lamps to light emitting diodes (LEDs) or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED signs may use only about 4W to 8 W, reducing electricity use by 80% to 90%. A 1998 Lighting Research Center survey found that about 80% of exit signs being sold use LEDs (LRC 2001). The lifetime of an LED exit sign is about 10 years, compared to 1 year for incandescent signs, which can reduce exit sign maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency way finding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them well suited for such applications (LRC 2001).

New LED exit signs are inexpensive, with prices typically starting at around $20. The U.S. EPA's ENERGY STAR program website (http://www.energystar.gov) provides a list of suppliers of LED exit signs.

Tritium exit signs are an alternative to LED exit signs. Tritium signs are self-luminous and thus do not require an external power supply. The advertised lifetime of these signs is around 10 years and prices typically start at around $150 per sign.

Electronic ballasts. A ballast regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts can require 12% to 30% less power than their magnetic predecessors (Cook 1998; Galitsky et al. 2005a). New electronic ballasts have smooth and silent dimming capabilities, in addition to longer lives (up to 50% longer), faster run-up times, and cooler operation than magnetic ballasts (Eley et al. 1993; Cook 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

Replacement of T-12 tubes with T-8 tubes. In many industrial facilities, it is common to find T-12 lighting tubes in use. T-12 lighting tubes are 12/8 inches in diameter (the "T" designation refers to a tube's diameter in terms of 1/8 inch increments). T-12 tubes consume significant amounts of electricity, and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Because of this, the maintenance and energy costs of T-12 tubes are high. T-8 lighting tubes have around twice the efficacy of T-12 tubes, and can last up to 60% longer, which leads to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% (Galitsky et al. 2005a).

Replacement of mercury lights. Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with energy savings of up to 50%.

At a Basic American Foods facility in Shelley, Idaho, the production area lighting system was upgraded using metal halide lamps. According to the company, the improved color rendition and increased light levels offered by the metal halide lamps helped production workers better detect defects in the plant's potato products. Plant sanitation was also improved, because staff could better see debris on the equipment and floors (Food Engineering 2002).

Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50% to 60% compared to mercury lamps (Price and Ross 1989).

High-intensity discharge (HID) voltage reduction. Reducing lighting system voltage can also save energy. A Toyota production facility installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Galitsky et al. 2005a). Commercial products are available that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

High-intensity fluorescent lights. Traditional HID lighting can be replaced with high-intensity fluorescent lighting systems, which incorporate high-efficiency fluorescent lamps, electronic ballasts, and high-efficacy fixtures that maximize output to work areas. These systems have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster startup and re-strike capabilities, better color rendition, higher pupil lumens ratings, and less glare than traditional HID systems (Martin et al. 2000).

Daylighting. Daylighting involves the efficient use of natural light in order to minimize the need for artificial lighting in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET 2001; IEA 2000). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains, which can reduce the need for cooling compared to skylights. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building; therefore, it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can sometimes be cost-effectively refitted with daylighting systems.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is almost always combined with artificial lighting to provide the necessary illumination on cloudy days or after dark (see also Figure 11.1). Daylighting technologies include properly placed and shaded windows, atria, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts can accommodate various angles of the sun and redirect daylight using walls or reflectors.

More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center of Wisconsin (http://www.daylighting.org/).

12 Self Generation

The use of on-site electricity generation appears to be quite limited in the U.S. fruit and vegetable processing industry. In 2002, only 5% of the industry's electricity was generated at individual facilities (U.S. Census Bureau 2004a, 2004b, 2004c, 2004d). The use of on-site generation was confined almost exclusively to the fruit and vegetable canning sub-sector, where the extensive use of steam in blanching, evaporating, pasteurizing, and sterilizing applications makes combined heat and power (CHP) systems particularly attractive.

Self generation (e.g., co-generation, tri-generation, or renewable energy systems) can be an attractive option for many facilities for reducing the energy intensity of utilities services. This chapter provides a brief overview of several self-generation measures applicable to the U.S. fruit and vegetable processing industry.

Combined heat and power (CHP). For industries like fruit and vegetable processing that have simultaneous requirements for process heat, steam, and electricity, the use of CHP systems may be able to save energy and reduce pollution. Combined heat and power plants are significantly more efficient than standard power plants because they take advantage of waste heat. In addition, electricity transmission losses are minimized when CHP systems are located at or near the facility.

Often, utility companies will work with individual companies to develop CHP systems for their facilities. In many cases, the utility company will own and operate the facility's CHP system, allowing fruit and vegetable processors to avoid the capital expenditures associated with CHP projects while reaping the benefits of a more energy-efficient source of heat and electricity. In addition to energy savings, CHP systems also have comparable or better availability of service than utility generation. In the automobile industry, for example, typical CHP units are reported to function successfully for 95% to 98% of planned operating hours (Price and Ross 1989).

Many large-scale CHP systems use steam turbines. Switching to natural gas-based systems is likely to improve the power output and efficiency of the CHP system, due to increased power production capability. Although the overall system efficiency of a steam turbine-based CHP system (80% HHV) is higher than that of a gas turbine-based CHP system (74% HHV), the electrical efficiency of a gas turbine-based CHP system is superior (27% to 37% for typical industrial scale gas turbines). Furthermore, modern gas-based CHP systems have low maintenance costs and will reduce emissions of NO_x, SO_2, CO_2, and particulate matter from power generation considerably, especially when replacing a coal-fired boiler (Energy Nexus Group 2002a, 2002b).

In general, the energy savings of replacing a traditional system (i.e., a system using boiler-based steam and grid-based electricity) with a standard gas turbine-based CHP unit is estimated at 20%-30% (Galitsky et al. 2005a). However, savings may be greater when replacing older or less maintained boilers.

Combined cycles (combining a gas turbine and a back-pressure steam turbine) offer flexibility for power and steam production at larger sites, and potentially at smaller sites as well. However, combined cycles are generally less attractive for smaller sites due to the high capital costs of the steam turbine. For larger sites, combined cycles may be an attractive option, depending on natural gas and electricity prices.

Steam-injected gas turbines (STIG) can absorb excess steam (e.g., due to seasonally reduced heating needs) to boost power production by injecting steam into the turbine. The size of typical STIGs starts around 5 MW. STIGs are found in various industries and applications, especially in Japan and Europe, as well as in the United States (for example, International Power Technology installed STIGs at Sunkist Growers in Ontario, California, in 1985) (Bailey and Worrell 2005). A STIG uses the exhaust heat from a combustion turbine to turn water into high-pressure steam, which is then fed back into the combustion chamber to mix with the combustion gas. The advantages of this system are (Willis and Scott 2000):

- The added mass flow of steam through the turbine increases power by about 33%.
- The machinery involved is simplified by eliminating the additional turbine and equipment used in combined cycle gas turbine.
- The steam is cool compared to combustion gases helping to cool the turbine interior.
- The system reaches full output more quickly than combined-cycle unit (30 minutes versus 120 minutes).

Additional advantages are that the amounts of power and thermal energy produced by the turbine can be adjusted to meet current power and thermal energy (steam) loads. If steam loads are reduced, the steam can then be used for power generation, increasing output and efficiency (Ganapathy 1994). Drawbacks include the additional complexity of the turbine's design.

The economics of a CHP system depend strongly on the local situation, including power demand, heat demand, power purchasing and selling prices, natural gas prices, as well as interconnection standards and charges, and utility charges for backup power. In some states, programs may offer support for installation of CHP systems (see also Appendix E).

Tri-generation. Many new CHP systems offer the option of tri-generation, which provides cooling in addition to electricity and heat. Cooling can be provided using either absorption or adsorption technologies, which both operate using recovered heat from the co-generation process.

Absorption cooling systems take advantage of the fact that ammonia is extremely soluble in cold water and much less so in hot water. Thus, if a water-ammonia solution is heated, it expels its ammonia. In the first stage of the absorption process, a water-ammonia solution is exposed to waste heat from the co-generation process, whereby ammonia gas is expelled. After dissipating the heat, the ammonia gas—still under high pressure—liquefies. The liquid ammonia flows into a section of the absorption unit where it comes into contact with hydrogen gas. The hydrogen gas absorbs the ammonia gas with a cooling effect. The hydrogen-ammonia mixture then meets a surface of cold water, which absorbs the ammonia again, closing the cycle.

One food company that has successfully implemented absorption technology is the Ghirardelli Chocolate Company, a California based manufacturer of chocolate products. Ghirardelli's manufacturing facility in San Leandro, California, uses an on-site electricity generating system, which is powered by four 350 kW natural gas-fired reciprocating engines. In 2003, the company installed a single-stage 145 ton absorption chiller that runs entirely on heat from the engines' exhaust and jacket water. According to the company, the combined area of the buildings being cooled by the absorption chiller is approximately 35,000 square feet (ESC 2005).

In contrast to absorption cooling, adsorption cooling utilizes the capacity of certain substances to adsorb water on their surface, from where it can be separated again with the application of heat. Adsorption units use hot water from the co-generation unit. These systems do not use ammonia or corrosive salts, but use silica gel (which also helps to reduce maintenance costs). Adsorption units were originally developed in Japan and are now also marketed in the United States.

The thermal performance of absorption and adsorption systems is similar, with a coefficient of performance between 0.68 and 0.75. The capital costs of both systems are also comparable. However, the reliability of an adsorption unit is expected to be superior and its maintenance costs are expected to be lower (Galitsky et al. 2005a).

Backpressure turbines. At many facilities, steam is produced at a higher pressure than is demanded by process requirements. Often, steam pressure is reduced for process use by passing steam through pressure reducing valves, essentially wasting thermal energy. A backpressure steam turbine can perform the needed pressure reduction while converting this otherwise wasted thermal energy to electricity for use throughout the facility. According to the U.S. DOE, backpressure turbines can be considered wherever a pressure reducing valve has constant steam flow of at least 3,000 pounds per hour and when the steam pressure drop is at least 100 psi (U.S. DOE 2002b).

Morning Star Packing Company, a manufacturer of tomato paste and other canned tomato products located in Williams, California, uses backpressure turbines to generate 100% of facility electricity needs (approximately 4.5 million kWh per year). In the mid- to late-1990s, the company installed three 1 MW backpressure turbines at a cost of around $847,000, including capital costs and installation expenses. Reported electricity cost savings have totaled nearly $500,000 per year. The company projected that over the 20-year lifetime of the backpressure turbines, they expect to save almost $9 million in total energy bills and realize a compound annual rate of return of more than 60% (Turbo Steam 2002).

Photovoltaic panels. Photovoltaic panels convert sunlight directly into electricity and can provide a reliable and renewable source of electricity to facilities with ample sunlight. Photovoltaic panels, which are typically mounted on the roof of a facility, convert electricity to DC current, which is subsequently sent through an inverter and transformer and converted into AC power. The AC power can be fed directly into a facility's power supply. While the capital and installation costs of photovoltaic systems are currently somewhat high (typically ranging from \$6 to \$8 per installed DC watt), manufacturers can often receive substantial rebates and tax credits from state and federal agencies that can help make photovoltaic investments more economically attractive. Inverters typically last 10 to 20 years, while photovoltaic panels can typically generate power for 25 to 40 years (FIRE 2005e).

Kettle Foods, a producer of all natural snacks based in Salem, Oregon, installed a 114 kW photovoltaic power system on the roof of its processing plant and headquarters in 2003. Reportedly, the system saves the company \$8,400 in energy costs each year, while also avoiding around 2,500 tons of CO_2 emissions. The initial capital and installation costs totaled \$675,000, but the company received over \$400,000 in clean energy incentives, Oregon energy tax credits, and U.S. federal energy tax credits, which helped to make the project more economically viable (FIRE 2005e). Over the 40-year life of the system, the company estimated a 7% average rate of return and a net present value of \$55,000. However, the project has also helped reinforce Kettle Foods' image as an environmental steward and has reportedly led to good corporate publicity.

13 Process-Specific Energy Efficiency Measures

Chapters 6 through 12 presented a wide variety of energy efficiency measures for the cross-cutting systems and technologies within fruit and vegetable processing facilities. In addition to these important cross-cutting measures, there are also a number of energy efficiency measures that are applicable to specific unit processes employed in the fruit and vegetable processing industry. In this chapter, the most significant of these process-specific energy efficiency measures are discussed. Measure descriptions are grouped under the following six categories, based on the processes to which they are applicable: (1) blanching, (2) drying and dehydrating, (3) evaporation and concentration, (4) frying, (5) pasteurization and sterilization, and (6) peeling. As discussed in Chapter 4, these six categories represent some of the most energy intensive unit processes employed in the fruit and vegetable processing industry.[23]

13.1 Energy Efficiency Measures for Blanching

Upgrading of steam blanchers. Blanching equipment may have a useful life of 15 years or more (Lung et al. 2006). The replacement of old steam blanchers with new, more efficient designs can typically lead to significant energy savings. Most modern steam blanchers are equipped with design features that help to retain heat, minimize steam losses, and efficiently circulate heat throughout the product stream. Common energy efficiency features of modern steam blanchers include (FMCITT 1997; Rumsey 1986a; FIRE 2005f):

- *Steam seals*, which help to minimize steam leakage at the blancher entrance and exit. Typical types of steam seals include water spray curtains at the blancher entrance and exit, hydrostatic seals that enclose the steam chamber, and rotary locks.

- *Insulation* of the steam chamber walls, ceiling, and floor to minimize heat losses.

- *Forced convection* of steam throughout the product depth using internal fans or steam injection, which provides more efficient and even heating of product and helps to reduce blanching times.

- *Process controls* that optimize the flow of steam based on such variables as product temperature, blanching time, and product depth.

- *Recovery of condensate* for use in water curtain sprays or for product cooling.

Heat and hold techniques. In traditional blanching, products are continuously subjected to the heating medium until a specified product core temperature is reached. In contrast, blanchers using the heat and hold technique expose products to just the minimum amount of steam required for blanching, via the use of a heating section and a holding section. In the heating section, products are exposed to just enough steam to heat the surfaces of the product

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[23] Energy efficiency measures for freezing—another highly energy intensive unit process discussed in Chapter 4—are presented in Chapter 9 of this Energy Guide.

to the necessary temperature for blanching. The product then proceeds to an adiabatic holding section, in which the product's surface heat is allowed to penetrate to its core, which raises the entire product to the required blanching temperature without the use of additional steam. Heat and hold blanchers have been reported to reduce blanching times by up to 60% and blanching energy intensity by up to 50% (Rumsey 1986a; FIRE 2005f).

In 2003, Stahlbush Island Farms, a grower, canner, and freezer of fruits and vegetables in Corvalis, Oregon, replaced an aging and inefficient blancher used for processing pumpkins with an ABCO heat and hold blancher. In addition to heat and hold features, the ABCO blancher also incorporated curtains and water sprays to minimize steam losses, a condensate recovery system, an internal steam recirculation system, a fully insulated steam chamber, and programmable logic controls. Stahlbush Island Farms reported annual natural gas savings of 29,000 therms (a 50% reduction compared to their previous blancher) and $16,000 in annual energy savings (FIRE 2005f). Project costs (which included the blancher, a feed conveyor, and a vibratory shaker) totaled $202,000, but with an Oregon energy efficiency tax credit of $70,855, the final simple payback period was 8 years.

Heat recovery from blanching water or condensate. Heat can be recovered from the discharge water of hot water blanchers via a heat exchanger. Similarly, in steam blanchers were condensate is not recycled internally, it might be possible to recover heat from the hot condensate exiting the blancher. Where fouling is manageable, in both cases heat can be recovered using a heat exchanger and used to pre-heat equipment cleaning water or boiler feed water (Lund 1986).

Steam recirculation. Some steam blanching systems with forced convection are also capable of recirculating and reusing the steam that does not condensate on the product at first pass, thus reducing the steam inputs into the blanching chamber.

The U.S. DOE sponsored the development of the Turbo-Flo blancher, which features a steam recirculation system in addition to hydrostatic seals, a fully insulated steam chamber, and blanching process controls. As of 2002, 40 units have been installed in food processing facilities in the United States. Reser's Fine Foods, an Oregon based processor of vegetables and specialty foods, has installed five Turbo-Flo blanchers at its processing facilities. According to the company, the Turbo-Flo blancher at its Beaverton, Oregon, facility increased product throughput by 300% while reducing the floor space required for blanching dramatically. At the California Prune Packing Company in Live Oak, California, a Turbo-Flo blancher installed in 1997 was reportedly four times more efficient than its predecessor (CADDET 2000b). Estimated payback periods are under two years (U.S. DOE 2002e).

13.2 Energy Efficiency Measures for Drying and Dehydrating

Maintenance. Improper maintenance of drying and dehydrating equipment can increase energy consumption by up to 10% (ISU 2005). An effective maintenance program should include the following actions, which should be performed on a regular basis (ISU 2005; BEE 2004; Traub 1999b, EEBPP 1996):

- Checking burner and combustion efficiency.
- Checking heat exchangers for fouling, excessive pressure drops, and leaks.
- Cleaning filters at fans.
- Checking for belt slippage and fan speeds.
- Avoiding air leaks through checks and repairs of doors and seals.
- Checking and repairing insulation on burners, heat exchangers, duct work, and the body of the dryer.
- Checking thermocouples and humidity sensors for fouling.
- Monitoring heat transfer efficiency.
- Ensuring that fuel and air ports and flues are clear of debris.
- Checking and repairing utility (i.e., steam, natural gas, and compressed air) supply lines.

Insulation. Any hot surfaces of drying equipment that are exposed to air, such as burners, heat exchangers, roofs, walls, ducts, and pipes, should be fully insulated to minimize heat losses. Insulation should also be checked regularly for damage or decay. Different insulation materials such as mineral wool, foam, or calcium silicate can be applied to various drying system components, depending on temperature (BEE 2004). Foam can be used for low temperature insulation while ceramics are useful under high temperature conditions.

Mechanical dewatering. Mechanical dewatering of fruits and vegetables prior to drying can reduce the moisture loading on the dryer and save significant amounts of energy. As a rule of thumb, for each 1% reduction in feed moisture, the dryer energy input can be reduced by up to 4% (BEE 2004). Mechanical dewatering methods include filtration, use of centrifugal force, gravity, mechanical compression, and high velocity air (ISU Extension 2005).

At the British Sugar beet factory in Wissington, England, six screw presses were employed to mechanically dewater wet beet pulp prior to dehydration in a rotary dryer. Each screw press had specific energy use of 23 kilojoules (kJ)/kg of water removed, compared to a specific energy use of 2,907 kJ/kg for the rotary dryer. By using the six screw presses for mechanical dewatering, British Sugar found that its energy costs in drying the beet pulp were 40 times less than they would have been if they had used the rotary dryers alone (EEBPP 1996).

Direct fired dryers. Direct fired dryers are generally more energy efficient than indirect heated dryers, because they remove the inefficiency of first transferring heat to air and then transferring heat from air to the product. Direct fired dryers can reduce primary fuel use by

35% to 45% compared to indirect (i.e., steam-based) heating methods (BEE 2004; ISU 2005).

Exhaust air heat recovery. A simple form of heat recovery in retrofit applications is to utilize the exhaust air of a dryer to preheat the inlet air stream, thereby saving energy. The success of this measure depends on the available space for additional duct work near the dryer (ISU 2005). Either the exhaust air can be directly injected into the inlet air stream, or a recuperation (i.e., heat exchanger) system can be employed to indirectly heat the inlet air stream using exhaust air (EEBPP 1996). In the former approach, the saturation of the exhaust air might limit the effectiveness of heat recovery (highly saturated exhaust air may raise the humidity of incoming air and reduce its drying capacity) (Traub 1999a). If there isn't sufficient room for additional duct work around the dryer, heat can be recovered from exhaust gases using "run-around coils," which contain a heating medium such as water to transfer heat to the inlet air stream via a heat exchanger (ISU Extension 2005).

Using dry air. The use of dry air reduces the amount of moisture in the air that requires heating and vaporization. Thus, by removing this moisture, the heating load on the dryer is reduced. Air can be dried using desiccants or dehumidifying techniques, but, in general, this measure is only practical for dryers with small volumes of air (Traub 1999b).

Heat recovery from the product. In cases where products are deliberately cooled using forced air after drying, it might be feasible to recycle the resulting warm air, either directly into the dryer or through a heat exchanger to preheat the inlet air stream (EEBPP 1996). However, for products that don't require cooling, the cooling fan and heat recovery system cost might be greater than the energy cost savings associated with the recovered heat (Traub 1999b).

Process controls. Process controls, such as feedback controllers, feed forward controllers, and model-based predictive controllers, can help to minimize dryer energy consumption by more precisely controlling energy inputs to meet the needs of the product being processed. Common sensors used in drying process control include thermocouples and resistance thermometers (for air temperature), infrared pyrometers (for product surface temperatures), and wet-bulb and dry-bulb thermometers, resistance sensors, and absorption capacitive sensors (for air humidity) (CADDET 1997b; ISU Extension 2005; BEE 2004).

At the British Sugar beet sugar factory in Wissington, England, sugar is extracted from the beets and the remaining spent beet pulp is dried using rotary dryers to produce cattle feed. The company chose to install a model-based predictive control system to more accurately control the process performance of its rotary dryers. Following installation, the company reported saving £32,900 per year ($54,290 in 1997 U.S. dollars), which was comprised of £18,900 ($31,185 in 1997 U.S dollars) in dryer energy savings and £14,000 ($23,100 in 1997 U.S dollars) per year in downstream energy cost savings (CADDET 1997b). Furthermore, increased yields boosted savings by another £61,600 ($101,640 in 1997 U.S dollars) per year, enabling a payback period of just 17 months.

13.3 Energy Efficiency Measures for Evaporation

Maintenance. Common sources of inefficiency and heat loss in evaporators include excessive venting, radiation and convective losses, poor vacuum system performance, air leakage, water leakage, fouling, and poor separator efficiency (Rumsey 1986b). An ongoing maintenance program for evaporators can help minimize and avoid many of these sources of energy loss. In general, a solid maintenance program should include the following (PG&E 2006):

- Inspection and prevention of air leaks into evaporators to minimize venting rates (air is non-condensable and thus must be vented from the system).

- Cleaning of heat transfer surfaces to allow efficient transfer of energy.

- Inspection and replacement of wet, damaged, or decayed insulation.

- Cleaning of vapor separation vessels to maintain product yields and pressure profiles.

- Inspection and prevention of water leaks into the system to avoid diluting the product streams.

- Maintaining the optimum pressure profile in the evaporator per the manufacturer's specifications (excess pressure inhibits evaporation by raising the boiling point).

Multiple effect evaporators. In general, significant energy efficiency gains can be realized by using multiple effect evaporators instead of single effect evaporators, where economically feasible. In multiple effect evaporators, the hot vapors that "boil" out of the liquid in one evaporator (or "effect") are used as the heating medium in another effect, which is operated at a lower pressure. By using multiple effects, the amount of water evaporated per pound of steam supplied to the evaporator system can be greatly increased. For example, a typical single effect evaporator will evaporate around 0.95 pounds of water per pound of steam input (i.e., a steam economy of 0.95); steam economy rises to around 1.8 for a double effect evaporator system, and to 2.6 for a triple effect evaporator system (Maroulis and Saravacos 2003).

There is a tradeoff between energy savings and the added capital costs of additional evaporator effects. Furthermore, there is practical limit to the number of effects that can be used for any given product application; in practice, up to five effects might be feasible for evaporator systems used in food processing (Maroulis and Saravacos 2003).

Vapor recompression. In general, energy efficiencies higher than that of multiple-effect evaporator systems can be realized using vapor recompression systems, in which the vapors exiting the evaporator are compressed (thereby raising vapor temperature) and reintroduced into the evaporator as a heating medium. There are two types of vapor recompression systems available: thermal vapor recompression (TVR) systems and mechanical vapor recompression (MVR) systems.

In TVR systems, the vapors exiting the evaporator are compressed in a steam ejector using high pressure steam and the mixture is reintroduced into the same evaporator unit as a heating medium. Part of the vapors exiting the evaporator must be removed in order to maintain the proper mass balance of steam entering the evaporator unit.

In MVR systems, the vapors exiting the evaporator are compressed mechanically (typically using centrifugal compressors or turbo fans) and then reintroduced into the evaporator unit as a heating medium. A small amount of heating steam is added to the system to make up the condensate formed during compression of water vapors (Maroulis and Saravacos 2003). The steam economy of MVR systems can range from 10 to 30, while TVR systems are less energy efficient and have a typical steam economy in the range of 4 to 8.

Because of compression limitations and the high costs of evaporation under vacuum, vapor recompression units are mainly applicable where the product is not too concentrated and can be boiled under atmospheric or moderate vacuum conditions (Blanchard 1992). Thermal recompression systems are most economical when high-pressure steam is available at low cost, while MVR systems are most economical when electricity is available at low cost (Maroulis and Saravacos 2003).

Sunmöre Meieri, a dairy processor based in Norway, opted for an MVR evaporator system to concentrate the basic ingredients of brown cheese (cream, milk and whey) from 11% dry matter to 55% dry matter. The MVR system saved the company around 27 GWh of energy per year (CADDET 1997c).

Concentration using membrane filtration. Because membrane concentration does not require a phase change (in contrast to evaporation), it is a more energy-efficient option for water removal than traditional steam-based evaporation methods. Membrane filtration systems have been successfully applied to the concentration of fruit and vegetable products, both in producing finished concentrated products directly and in pre-concentrating products prior to evaporation. The latter approach reduces the moisture content of the evaporator feed stream and thus reduces the energy requirements of the evaporator. The most common types of membrane filtration systems used in the food processing industry are reverse osmosis systems and ultra-filtration systems (Martin et al. 2000).

At Golden Town Apple Products, a manufacturer of peeled apples and apple juices based in Canada, a combination of ultra-filtration and reverse osmosis has been used for apple juice concentration. In this process, the juice is heated to about 140°F (60°C) and afterwards passed through a reverse osmosis membrane and an ultra-filtration membrane to produce apple juice concentrate. The system has maximum capacities of 3,000 liters per hour for feedstock, 1,500 liters per hour for final concentrate, and 1,500 liters per hour for water removed by reverse osmosis. The energy savings associated with this system were estimated at 66% compared to a traditional evaporation process. Additionally, the volume of equipment required for concentration was reduced by 50%. The payback period for the system was estimated at 2.5 years (Martin et al. 2000).

Freeze concentration. For certain types of fruit juices and extracts, freeze concentration can offer a more energy-efficient concentration option than traditional evaporation methods. In freeze concentration, fruit juices are concentrated using a combination of freezing and mechanical separation. First, fruit juices are frozen to produce a slurry of frozen fruit liquids and ice crystals. Next, a separation device (such as a centrifuge or filter press) is used to separate the ice crystals from the fruit liquids. Energy savings are due to the fact that crystallizing a pound of water requires only about one-eighth the energy required to vaporize the same amount (SCE 2005).

In addition to energy savings, freeze concentration is said to produce fruit juice concentrates without appreciable loss in taste, aroma, color, or nutritive value, and to result in less equipment corrosion as a result of the low operating temperatures of the process (Luh et al. 1986; SCE 2005). However, the high capital and refrigeration costs associated with freeze concentration might make it attractive for only high-value juices and extracts (Fellows 2000). To date, freeze concentration has been successfully applied in the making of fruit juices, beer, wine, vinegar, milk, and coffee (SCE 2005).

13.4 Energy Efficiency Measures for Frying

Heat recovery from fryer exhaust gases. Heat can be recovered indirectly from a fryer's fat-laden exhaust gases via a heat exchange system and used for pre-heating air and water for use in other facility processes. Conditioning of the exhaust gas is required, however, to remove fats and to reduce fouling of the heat exchange system.

McCain Foods, a global manufacturer of frozen potato products, installed a special system for recovering heat from exhaust gases on the potato frying line at its Scarborough, England, facility in 1995. Fryer exhaust gases were first saturated with water vapor using turbine washers, then routed to a two-pass shell and tube vapor condensing heat exchanger. The heat exchanger shells were oriented vertically, which allowed condensate, fat, and fatty acids to drain freely into a sump below the heat exchangers. The heat exchanger was used to pre-heat air for the facility's potato chip dryers, to heat water used in potato blanchers, and to provide facility hot water. Exhaust gases exiting the vapor condenser passed through a scrubbing tower and were discharged to the atmosphere. Heat recovery from the fryer exhaust gases saved the company a reported £77,060 ($123,000 in 1995 U.S. dollars) per year in natural gas costs (CADDET 1995).

Heat recovery via exhaust gas combustion. It is also possible to recover additional heat from a fryer's fat-laden exhaust gases using direct combustion. Commercially-available fryer gas combustion systems exist that can recover useful heat in a two-stage process. In the first stage, heat is recovered from exhaust gases exiting the fryer using economizers that that pre-heat facility and process water. In the second stage, exhaust gases are combusted in a small natural gas-fired furnace. Exhaust gases exit the furnace at around 700° C to 800° C and are passed through a second heat exchanger, which is used to heat fryer oil (Gould 1996; European Commission 2006).

Kitchen Range Foods, a UK based manufacturer of frozen fried potato products and frozen vegetables, installed a fryer gas combustion heat recovery unit on its frying line in 2002. The heat recovery system reportedly supplies 10% of the energy needed to heat the fryers, eliminates exhaust odor problems, and produces no effluent (Food Engineering & Ingredients 2002).

Heat recovery via adsorption cooling. As discussed in Chapter 12, adsorption cooling systems can use waste heat instead of electricity to produce chilled water for use in facility air conditioning and process cooling applications.

In 2004, the California Energy Commission financed a demonstration project to evaluate the use of adsorption cooling technology to generate chilled water from fryer exhaust gas heat. A 300 ton adsorption chiller was installed on a potato chip frying line that fried about 20,000 pounds of potato chips per hour and produced about 15,000 pounds of exhaust water vapor (at 220° F) per hour. Formerly, the exhaust was discharged to the atmosphere. The project was estimated to save about 1.5 million kWh per year in facility air conditioning energy, amounting to about $123,000 in annual energy cost savings (CEC 2004). According to Flex Your Power (a partnership between California's utilities, residents, businesses, government agencies, and nonprofit organizations), the simple payback period associated with adsorption chillers generally ranges from one to three years (Flex Your Power 2006b).

Using spent fryer oil as fuel. The frying process can generate significant amounts of spent oil, which can be a costly solid waste problem for many companies. However, spent fryer oil can be used as a diesel engine fuel in lieu of disposal at facilities that have diesel co-generation units or diesel backup power generators. Most diesel engines can run on vegetable oils (also known as “bio-diesel” fuels) if the oils are properly filtered to remove contaminants and if special modifications are made to the fuel injection system. Using spent oil as a bio-diesel fuel reduces solid waste while at the same time reducing a company’s necessary purchases of diesel fuels.

The Mayno Food Company, a Japanese firm that manufactures tempura (deep-fried vegetables and shellfish), decided to install a diesel co-generation system in 1997 that burns a mixture of spent vegetable oil and marine gas oil. The system features a fuel mixer to blend vegetable oil with marine gas oil, a line heater to adjust the viscosity of the fuel, a filter and sedimentation tank to remove contaminants from the spent vegetable oil, and a specially-designed fuel injection system. The system runs on a 70:30 fuel ratio of spent vegetable oil and marine gas oil and burns 32 to 42 tons of spent vegetable oil per month. As of 2002, the system was running with no major problems and was able to run with fuel and maintenance costs that were 50% less than a co-generation system running on marine gas oil alone (CADDET 2002). The system was also reported to reduce both emissions of sulfur oxides (SO_x) and the smoke density of the exhaust.

13.5 Energy Efficiency Measures for Pasteurization and Sterilization

Sterilizer insulation. All exposed surfaces of sterilizers should be properly insulated to minimize heat losses. Furthermore, insulation should be checked regularly for damage or decay and repaired promptly when needed. The typical payback for insulating sterilizers where the temperatures of exposed surfaces are greater than 75° C is two to three years (UNIDO 1995).

Heat recovery from pasteurization. While most modern pasteurizers use some form of internal heat regeneration, the heat contained in rejected water can also be recovered using heat pumps or a heat exchanger and used to pre-heat air or water in other facility applications.

Compact immersion tube heat exchangers. Compact immersion tube heat exchangers consist of a combustion chamber and a heat exchange tube that is coiled inside a reservoir of water. Exhaust from the combustion chamber, which is fired by natural gas, is circulated directly through the immersed tubes, which transmit heat to the water in the reservoir. The hot water is then circulated to another heat exchanger for use in pasteurization and sterilization processes. Compact immersion tube heat exchangers reportedly use up to 35% less energy than centralized water heating systems (CADDET 1992).

The A. Lassonde Company pasteurizes around 30 million liters of apple juice per year at its Rougement, Quebec, facility. To help reduce its energy bills, the company replaced its old electric water heating system used for pasteurization with a pair of 880 kW natural gas-fired compact immersion tube water heating units. The company reported energy cost savings of $18,100 per year (in 1997 U.S. dollars), maintenance cost savings of $13,000 per year (in 1997 U.S. dollars), and a payback period of less than two years (CADDET 1997d).

Helical heat exchangers. Helical heat exchangers can reportedly offer increased heat transfer rates, reduced fouling, and reduced maintenance costs compared to traditional shell-and-tube heat exchangers. These heat exchangers might therefore offer an energy-efficient heat exchange option for continuous pasteurization and sterilization processes (Stehlik and Wadekar 2002).

Induction heating of liquids. An induction heater works by dissipating the energy generated when the secondary winding of a transformer is short-circuited, which instantly imparts heat to liquid circulating in a coil around the transformer core. Applications in the fruit and vegetable processing industry include continuous liquid sterilization and pasteurization processes. Energy savings compared to boiler-based methods of liquid heating have been estimated at up to 17% (CADDET 1997e).

The Laiterie Chalifoux dairy in Sorel, Quebec, installed induction heaters for milk pasteurization and realized a simple payback period of 3.3 years (CADDET 1997e).

13.6 Energy Efficiency Measures for Peeling

Heat recovery from discharge steam. Ideally, residual steam from steam-based peelers should be harnessed for heat recovery rather than being discharged directly to the atmosphere. Heat can be recovered from the discharge steam using condensing heat exchange systems and used to heat facility or process water.

The Fritesspecialist company in Arcen, the Netherlands, manufactures both fresh and frozen potato products. In the late 1990s. the company installed a condensing heat exchange system to recover energy from its steam-based potato peeling process for use as a heating medium for pasteurizing potato pre-heating water. Previously, the company released steam directly to the atmosphere, which was perceived as a nuisance in the surrounding neighborhood. The system works by discharging steam from the peeler into a blow down vessel, in which a spray of recirculated process water condenses the steam into hot water. The hot water collected at the bottom of the vessel is fed through a heat exchanger to pasteurize process water. The company reportedly saved 852,000 m^3 of natural gas per year with a simple payback period of 3.4 years (CADDET 2000c).

Multi-stage abrasive peeling. In general, abrasive peeling methods consume less energy than steam-based peeling methods (European Union 2006). However, a major drawback of traditional abrasive peeling methods is that along with the removal of peels, a significant amount of usable product is usually lost during the process. Multi-stage abrasive peelers can reduce the amount of usable product that is lost—and thereby increase product yields—by routing the product through a series of progressively milder abrasive drums. While no energy efficiency data on multi-stage abrasive peeling are yet available, the process is expected to save energy in upstream processes, because increased yields mean that less product must be processed prior to peeling to maintain a given production rate.

Utz Quality Foods of Hannover, Pennsylvania, has used a multi-stage abrasive peeler on its potato chip processing line since 2001. The new peeling process was estimated to reduce potato usage by 354,000 pounds per year while maintaining the same production rate (Food Engineering 2003). The savings in reduced potato costs were estimated at $31,860 per year. Additional reported benefits included less potato waste for disposal as well as fewer quality problems with downstream processes such as slicing and frying.

Dry caustic peeling. Caustic peeling methods are generally less energy- and water-intensive options than steam-based peeling methods (European Union 2006). However, wet caustic peeling methods can generate wastewater with a very high pH and organic load, which leads to high wastewater treatment costs. In contrast, dry caustic peeling methods use less water and less caustic solution than wet caustic peeling methods and thus generate less wastewater. The wastewater generated by dry caustic peeling also has lower pH and organic loading than wet caustic peeling methods, which reduces wastewater treatment costs (U.S. EPA 1999). The dry caustic peeling process subjects products to a heated caustic solution to soften the skin, which is then removed by dry rubber discs or rollers. A final rinse to remove residues of peel and caustic is the only fresh water used.

In a demonstration project at a Del Monte peach peeling and canning facility, dry caustic peeling methods generated nearly 90% less wastewater and had over 50% less organic loading than wet caustic peeling methods (U.S. EPA 1999).

14 Emerging Energy-Efficient Technologies

Chapters 6 through 13 discussed a wide range of energy efficiency measures and practices that are based on proven, commercially available technologies. In addition to these opportunities, there are also a number of emerging technologies that hold promise for improving energy efficiency in the U.S. fruit and vegetable processing industry. (An emerging technology is defined as a technology that was recently developed or commercialized with little or no market penetration in the food processing industry at the time of this writing.)

New and improved technologies for food processing are being developed and evaluated continuously, many of which can provide not only energy savings, but also water savings, increased reliability, reduced emissions, higher product quality, and improved productivity. In this chapter, several promising emerging technologies for fruit and vegetable processing (both cross-cutting and process-specific) are briefly discussed. Where possible, information on potential energy savings compared to existing technologies and other technology benefits are provided. However, for many emerging technologies, such information is scarce or non existent in the published literature. Thus, the energy savings and other benefits discussed here are preliminary estimates. Actual technology performance will depend on the facility, the application of the technology, and the existing production equipment with which the new technology is integrated.

14.1 Emerging Energy-Efficient Technologies for Fruit and Vegetable Processing

Heat pump drying. Heat pumps are a class of active heat recovery equipment that allows low temperature waste heat to be increased to a higher, more useful temperature for other process heating applications. The use of heat pumps allows for the recovery of waste heat where traditional (i.e., passive) heat recovery methods are not practical. As an active heat recovery method, heat pumps require the input of energy to convert low temperature waste heat into high temperature process heat. However, in general it is still less energy intensive to use a heat pump to transform low temperature waste heat into useful process heat than it is to supply that process heat via traditional energy sources (i.e., via electricity or fuel combustion) (U.S. DOE 2003).

Perera and Rahman (1997) have reported that heat pump dehumidifying dryers offer several advantages over conventional hot-air dryers for the drying of food products, including higher energy efficiency, better product quality, and the ability to operate regardless of ambient weather conditions. Heat pump dehumidifying dryers consist of a condenser, a compressor, an evaporator, and a fan to provide air movement, while the heat pump is located along with the product in an enclosed chamber. Dry, heated air is passed continuously over the product, and, as it picks up moisture, it condenses on the heat pump, giving up its latent heat of vaporization, which is taken up by the refrigerant in the evaporator. This heat is used to reheat the cool dry air passing over the hot condenser of the heat pump.

Ohmic heating. Ohmic heating is a thermal processing method in which an alternating electrical current is passed through food products to generate heat internally. Ohmic heating is said to produce a uniform, inside-out heating pattern that heats foods faster and more evenly than conventional outside-in heating methods. According to Lima et al. (2002), potential applications for ohmic heating relevant to fruit and vegetable processing include blanching, evaporation, dehydration, fermentation, and extraction.

In tests at the Louisiana State University Agricultural Center, sweet potato samples were processed using ohmic heating prior to freeze drying. Ohmic heating reportedly increased the rate of freeze-drying up to 25% compared to samples that did not undergo ohmic heating, which led to significant savings in both processing time and energy use (Lima et al. 2002). However, ohmic heating parameters such as the frequency of the alternating current, the applied voltage, the temperature to which the sample is heated, and the electrical conductivity of the food can all have a significant effect on the performance of the process.

Infrared drying. In conventional drying methods, substantial amounts of air must be heated and circulated around the product to be dried. In contrast, infrared drying uses infrared radiation to heat only the material that needs to be heated—not the surrounding air—and thus saves energy compared to conventional methods.

For drying apple slices, a comparison of infrared drying with convective drying done using equivalent processing parameters showed that energy costs were lower and that the time of the drying process could be shortened by up to 50% using infrared methods (Nowak and Lewicki 2004).

Pulsed fluid-bed drying. The pulsed fluid-bed dryer is a modification of the conventional fluid-bed dryer (used widely in the dehydration of fruits and vegetables). In pulsed fluid-bed drying, gas pulses cause high-frequency vibrations within the bed of product particles. Reported advantages of the pulsed fluid-bed drying approach include easier fluidization of irregular particle shapes, fluidization with 30% to 50% less air than conventional methods (leading to energy savings in heating and circulating hot air), and reduced channeling of particles (CADDET 2000d). Additionally, pulsed fluid-bed dryers are roughly half the size of conventional conveyor-type dryers. Successful trial applications in the food industry include the drying of carrot cubes and the drying of chopped onions.

In the drying of carrot cubes, a pulsed fluid-bed dryer reduced the total drying time by two to three times compared to traditional fluid-bed drying methods while providing a final product that was highly uniform in color and moisture content. Similarly, for chopped onions, the final products were of high color and reconstitution quality and uniform in moisture content (CADDET 2000d).

Pulsed electric field pasteurization. The use of pulsed electric fields to pasteurize liquid food products is showing promise as an emerging technology. Pulsed electric field pasteurization for juices may provide superior taste and freshness compared to juices undergoing conventional heat treatment. In the pulsed electric field process, liquids are exposed to high voltage pulses of electricity to inactivate harmful micro-organisms as well as enzymes that degrade the quality of fruit juices over time. The energy savings associated with pulsed electric field processing arise from the fact that the process operates at lower temperatures than conventional heat-based pasteurization methods and thus the pasteurized juices require less cooling energy (Lung et al. 2006).

Pulsed electric field pasteurizing has been successfully employed by the Genesis Juice Corporation of Eugene, Oregon, in the production of organic bottled fruit juices (Clark 2006). The company reported that the major motivation for using the new technology was to avoid the loss of flavor associated with conventional thermal pasteurization methods.

Advanced rotary burners. The U.S. DOE has sponsored the development of a new rotary burner design, which is said to reduce emissions and energy costs compared to existing low-emission burners that require electrical air distribution systems to aid combustion. In the fruit and vegetable processing industry, the new rotary burner could be applied to boilers, fryers, dryers, and other process equipment requiring combustion. The rotary burner uses a gas expansion technique to more effectively mix air and fuel for combustion, which, according to the U.S. DOE (2002f):

- Increases fuel efficiency up to 4% versus conventional rotary and stationary burners.
- Transfers heat more efficiently through heat radiation and convection processes.
- Has near perfect mixing of gas and air, which results in low nitrous oxide emissions.
- Is suitable for limited space.

Geothermal heat pumps for HVAC. Geothermal heat pumps take advantage of the cool, constant temperature of the earth to provide heating and cooling to a building. To date, most applications of geothermal heat pumps have been in the residential and commercial sectors rather than in the industrial sector. However, geothermal heat pumps may be a viable replacement for traditional HVAC systems in office or warehouse spaces in the fruit and vegetable processing industry.

In winter, a water solution is circulated through pipes buried in the ground, which absorbs heat from the earth and carries it into the building structure. A heat pump system inside the building transfers this heat to air that is circulated through the building's ductwork to warm the interior space. In the summer, the process is reversed: heat is extracted from the air in the building and transferred through the heat pump to the underground piping, where heat is transferred back to the earth. The only external energy needed is a small amount of electricity to operate fans and ground loop pumps (GHPC 2005).

The Geothermal Heat Pump Consortium (2005) claims that the technology can reduce space heating and cooling energy consumption by 25% to 50% compared to traditional building HVAC systems.

Carbon dioxide (CO_2) as a refrigerant. In the food industry, CO_2 can be used for quick freezing, surface freezing, chilling, and refrigeration. In cryogenic tunnels and spiral freezers, high pressure liquid CO_2 is injected through nozzles that convert it to a mixture of CO_2 gas and dry ice that covers the surface of the food product. Liquid CO_2 is reported to generate faster cooling rates than conventional freezing processes. In addition, liquid CO_2 freezing equipment eliminates the need for compressor systems, thereby taking up less room than comparable mechanical freezers.

Since 2001, the frozen vegetable producer Ardo B.V., located in Zundert, the Netherlands, has been operating a 560 kW combined ammonia-CO_2 freezer, which uses ammonia in the higher temperature range and CO_2 in the lower temperature range. The energy savings of this system, in comparison to a conventional ammonia-based expansion system, have been estimated at around $66,000 per year. The estimated payback period is 11 years. (SenterNovem 1999).

Magnetically-coupled adjustable-speed drives. Magnetically-coupled adjustable-speed drives (MC-ASDs) are a new type of ASD, in which the physical connection between the motor and the driven load is replaced with a gap of air, and the amount of torque transferred is controlled by varying the air gap distance between rotating plates in the assembly. According to Worrell et al. (2004), compared to existing ASDs, MC-ASDs have several advantages in addition to greater energy efficiency, including:

- A greater tolerance for motor misalignment.
- Little impact on power quality.
- The ability to be used with regular duty motors (instead of inverters).
- Expected lower long term maintenance costs.
- Extended motor and equipment lives, due to elimination of vibration and wear on equipment.

One commercially-available model, the MagnaDrive, is currently installed in pump, fan, and blower installations in the pulp and paper, mining, food processing, and raw materials processing industries, as well as in irrigation, power generation, water treatment, and HVAC systems. Reportedly, applications of the MagnaDrive provided energy savings of 25% to 66% compared to non-adjustable speed drives (Worrell et al. 2004).

15 Basic Water Efficiency Measures

In many U.S. fruit and vegetable processing facilities, water is a resource that can be just as critical and costly as energy in the production process. Water is used throughout the fruit and vegetable processing industry for process cooling, boiler systems, water fluming, blanching, peeling, cooking, product rinsing, and equipment cleaning, as well as in the products themselves as a primary ingredient (e.g., in canned fruits, vegetables, and soups). In California alone, the water consumption of the fruit and vegetable processing industry has been estimated at nearly 23 billion gallons per year (Pacific Institute 2003).

The specific water usage (i.e., gallons of water per ton of product) required in fruit and vegetable processing depends heavily on the type of product manufactured as well as on the water management practices at individual facilities. Reported values of specific water usage in the U.S. fruit and vegetable processing industry range from several hundred gallons per ton of product (Mannapperuma et al. 1993) to tens of thousands of gallons per ton of product (U.S. AEP 2002). This range suggests significant variation in water usage across the industry. According to a study by the World Bank (1998), however, good facility water management programs can often help reduce specific water usage to the "best practice" levels indicated in Table 15.1 for different processed fruit and vegetable products.

Table 15.1. Representative best practice values of specific water use for various processed fruit and vegetable products

Product Category	Specific Water Use (gallons/ton)
Canned fruits	730 – 1,170
Canned vegetables	1,020 – 1,750
Frozen vegetables	1,460 – 2,500
Fruit juices	2,000
Jams	1,750
Baby foods	1,750 – 2,630

Source: World Bank (1998)

This chapter provides a brief overview of basic, proven water efficiency measures applicable to typical fruit and vegetable processing plants. In addition to reducing facility utility bills for water purchases, improved water efficiency can also lead to reduced energy consumption for water pumping and treatment, reduced wastewater discharge volumes, and reduced wastewater treatment costs. Furthermore, the recovery and recycling of water can also provide opportunities for energy recovery, which can help to further reduce facility energy costs. Water efficiency also reduces loads on local fresh water and wastewater treatment plants, which leads to indirect energy savings in the industrial water supply chain. According to Envirowise, a UK government program that promotes business resource efficiency, fruit and vegetable processing companies that have not implemented any water saving measures can often reduce water and effluent costs by 50% through water efficiency programs (Envirowise 2001). Companies that have already implemented some measures—but not a systematic approach—can often still achieve a 20% decrease in water and effluent costs.

The water efficiency measures discussed in this chapter are grouped into three major categories, depending on their general area of applicability: (1) general water management measures, (2) cleaning and sanitation, and (3) water reuse and recycling. While there are many opportunities for water efficiency in the typical food processing facility, this chapter focuses on the most significant measures for water efficiency applicable to fruit and vegetable processing. Wherever possible, references to literature and online resources are provided for further information on individual measures and on the topic of industrial water efficiency in general.

15.1 General Water Management Measures

Strategic water management program. Similar to a strategic energy management program (discussed in Chapter 6), a strategic, organization-wide water management program can be one of the most successful and cost-effective ways to bring about sustainable water efficiency improvements. Strategic water management programs help to ensure that water efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement.

Establishing and maintaining a successful industrial water management program generally involves the following key steps (NCDENR 1998; NHDES 2001; CDWR 1994):

1) *Establish commitment and goals.* Goals for water savings should be qualitative and included in statements of commitment and company environmental policies. A commitment of staff, budget, and resources should be established at the outset of the water management program to ensure success.

2) *Line up support and resources*. Internal and external staff and resources should be identified and secured, including a water program manager, with buy in from senior level management. Many of the recommendations for establishing an Energy Team (see Chapter 6) are applicable at this stage.

3) *Conduct a water audit*. A facility water audit should be performed to identify and document all end uses of water, daily or hourly water consumption rates for all end uses, and water efficiency practices already in place.

4) *Identify water management opportunities*. Based on the results of the audit, opportunities for the elimination, reduction, and reuse of water applicable to each end use should be identified.

5) *Prepare an action plan and implementation schedule*. Cost-benefit analyses on all identified opportunities can be performed to determine the most practical ways for meeting the established goals for water efficiency. An action plan with specific goals, timelines, and staff responsibilities for water efficiency updates should be established to implement all feasible opportunities.

6) *Track results and publicize successes*. Progress toward established water efficiency goals should be tracked and publicized as a means of highlighting successes and educating personnel on water efficiency. Successes should be acknowledged and awarded on a regular basis.

Good housekeeping. A general housekeeping program for facility water systems can ensure that water supplies and end uses continue to operate at optimal efficiency and that potential maintenance issues are identified and addressed promptly. In general, good housekeeping for water efficiency involves the following actions (Envirowise 2001; NCDNER 1998):

- Inspection of all water connections, piping, hoses, valves, and meters regularly for leaks, with prompt repair of leaks when found.
- Inspection and replacement of faulty valves and fittings.
- Switching off water sprays and hoses when not in use.
- Measuring and optimizing process flow rates.
- Keeping spray nozzles free of dirt and scale.
- The elimination of excessive overflow from washing and soaking tanks.
- Installing water meters on equipment to better enable monitoring and reduction of water consumption.
- Installing guards on conveyors and catch trays on equipment to reduce the amount of food waste that must be cleaned off of floors.
- Disconnecting or removing redundant pipework.

At the J.W. Lees and Company Brewery in Manchester, England, good housekeeping practices for water management reportedly saved the company £66,600 per year in water costs ($106,000 in 1996 U.S. dollars) with first year investment costs of only £2,750 ($4,400 in 1996 U.S. dollars) (Envirowise 1996).

Recycling of product waste as animal feed. Instead of discharging fruit and vegetable solids into the wastewater stream, this waste can be reclaimed (often manually by using brooms and shovels or by using screens on drains) and used as animal feed. This measure can reduce the use of water because often product wastes are discarded by the hosing down or rinsing of surfaces. Additionally, this measure can reduce the need for manufacture of animal feed from raw materials, leading to indirect energy and water savings in the animal feed supply chain (European Commission 2006).

Use of water efficient building fixtures. For building fixtures such as toilets, showers, and faucets, water efficient designs can be installed that lead to significant water savings. For example, low-flow toilets typically require only 1.6 gallons per flush, compared to 3.5 gallons per flush required for standard toilets (Galitsky et al. 2005b). Additional options include low-flow shower heads, aerating faucets, self-closing faucets, and proximity sensing faucets that turn on and off automatically.[24]

Dry conveyors. Where feasible, water flumes might be replaced by belt conveyors or chutes to save significant quantities of water (Envirowise 2002). However, the applicability of this measure will depend on the extent to which existing water flumes are integrated with other facility processes (e.g., washing), how susceptible the product is to bruising or damage, and the flexibility of the installed equipment layout.

Use of small diameter hoses. All applications of hoses should be assessed, and, where feasible, the smallest possible diameter hoses should be installed. Small diameter hoses provide a low flow, high pressure condition, which can reduce the volume of water required for a given task (Lom and Associates 1998).

Air cooling. The use of air cooling instead of water cooling can lead to water savings in situations where air is a feasible process cooling alternative (e.g., blanching). However, from an energy perspective, water cooling is generally preferable to air cooling (Kiwa 2005). Thus, the switch to air cooling should be carefully examined for each prospective process application to determine whether or not a favorable compromise between energy use and water use exists.

Use of automated start/stop controls. For end uses of water with intermittent demand, sensors (e.g., photocells) can be employed to detect the presence of materials and to supply water only when it is required by the process. Such sensors will turn off water supplies automatically when not required and also during non-production periods, thereby saving water (European Commission 2006).

Reducing demand for steam and hot water. Reducing the demand for steam and hot water not only saves energy but also reduces the need for treated boiler water. Typically, fresh water must be treated to remove contaminants that might accumulate in the boiler, so reducing demand not only decreases boiler water use, but can also reduce the amount of purchased chemicals for boiler water treatment (Galitsky et al. 2005b). The combined energy, water, and chemicals savings associated with reducing steam and hot water demand make it a particularly attractive measure.

Steam and hot water demand can be reduced through the general steam system energy efficiency strategies discussed in Chapter 7 of this Energy Guide, as well as through process-specific modifications. For example, where feasible, dry caustic peeling methods can be employed in lieu of wet caustic peeling or steam-based peeling methods to reduce process

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[24] For additional information on water-saving fixtures and appliances, visit the U.S. EPA's WaterSense website at http://www.epa.gov/owm/water-efficiency/ and the U.S. DOE's Federal Energy Management Program Water Efficiency website at http://www.eere.energy.gov/femp/technologies/water_efficiency.cfm.

water consumption. Dry caustic peeling has been shown to reduce water consumption by up to 75% compared to wet caustic peeling in the processing of beets (Envirowise 2001). Additional examples include the use of air cooling instead of water cooling to cool products after blanching, or the use of steam-based blanching methods instead of water-based blanching methods.

Reducing cooling tower bleed-off. Cooling tower "bleed-off" refers to water that is periodically drained from the cooling tower basin to prevent the accumulation of solids. Bleed-off volumes can often be reduced by allowing higher concentrations of suspended and dissolved solids in the circulating water, which saves water. The challenge is to find the optimal balance between bleed-off and makeup water concentrations (i.e., the concentration ratio) without forming scales. The water savings associated with this measure can be as high as 20% (Galitsky et al. 2005b).

The Ventura Coastal Plant, a manufacturer of citrus oils and frozen citrus juice concentrates in Ventura County, California, was able to increase the concentration ratios of its cooling towers and evaporative coolers such that bleed-off water volumes were reduced by 50%. The water savings amounted to almost 5,200 gallons per day, saving the company $6,940 per year in water costs (CDWR 1994). With capital costs of $5,000, the simple payback period was estimated at around seven months.

15.2 Cleaning and Sanitation Water Efficiency Measures

Dry cleaning of equipment and surfaces. Fruit and vegetable wastes and residues should be removed manually from floors and equipment before the application of cleaning water to reduce water consumption. Dry cleaning can be done using brushes, squeegees, brooms, shovels, and vacuums. Often, solid and liquid wastes are chased down floor drains using a hose; a better practice is to use brooms or shovels and to dump wastes into a container designated for solid waste (European Commission 2006).

High pressure low volume sprays. In applications such as truck, container, surface, and floor cleaning, total water consumption can be reduced by using high pressure low volume spray systems, which employ small diameter hoses and/or flow restricting spray nozzles. Such systems can also be fitted with manual triggers, which allow personnel to regulate use, or automatic shut-off valves to further reduce water consumption (RACCP 2001; European Commission 2006).

At a fruit jam manufacturing facility in Manchester, England, cleaning hoses in the fruit room were identified as one of the highest end uses of water in the facility (17% of total site water consumption). The company installed trigger nozzles on the cleaning hoses and trained plant personnel in their use. The new nozzles and training cost only £100 ($145 in 2001 U.S. dollars), but resulted in savings of £3,000 to £4,000 per year ($4,350 to $5,800 in 2001 U.S. dollars) (Envirowise 2001). The simple payback period for this measure was less than two weeks.

Similarly, Harvest FreshCuts (an Australian processor of fresh salads and vegetable products) was able to reduce the water it uses for cleaning by 10% through the installation of efficient high pressure spray nozzles on hoses, regular hose and nozzle maintenance, and operator training (QGEPA 2003).

Clean equipment immediately after use. Waiting too long to clean equipment can allow product residues to become dry and crusty and harder to remove, requiring more water consumption in the cleaning phase. Processing equipment should be immediately cleaned after production has stopped to minimize the water necessary for cleaning (Envirowise 2002).

Optimization of clean-in-place performance. Clean-in-place processes should be programmed to use only enough water and detergent to perform the desired cleaning task at a particular piece of equipment. Dry cleaning prior to clean-in-place cycles can further reduce the minimum amount of water and detergent needed (European Commission 2006).

An environmental assessment at Harvest FreshCuts (an Australian processor of fresh salads and vegetable products) determined that by introducing a cleaning system that ensured accurate water and chemical usage during the cleaning cycle, the volume of internally recycled water could be increased by 40% (QGEPA 2003).

Pigging. A pig is a solid plug or ball that is pushed through a pipe (either by product flows or by another propellant, such as compressed air) to remove deposits adhering to pipe walls. Pigging can be performed instead of rinsing pipes with water to reduce water consumption, where the piping system is amenable to pigging (Envirowise 2002).

At Nelsons of Aintree, a jam manufacturer based in the United Kingdom, a pigging system was installed to clean a long pipeline used for transporting jam. Previously, cleaning the pipeline used large volumes of water and flushed most of the jam residues into a drain. In the new system, rubber pigs made from food grade rubber are propelled through the pipe using compressed air and stopped at the other end of the pipe by a bar that stops the pig but allows jam to pass. The pig is returned by switching the direction of the compressed air via a valve. The pigging system saved the company £105,280 per year ($158,000 in 2000 U.S. dollars) by reducing water use, effluent discharge volumes, and energy consumption and another £134,780 per year ($202,000 in 2000 U.S. dollars) in avoided product losses (ETBPP 2000). Reportedly, the system allowed the company to save 173 tons of jam per year while reducing water use by around 528,000 gallons per year.

Low pressure foam cleaning. Traditionally, walls, floors, and equipment are cleaned using brushes, high pressure spray hoses, and detergents. Low pressure foam cleaning methods, in which cleaning foam is sprayed on surfaces and allowed to settle for 10 to 20 minutes before rinsing with low pressure water, can save both water and energy compared to high pressure cleaning methods (RACCP 2001; European Union 2006). However, this method does not provide scouring ability and thus might not be a feasible replacement for all high pressure cleaning applications.

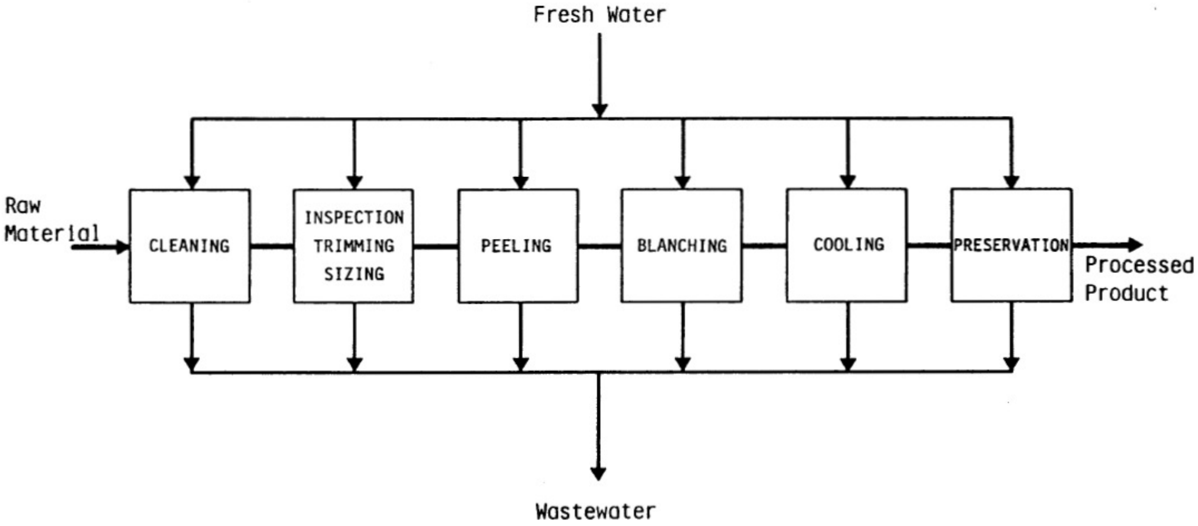
Control of volume in clean-in-place processes. The control of water flows for burst rinsing and clean-in-place processes should be based on required water volume, not a pre-determined time, to reduce cleaning water quantities (NDCC 1997).

Pre-soaking of floors and equipment. An effective means of reducing water consumption in cleaning is to pre-soak soiled surfaces on floors and open equipment prior to cleaning. Pre-soaking can be effective at loosening dirt and hardened food residues so that less water is required in the actual cleaning operations (European Commission 2006).

15.3 Water Recovery, Reuse, and Recycling Measures

In the conventional method of once-through water use (depicted in Figure 15.1), fresh water is used once for process and cleaning applications and any water not contained in the final product is then discharged into the wastewater stream. Although once-through water use methods are increasingly less common in modern fruit and vegetable processing facilities, they represent the most inefficient methods of using water and should be avoided wherever possible. Preferably, water should be recovered and reused or recycled within the facility to reduce fresh water purchasing and treatment costs while also reducing the volume and associated costs of wastewater treatment and disposal. According to Raghupathy (2005), at least 50% to 60% of water in typical food processing facilities can be recovered for reuse. However, the extent to which fresh water use can be reduced via water reuse and recycling measures in any fruit and vegetable processing facility will ultimately depend on product hygiene considerations.

Figure 15.1: Schematic of once-through water use in a representative fruit and vegetable processing system



Source: Montgomery (1981)

The potential applications of water recovered from fruit and vegetable processing operations can be classified into three general categories, ranked in order of increasing risk of product hygienic contamination (Montgomery 1981):

1) Water that may contact the product during initial processing stages or may contact the product container, but has little likelihood of being incorporated into the final product. Such applications include initial fluming, initial product washing, container cooling, equipment pre-rinsing, and surface pre-soaking.

2) Water that directly contacts the product before, during, or after processing and might be incorporated into the final product. Such applications include blanching, direct product cooling, or equipment and container rinsing.

3) Water that is directly incorporated into the product and filling of product containers.

In general, recycling is feasible and practiced commonly in the U.S. food processing industry in the first two applications but generally not practiced in the third application due to hygienic concerns. Where feasible, the elimination of once-through water use can lead to significant water savings, as illustrated by the following case studies.

At the Gangi Brothers Packing Company, a canned tomato product manufacturer in San Jose, California, water is used in fluming tomatoes from trucks, tomato rinsing, vacuum pump seals, boiler makeup, and process cooling. In 1989, the company implemented an aggressive water efficiency program, which included the recycling of flume water and the installation of evaporative cooling towers to recycle cooling water. Reportedly, the company reduced its water consumption by 94 million gallons per year, which led to savings of around $130,000 per year (CDWR 1994). The reported payback period on the equipment and modifications was less than one year.

Stahlbush Island Farms, a grower, canner, and freezer of fruits and vegetables in Corvalis, Oregon, reduced its consumption of water by more than 50% through innovative water recovery and recycling systems. Water is pumped from wells at a temperature of about 55° F, where it is quickly used to cool hot pumpkin puree. Next, the water passes through a second heat exchanger, where it cools oil from the facility's refrigeration system compressors. When the water leaves the second heat exchanger, it has been heated to around 100° F. The warm water is then pumped to a surge tank, where it is used in one of four different applications: (1) to wash pumpkins as they enter the processing plant, (2) to clean food processing equipment, (3) for condenser water in the facility's refrigeration cycle, and (4) for boiler makeup water (ODEQ 1996). As an additional benefit, the recycled water is used to provide warm boiler makeup water and to preheat the washed pumpkins, saving energy.

Listed below are some of the most significant opportunities for water recovery, reuse, and recycling applicable to fruit and vegetable processing facilities.

Reuse of washing water. In the initial washing of fruits and vegetables, a large volume of water is often necessary and the concentration of dirt in the wastewater exiting the process is typically low. In many instances, a recirculation system can be installed to maintain an acceptable concentration of dirt in the wash water while reducing fresh water inputs. A basic recirculation system consists of a strainer or filter to remove solids and a pump for circulating water back to the washing process (RACCP 2001). For wash water with high dirt concentrations, a flotation unit or centrifugal separator can be added to help remove solids. Additionally, ultraviolet or ozone treatment modules can be added to reduce bacterial loads, where needed.

Cooling towers. Once-through cooling systems can be replaced by cooling towers, which continuously recycle cooling water and lead to significant water savings. The U.S. DOE (2006g) estimates that to remove the same heat load, once-through cooling systems can use as much as 40 times more water than a cooling tower (operated at 5 cycles of concentration). In a cooling tower, circulating warm water is put into contact with an air flow, which evaporates some of the water. The heat lost by evaporation cools the remaining water, which can then be recirculated as a cooling medium. For example, cooling towers can be used to recirculate water from evaporative can coolers in the canning process, with recycling occurring continuously until the water no longer meets cleanliness standards (RACCP 2001).

The U.S. DOE (2006h) offers the following guidelines for operating cooling towers at optimal water efficiency:

- Consider using acid treatment (e.g., sulfuric or ascorbic acid), where appropriate. Acids can improve water efficiency by controlling scale buildup created from mineral deposits.

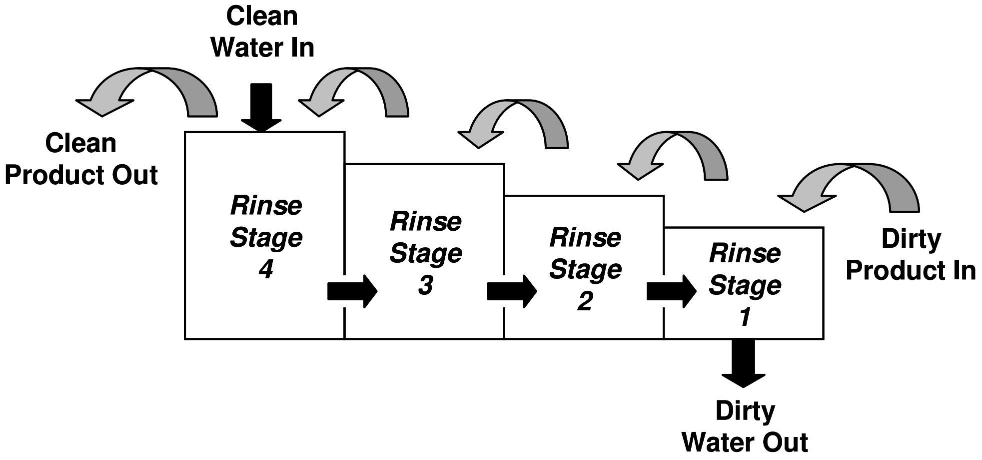
- Install a sidestream filtration system that is composed of a rapid sand filter or high-efficiency cartridge filter to cleanse the water. These systems enable the cooling tower to operate more efficiently with less water and chemicals.

- Consider alternative water treatment options such as ozonation or ionization, to reduce water and chemical usage.

- Install automated chemical feed systems on large cooling tower systems (over 100 tons). The automated feed system should control bleed-off by conductivity and add chemicals based on makeup water flow. Automated chemical feed systems minimize water and chemical use while optimizing control against scale, corrosion and biological growth.

Counter-current washing. Figure 15.2 provides a schematic of the counter-current washing approach. In contrast to once-through product washing methods, counter-current washing makes use of progressively dirtier rinse water to provide pre-rinsing for incoming product streams, thereby saving water. As illustrated in Figure 15.2, rinse water flows in the opposite direction of the product flow, thereby ensuring that the dirtiest water is used for the first rinse and that clean water is used for the final rinse. Counter-current washing systems can save up to 40% of the water used in traditional, once-through washing systems (Envirowise 2002).

Figure 15.2: Schematic of the counter-current rinsing approach



Recycling of final rinse water. Final rinsing is done to remove residues of detergents from the equipment after it has been cleaned. The final rinse water, while not suitable for additional final rinsing applications, can be recovered and used for initial rinsing or intermediate rinsing purposes rather than being discharged to the wastewater stream (Korsström 2001).

Recycling of evaporator condensate. Depending on the quality (e.g., organic content) of condensate reclaimed from products in evaporation processes, condensate water can be reused for other low-grade facility applications such as equipment pre-rinsing and surface pre-soaking. Additionally, condensate recovery systems can be fitted with heat exchangers such that hot condensate can be used for pre-heating the evaporation process input streams, which saves energy (European Commission 2006).

Segregation of wastewater systems. When all facility wastewater streams are combined into a common wastewater flow, opportunities for recovering and recycling the wastewater streams with reclaimable water (e.g., streams with manageable solids content and/or bacterial loading) are lost. Where feasible, the use of separate process wastewater systems should be considered to maximize opportunities for water recovery and recycling.

For example, in 1993 a UK based snack food company performed a facility audit to determine if water savings could be realized if process wastewater streams were segregated prior to on-site treatment. The company found that by segregating its potato wash water, hot starch water, and cold starch water streams for separate recovery and treatment, its water consumption could be reduced by 19% (Envirowise 2001). The potato wash water was reused after grit removal and the cold starch water was recycled after good quality starch was recovered. The annual savings in water supply costs were estimated at £90,000 ($135,000 in 1993 U.S. dollars).

Membrane filtration. Membrane filtration technologies have been applied in many industries to clean wastewater prior to disposal and to recover water for recycling in various facility and process applications. Membrane systems used in wastewater treatment at fruit and vegetable processing facilities have been documented to reduce freshwater intake and effluent by as much as 85% (CADDET 2004c). The potential barriers to implementation include relatively high capital costs, as well as the need for specific membranes for specific applications (Martin et al. 2000).

At the Tri Valley Growers' Oberti Olive facility in Madera, California, reverse osmosis and ultra-filtration membrane systems were installed to treat the facility's well water, flotation brine, oil mill slurry, yeast broth, and biotower water. The membrane systems reportedly reduced the company's freshwater intake and effluent discharge by 80% to 85%, allowed for the recovery of salt from brine water, allowed for the recovery of solids for sale as animal feed, and reduced land use by evaporation ponds by 85% (Aumann 2000; CADDET 2004c).

At the Michigan Milk Producers Association facility in Ovid, Michigan, a reverse osmosis membrane filtration system was installed to concentrate organic impurities in evaporator condensate. The filtered hot condensate water is reused for clean-in-place water, tank wash-down water, and boiler makeup water. The reported benefits include a reduction in well water consumption and wastewater discharges of 100,000 to 150,000 gallons per day, a reduction in boiler and wash water treatment costs of $6,000 to $8,000 per month, and a reduction in scale buildup on pipes (EPRI 1991).

Hydrocyclones. For wastewater streams with significant solids content, such as heavily soiled wash water, hydrocyclones can be used to separate out solids (using high centrifugal forces) and reclaim water for use in other facility applications. Such systems can often have three major benefits. First, a significant amount of water can be recovered and recycled within a facility, reducing the necessary purchases of fresh water. Second, because wastewater ultimately has less solids content, wastewater disposal costs are often reduced. Third, recovered solids can often be recycled as animal feed, mulch, or agricultural additives.

At the Smith Snack Food Company, the largest manufacturer of potato- and corn-based snack foods in Australia, a hydrocyclone system was installed in 1997 to reduce the solids content in wastewater streams at the company's Adelaide facility. Hydrocyclones were installed on the facility's corn and potato washing lines, with solids being collected in a sludge tank and reclaimed water being recycled back into the initial washing processes for potatoes and corn. The system reportedly reduced water consumption in the washing processes by more than 80% while also saving the company around $130,000 per year ($91,000 in 1997 U.S. dollars) in reduced wastewater disposal costs (ADEH 1997). The simple payback period was estimated at just five weeks.

Recycling of can cooling water. When can cooling water is not recirculated, it can be recovered and used for the initial washing of incoming products, as a rinse for caustic peeling processes, in canning belt lubrication, and in miscellaneous facility cleanup operations (e.g., pre-soaking and equipment pre-rinsing) (NCDENR 1998).

Recycling of blanching and cooking water. Water used for blanching, post-blanching cooling, and cooking of fruits and vegetables can, in general, be collected and reused for the initial washing of incoming products without treatment (European Commission 2006).

Reuse of flume water. Instead of discharging flume water to the wastewater stream, it can be recovered, filtered, and reused continuously in fluming applications. Alternatively, flume water can be recovered and recycled for use in equipment pre-rinsing and pre-soaking applications elsewhere in the facility (CDWR 1994; Envirowise 2001).

Reuse of compressor cooling water. Cooling water from compressors (e.g., in refrigeration and compressed air systems) can be reused as seal water in vacuum pumps instead of fresh water, or as secondary water for other purposes, such as equipment pre-soaking (Korsström 2001). Warm cooling water can also be stored in insulated tanks for later use in facility cleaning, pre-soaking, and equipment pre-rinsing applications (NDCC 1997).

16 Summary and Conclusions

The U.S. fruit and vegetable processing industry spent nearly $810 million on purchased fuels and electricity in 2002, making energy a significant cost driver for the industry. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings in the face of ongoing energy price volatility. Considering the negative impacts of the 2001 spike in U.S. natural gas prices on the industry's operating costs, as well as more recent sharp increases in natural gas prices across the nation, energy efficiency improvements are needed today more than ever. Many companies in the U.S. fruit and vegetable processing industry have already accepted the challenge to improve their energy efficiency in the face of high energy costs and have begun to reap the rewards of energy efficiency investments.

This Energy Guide has summarized a large number of energy-efficient technologies and practices that are proven, cost-effective, and available for implementation today. Energy efficiency improvement opportunities have been discussed that are applicable at the component, process, facility, and organizational levels. Preliminary estimates of savings in energy and energy-related costs have been provided for many energy efficiency measures, based on case study data from real-world industrial applications. Additionally, typical investment payback periods and references to further information in the technical literature have been provided, when available.

A key first step in any energy improvement initiative is to establish a focused and strategic energy management program, as depicted in Figure 6.1, which will help to identify and implement energy efficiency measures and practices across and organization and ensure continuous improvement.

Tables 5.1 to 5.3 summarize the energy efficiency measures presented in this Energy Guide. While the expected savings associated with some of the individual measures in Tables 5.1 to 5.3 may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Many of the measures in Tables 5.1 to 5.3 have relatively short payback periods and are therefore attractive economic investments on their own merit. The degree of implementation of these measures will vary by plant and end use; continuous evaluation of these measures will help to identify further cost savings in ongoing energy management programs.

In recognition of the importance of water as a resource in the U.S. fruit and vegetable processing industry, as well as its rising costs, this Energy Guide has also provided information on basic, proven measures for improving plant-level water efficiency, which are summarized in Table 5.4.

For all energy and water efficiency measures presented in this Energy Guide, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

Acknowledgements

This work was supported by the Climate Protection Partnerships Division of the U.S. Environmental Protection Agency as part of its ENERGY STAR program through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Many people within and outside of the fruit and vegetable processing industry provided valuable insights in the preparation of this Energy Guide. The authors are particularly grateful to the following people (in alphabetical order) for their helpful comments and advice during the development of this Energy Guide: John Batura of Campbell's Soup Company, Joseph Benevides of Ocean Spray Cranberries, Austin H. Bonnett (IEEE Fellow), Alan Christie of the J.R. Simplot Company, Elizabeth Dutrow of the U.S. Environmental Protection Agency, Dan Fonner of Heinz North America, Paul Halberstadt of ConAgra Foods, Al Halvorsen of Frito-Lay, Don Hertkorn of ICF Consulting, Ted Jones and Ilene Mason of the Consortium for Energy Efficiency, John Malinowski of Baldor Electric Company, Aimee McKane of Lawrence Berkeley National Laboratory, Leland McPherrin of Escalon Premier Brands, Rob Neenan of the California League of Food Processors, Richard Pate of the Pacific Gas and Electric Company, Linda Raynes of the Electrical Apparatus Service Association, Jon Russett of General Mills, and Terry Young of ConAgra Foods.

Any remaining errors in this Energy Guide are the responsibility of the authors. The views expressed in this Energy Guide do not necessarily reflect those of the U.S. Environmental Protection Agency, the U.S. Department of Energy, or the U.S. Government.

Glossary

ASD	Adjustable-speed drive
bhp	Boiler horsepower
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
cfm	Cubic feet per minute
CO	Carbon monoxide
CO_2	Carbon dioxide
EASA	Electrical Apparatus Service Association
HID	High-intensity discharge
hp	Horsepower
HVAC	Heating, ventilation, and air conditioning
IAC	Industrial Assessment Center
kJ	Kilojoule
KWh	Kilowatt hour
LCC	Life cycle costing
LED	Light emitting diode
MBtu	Million British thermal units
MC-ASD	Magnetically-coupled adjustable-speed drive
MECS	Manufacturing Energy Consumption Survey
MVR	Mechanical vapor recompression
NAICS	North American Industry Classification System
NEMA	National Electrical Manufacturers Association

NO_X	Nitrogen oxides
psi	Pounds per square inch
SIC	Standard Industry Classification
SO_2	Sulfur dioxide
SO_x	Sulfur oxides
STIG	Steam-injected gas turbine
TBtu	Trillion British thermal units
TWh	Terawatt hour
TVR	Thermal vapor recompression
USDA	United States Department of Agriculture
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency

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Appendix A: Major Products of the U.S. Fruit and Vegetable Processing Industry

Tables A.1 through A.4 summarize the major products and product categories manufactured by each sub-sector of the U.S. fruit and vegetable processing industry, based on 2002 value of product shipments data from the U.S. Census Bureau (U.S. Census 2004a, 2004b, 2004c, 2004d).[25]

Table A.1: Major products of the U.S. frozen fruit, juice, and vegetable manufacturing sub-sector, 2002

NAICS 311411 Products and Product Categories	2002 Value of Product Shipments ($1,000)	% of Sub-Sector Total
Total NAICS 311411 output	**8,679,817**	
Frozen vegetables	**5,803,345**	**67%**
Frozen French fried potatoes	2,341,512	27%
Frozen vegetable combinations	607,450	7%
Other frozen potato products (patties, puffs, etc.)	524,223	6%
Frozen sweet yellow corn (cut and cob)	326,083	4%
Frozen onions (rings, diced, chopped)	277,067*	3%
Frozen green peas	151,531	2%
Frozen green beans	133,438	2%
Frozen broccoli	122,323	1%
Frozen fruits, juices, ades, drinks, and cocktails	**2,446,828**	**28%**
Frozen concentrated orange juice (all sizes)	1,504,523	17%
Frozen strawberries	207,012	2%
Frozen apples and applesauce	152,633	2%
Frozen berries (blueberries, raspberries, blackberries, etc.)	100,421	1%
Frozen concentrated grapefruit juice	92,386	1%
Frozen concentrated grape juice (all sizes)	46,847	1%

* based on 1997 U.S. Census Bureau data

Sources: U.S. Census (1999a, 2004a)

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[25] Tables A.1 through A.4 list only major products manufactured by each sub-sector. Major products are defined as those with high value of shipments (as of 2002). These tables do not list every product or product category manufactured by each sub-sector. Thus, the products listed do not represent 100% of the total value of shipments for each sub-sector. For a full list of products manufactured by each sub-sector of the U.S. fruit and vegetable processing industry, see U.S. Census (2004a, 2004b, 2004c, 2004d).

Table A.2: Major products of the U.S. fruit and vegetable canning sub-sector

NAICS 311421 Products and Product Categories	2002 Value of Product Shipments ($1,000)	% of Sub-Sector Total
Total NAICS 311421 output	**18,757,575**	
Canned catsup and other tomato based sauces	**4,273,116**	**23%**
Canned spaghetti, pizza, and marina sauces	1,427,515	8%
Canned catsup	843,708	4%
Canned tomato paste	581,282	3%
Canned salsa	557,521	3%
Canned fruit juices, nectars, and concentrates	**3,283,334**	**18%**
Canned orange juice	1,593,435	8%
Canned fruit juice mixtures	709,627	4%
Canned apple juice	413,335	2%
Canned vegetables, except hominy and mushrooms	**2,775,443**	**15%**
Canned tomatoes, including stewed	739,027	4%
Canned corn, whole kernel & cream	582,334	3%
Canned beans, green and wax	462,044	2%
Canned green peas	152,295	1%
Canned fruits, except baby foods	**2,164,481**	**12%**
Canned peaches	458,173*	2%
Canned applesauce	381,761	2%
Canned olives	324,210	2%
Canned fruit cocktail	230,636	1%
Canned pie mixes	182,788	1%
Fresh fruit juices and nectars	**1,763,608**	**9%**
Fresh orange juices and nectars	831,791	4%
Pickles and other pickled products	**1,475,140**	**8%**
Canned jams, jellies, and preserves	**969,550**	**5%**
Canned vegetable juices	**601,700**	**3%**
Canned tomato juice	530,000	3%

* based on 1997 U.S. Census Bureau data.

Sources: U.S. Census (2000, 2004b)

Table A.3: Major products of the specialty canning sub-sector

NAICS 311422 Products and Product Categories	**2002 Value of Product Shipments ($1,000)**	**% of Sub-Sector Total**
Total NAICS 311422 output	**6,528,654**	
Canned soups and stews, except frozen and seafood	**3,316,050**	**51%**
Canned dry beans (including baked and chili con carne)	**1,175,484**	**18%**
Canned specialties and nationality foods	**776,119**	**12%**
Canned spaghetti and ravioli	268,435	4%
Canned Spanish foods (Mexican rice, tortillas, etc.)	144,844	2%
Canned baby foods, except cereal and biscuits	**560,251**	**9%**

Source: U.S. Census (2004c)

Table A.4: Major products of the dried and dehydrated food manufacturing sub-sector

NAICS 311423 Products and Product Categories	**2002 Value of Product Shipments ($1,000)**	**% of Sub-Sector Total**
Total NAICS 311423 output	**4,553,355**	
Dried and dehydrated fruits and vegetables, including freeze-dried	**2,533,441**	**56%**
Potatoes (except flour), dried and dehydrated	402,453	9%
Prunes	273,374*	6%
Onions	241,758	5%
Raisins	237,119	5%
Apples	95,912*	2%
Soup mixes, dried, dehydrated, and freeze-dried	**1,077,242**	**24%**

* based on 1997 U.S. Census Bureau data.

Source: U.S. Census (1999b, 2004d)

Appendix B: Basic Energy Efficiency Actions for Plant Personnel

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined below (Caffal 1995).

- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.

- Switch off unnecessary lights; rely on daylighting whenever possible.

- Use weekend and night setbacks on HVAC in offices or conditioned buildings.

- Report leaks of water (both process water and dripping taps), steam, and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.

- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.

- Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.

- Check to make sure the pressure and temperature of equipment is not set too high.

- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.

- Carry out regular maintenance of energy-consuming equipment.

- Ensure that the insulation on process heating equipment is effective.

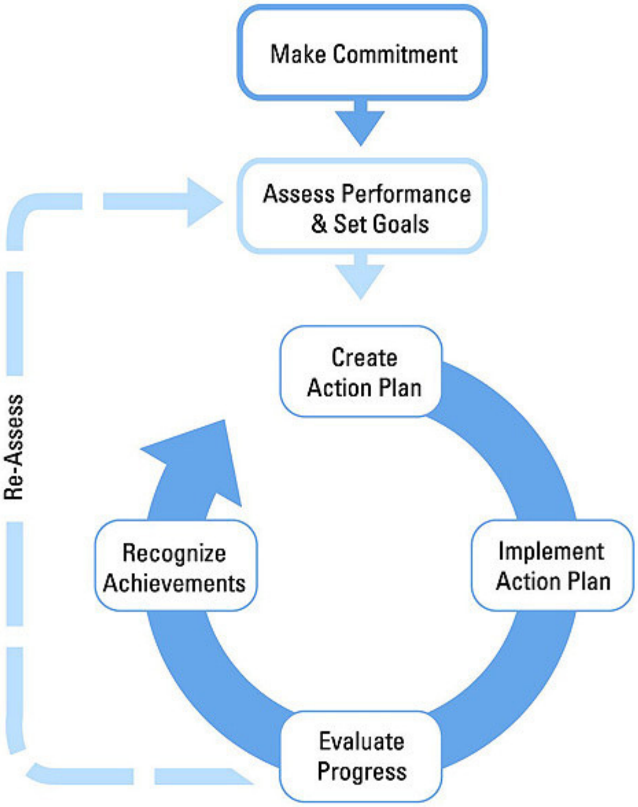
Appendix C: Guidelines for Energy Management Assessment Matrix

CHANGE FOR THE
BETTER WITH
ENERGY STAR

Energy Management Program Assessment Matrix

Introduction
The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.



This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – http://www.energystar.gov/.

How To Use The Assessment Matrix
The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

- No evidence
- Most elements
- Fully Implemented

1. Print the assessment matrix.

2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.

3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.

4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.

Energy Management Program Assessment Matrix

	Little or no evidence	Some elements	Fully implemented	Next Steps
Make Commitment to Continuous Improvement				
Energy Director	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
Energy Team	No company energy network	Informal organization	Active cross-functional team guiding energy program	
Energy Policy	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
Assess Performance and Opportunities				
Gather and Track Data	Little metering/no tracking	Local or partial metering/tracking/ reporting	All facilities report for central consolidation/analysis	
Normalize	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
Establish baselines	No baselines	Various facility-established	Standardized corporate base year and metric established	
Benchmark	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
Analyze	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
Technical assessments and audits	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
Set Performance Goals				
Determine scope	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
Estimate potential for improvement	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
Establish goals	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
Create Action Plan				
Define technical steps and targets	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

Energy Management Program Assessment Matrix

	Little or no evidence	Some elements	Fully implemented	Next Steps
Implement Action Plan				
Create a communication plan	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
Raise awareness	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
Build capacity	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
Motivate	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
Track and monitor	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
Evaluate Progress				
Measure results	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
Review action plan	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
Recognize Achievements				
Provide internal recognition	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
Get external recognition	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	

CHANGE FOR THE BETTER WITH ENERGY STAR

Energy Management Program Assessment Matrix

Interpreting Your Results

Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

Resources and Help

ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.

2. Become an ENERGY STAR Partner, if you are not already.

3. Review ENERGY STAR Tools and Resources.

4. Find more sector-specific energy management information at http://www.energystar.gov/industry.

5. Contact ENERGY STAR for additional resources.

Appendix D: Teaming Up to Save Energy Checklist

The following checklist can be used as a handy reference to key tasks for establishing and sustaining an effective energy team. For more detailed information on energy teams, consult the U.S. EPA's *Teaming Up to Save Energy* guide (U.S. EPA 2006), which is available at http://www.energystar.gov/.

ORGANIZE YOUR ENERGY TEAM		√
Energy Director	Able to work with all staff levels from maintenance to engineers to financial officers. Senior-level person empowered by top management support	
Senior Management	Energy director reports to senior executive or to a senior management council. Senior champion or council provides guidance and support	
Energy Team	Members from business units, operations/engineering, facilities, and regions. Energy networks formed. Support services (PR, IT, HR).	
Facility Involvement	Facility managers, electrical personnel. Two-way information flow on goals and opportunities. Facility-based energy teams with technical person as site champion.	
Partner Involvement	Consultants, vendors, customers, and joint venture partners. Energy savings passed on through lower prices.	
Energy Team Structure	Separate division and/or centralized leadership. Integrated into organization's structure and networks established.	
Resources & Responsibilities	Energy projects incorporated into normal budget cycle as line item. Energy director is empowered to make decisions on projects affecting energy use. Energy team members have dedicated time for the energy program.	
STARTING YOUR ENERGY TEAM		√
Management Briefing	Senior management briefed on benefits, proposed approach, and potential energy team members.	
Planning	Energy team met initially to prepare for official launch.	
Strategy	Energy team met initially to prepare for official launch.	
Program Launch	Organizational kickoff announced energy network, introduced energy director, unveiled energy policy, and showcased real-world proof.	
Energy Team Plans	Work plans, responsibilities, and annual action plan established.	
Facility Engagement	Facility audits and reports conducted. Energy efficiency opportunities identified.	

BUILDING CAPACITY		√
Tracking and Monitoring	Systems established for tracking energy performance and best practices implementation.	
Transferring Knowledge	Events for informal knowledge transfer, such as energy summits and energy fairs, implemented.	
Raising Awareness	Awareness of energy efficiency created through posters, intranet, surveys, and competitions.	
Formal Training	Participants identified, needs determined, training held. Involvement in ENERGY STAR Web conferences and meetings encouraged. Professional development objectives for key team members.	
Outsourcing	Use of outside help has been evaluated and policies established.	
Cross-Company Networking	Outside company successes sought and internal successes shared. Information exchanged to learn from experiences of others.	
SUSTAINING THE TEAM		√
Effective Communications	Awareness of energy efficiency created throughout company. Energy performance information is published in company reports and communications.	
Recognition and Rewards	Internal awards created and implemented. Senior management is involved in providing recognition.	
External Recognition	Credibility for your organization's energy program achieved. Awards from other organizations have added to your company's competitive advantage.	
MAINTAINING MOMENTUM		√
Succession	Built-in plan for continuity established. Energy efficiency integrated into organizational culture.	
Measures of Success	Sustainability of program and personnel achieved. Continuous improvement of your organization's energy performance attained.	

Appendix E: Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

Tools for Self-Assessment

Steam System Assessment Tool

Description:	Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group:	Any industry operating a steam system
Format:	Downloadable software package (13.6 MB)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Steam System Scoping Tool

Description:	Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group:	Any industrial steam system operator
Format:	Downloadable software (Excel)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

3E Plus: Optimization of Insulation of Boiler Steam Lines

Description:	Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.
Target Group:	Energy and plant managers
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

MotorMaster+

Description:	Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.
Target Group:	Any industry
Format:	Downloadable software (can also be ordered on CD)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description: Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.
Target Group: Any industry
Format: Software package (not free)
Contact: Electric Power Research Institute (EPRI), (800) 832-7322
URL: http://www.epri-peac.com/products/asdmaster/asdmaster.html

The 1-2-3 Approach to Motor Management

Description: A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.
Target Group: Any industry
Format: Downloadable Microsoft Excel spreadsheet
Contact: Consortium for Energy Efficiency (CEE), (617) 589-3949
URL: http://www.motorsmatter.org/tools/123approach.html

AirMaster+: Compressed Air System Assessment and Analysis Software

Description: Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices
Target Group: Any industry operating a compressed air system
Format: Downloadable software
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Fan System Assessment Tool (FSAT)

Description: The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.
Target Group: Any user of fans
Format: Downloadable software
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Combined Heat and Power Application tool (CHP)

Description: The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.
Target Group: Any industrial heat and electricity user
Format: Downloadable software
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Pump System Assessment Tool 2004 (PSAT)

Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
Target Group: Any industrial pump user
Format: Downloadable software
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Quick Plant Energy Profiler

Description: The Quick Plant Energy Profiler, or Quick PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. Quick PEP is designed so that the user can complete a plant profile in about an hour. The Quick PEP online tutorial explains what plant information is needed to complete a Quick PEP case.
Target Group: Any industrial plant
Format: Online software tool
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

ENERGY STAR Portfolio Manager

Description: Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.
Target Group: Any building user or owner
Format: Online software tool
Contact: U.S. Environmental Protection Agency
URL: http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Assessment and Technical Assistance

Industrial Assessment Centers

Description: Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant’s performance and recommends ways to improve efficiency.
Target Group: Small- to medium-sized manufacturing facilities with gross annual sales below $75 million and fewer than 500 employees at the plant site.
Format: A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/iacs.html

Save Energy Now Assessments

Description: The U.S. DOE conducts plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.
Target Group: Large plants
Format: Online request
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/saveenergynow/

Manufacturing Extension Partnership (MEP)

Description: MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.
Target Group: Small- and medium-sized plants
Format: Direct contact with local MEP Office
Contact: National Institute of Standards and Technology, (301) 975-5020
URL: http://www.mep.nist.gov/

Small Business Development Center (SBDC)

Description: The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.
Target Group: Small businesses
Format: Direct contact with local SBDC
Contact: Small Business Administration, (800) 8-ASK-SBA
URL: http://www.sba.gov/sbdc/

ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business

Description: ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.
Target Group: Any user of labeled equipment.
Format: Website
Contact: U.S. Environmental Protection Agency
URL: http://www.energystar.gov/index.cfm?c=business.bus_index

Training

ENERGY STAR

Description:	As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.
Target Group:	Corporate and plant energy managers
Format:	Web-based teleconference
Contact:	Climate Protection Partnerships Division, U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/

Best Practices Program

Description:	The U.S. DOE Best Practices Program provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences.
Target Group:	Technical support staff, energy and plant managers
Format:	Various training workshops (one day and multi-day workshops)
Contact:	Office of Industrial Technologies, U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/training.html

Compressed Air Challenge®

Description:	The not-for-profit Compressed Air Challenge® develops and provides training on compressed air system energy efficiency via a network of sponsoring organizations in the United States and Canada. Three levels of training are available: (1) Fundamentals (1 day); (2) Advanced (2 days); and (3) Qualified Specialist (3-1/2 days plus an exam). Training is oriented to support implementation of an action plan at an industrial facility.
Target Group:	Compressed air system managers, plant engineers
Format:	Training workshops
Contact:	Compressed Air Challenge: Info@compressedairchallenge.org
URL:	http://www.compressedairchallenge.org/

Financial Assistance

Below major federal programs are summarized that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs). However, these programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Industries of the Future - U.S. Department of Energy

Description: Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.
Target Group: Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.
Format: Solicitations (by sector or technology)
Contact: U.S. Department of Energy – Office of Industrial Technologies
URL: http://www.eere.energy.gov/industry/technologies/industries.html

Inventions & Innovations (I&I)

Description: The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to $75,000) and 2) prototype development or commercialization of a technology (up to $250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.
Target Group: Any industry (with a focus on energy-intensive industries)
Format: Solicitation
Contact: U.S. Department of Energy – Office of Industrial Technologies
URL: http://www.eere.energy.gov/inventions/

Small Business Administration (SBA)

Description: The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.
Target Group: Small businesses
Format: Direct contact with SBA
Contact: Small Business Administration
URL: http://www.sba.gov/

State and Local Programs

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Summary of Motor and Drive Efficiency Programs by State
Description: A report that provides an overview of state-level programs that support the use of NEMA Premium® motors, ASDs, motor management services, system optimization and other energy management strategies.
Target Group: Any industry
Contact: Consortium for Energy Efficiency (CEE), (617) 589-3949
URL: http://www.motorsmatter.org/tools/123approach.html

California – Public Interest Energy Research (PIER)
Description: PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.
Target Group: Targeted industries (e.g. food industries) located in California
Format: Solicitation
Contact: California Energy Commission, (916) 654-4637
URL: http://www.energy.ca.gov/pier/funding.html

California – Energy Innovations Small Grant Program (EISG)
Description: EISG provides small grants for development of innovative energy technologies in California. Grants are limited to $75,000.
Target Group: All businesses in California
Format: Solicitation
Contact: California Energy Commission, (619) 594-1049
URL: http://www.energy.ca.gov/research/innovations/index.html/

California – Savings By Design
Description: Design assistance is available to building owners and to their design teams for energy-efficient building design. Financial incentives are available to owners when the efficiency of the new building exceeds minimum thresholds, generally 10% better than California's Title 24 standards. The maximum owner incentive is $150,000 per free-standing building or individual meter. Design team incentives are offered when a building design saves at least 15%. The maximum design team incentive per project is $50,000.
Target Group: Nonresidential new construction or major renovation projects
Format: Open year round
URL: http://www.savingsbydesign.com/

Indiana – Industrial Programs

Description: The Energy Policy Division of the Indiana Department of Commerce operates two industrial programs. The Industrial Energy Efficiency Fund (IEEF) is a zero-interest loan program (up to $250,000) to help Indiana manufacturers increase the energy efficiency of manufacturing processes. The fund is used to replace or convert existing equipment, or to purchase new equipment as part of a process/plant expansion that will lower energy use. The Distributed Generation Grant Program (DGGP) offers grants of up to $30,000 or up to 30% of eligible costs for distributed generation with an efficiency over 50% to install and study distributed generation technologies such as fuel cells, micro turbines, co-generation, combined heat & power and renewable energy sources. Other programs support can support companies in the use of biomass for energy, research or building efficiency.
Target Group: Any industry located in Indiana
Format: Application year-round for IEEF and in direct contact for DGGP
Contact: Energy Policy Division, (317) 232-8970.
URL: http://www.iedc.in.gov/Grants/index.asp

Iowa – Alternate Energy Revolving Loan Program

Description: The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.
Target Group: Any potential user of renewable energy
Format: Proposals under $50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.
Contact: Iowa Energy Center, (515) 294-3832
URL: http://www.energy.iastate.edu/funding/aerlp-index.html

New York – Industry Research and Development Programs

Description: The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.
Target Group: Industries located in New York
Format: Solicitation
Contact: NYSERDA, (866) NYSERDA
URL: http://www.nyserda.org/programs/Commercial_Industrial/default.asp?i=2

Wisconsin – Focus on Energy

Description: Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.
Target Group: Industries in Wisconsin
Format: Open year round
Contact: Wisconsin Department of Administration, (800) 762-7077
URL: http://focusonenergy.com/portal.jsp?pageId=4