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Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry

An ENERGY STAR® Guide for Energy and Plant Managers

Adrian Brush, Eric Masanet, and Ernst Worrell

Environmental Energy Technologies Division

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ABSTRACT

The U.S. dairy processing industry—defined in this Energy Guide as facilities engaged in the conversion of raw milk to consumable dairy products—consumes around $1.5 billion 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. dairy processing industry to reduce energy consumption and greenhouse gas emissions 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. dairy 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 dairy 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 dairy 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 dairy processing, a summary of basic, proven measures for improving water efficiency are also provided. The information in this Energy Guide is intended to help energy and plant managers in the U.S. dairy 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 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 for industry is to help U.S. manufacturers improve their 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 Dairy Processing Focus, which works with U.S. dairy 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. dairy processing industry. Given the importance and rising costs of water as a resource in dairy 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 dairy processing industry in the United States—defined in this Energy Guide as facilities engaged in the conversion of raw milk into consumable dairy products—is an important industry from both an economic and energy use perspective. In 2008, the industry generated over $90 billion in product shipments and employed over 134,000 people directly in nearly 1,600 different facilities. Although dairy processing facilities can be found throughout the United States, Wisconsin and California account for over a quarter of total industry employment. The industry spent nearly $1.5 billion on energy costs in 2008: $726 million for purchased electricity and $731 million for purchased fuels, which consisted primarily of natural gas. Because the costs of electricity and natural gas can be volatile in the United States, energy efficiency improvements are becoming an increasingly important focus area in the U.S. dairy 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. dairy processing industry in Chapter 2. A description of the main production processes employed in dairy processing is provided in Chapter 3. In Chapter 4, the use of energy in the dairy processing industry is discussed along with an overview of the main end uses of energy in typical fluid milk, butter, cheese, ice cream, and concentrated dairy product facilities. Chapters 5 through 13 describe a wide range of available measures for improving energy efficiency in U.S. dairy 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, 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 dairy processing.

Given that the U.S. dairy 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 fluid milk, butter, cheese, dry and concentrated dairy product, and ice cream manufacturing facilities.

Lastly, recognizing the importance of water as a resource in dairy processing, this Energy Guide concludes with information on basic, proven measures for improving water efficiency in Chapter 15. This chapter provides information on improving water efficiency in water intensive Clean-In-Place (CIP) systems, as well as general housekeeping.

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

Table 1.1. Key economic and energy use data for the U.S. dairy processing industry.

Value of product shipments (2008)	
Fluid milk manufacturing	$30.6 billion
Creamery butter manufacturing	$2.7 billion
Cheese manufacturing	$34.2 billion
Dry, condensed, and evaporated dairy product manufacturing	$15.1 billion
Ice cream and frozen desserts	$7.9 billion
Total	$90.6 billion
Employment (2008)	
Fluid milk manufacturing	56,328
Creamery butter manufacturing	1,528
Cheese manufacturing	41,313
Dry, condensed, and evaporated dairy product manufacturing	14,749
Ice cream and frozen desserts	20,303
Total	134,221

Number of establishments (2008)	
Fluid milk	473
Creamery butter manufacturing	30
Cheese manufacturing	497
Dry, condensed, and evaporated dairy product manufacturing	187
Ice cream and frozen desserts	396
Total	1,583
Electricity expenditures (2008)	
Fluid milk manufacturing Creamery butter manufacturing	$287 million
Cheese manufacturing	$229 million
Dry, condensed, and evaporated dairy product manufacturing	$115 million
Ice cream and frozen desserts	$95 million
Total	$726 million

Table 1.2. Key economic and energy use data for the U.S. dairy processing industry (cont.).

Fuel expenditures (2008)	
Fluid milk manufacturing	$231 million
Creamery butter manufacturing	
Cheese manufacturing	$284 million
Dry, condensed, and evaporated dairy product manufacturing	$193 million
Ice cream and frozen desserts	$24 million
Total	$731 million
Site electricity use (2008)	
Fluid milk manufacturing	13.0 TBtu
Creamery butter manufacturing	
Cheese manufacturing	13.0 TBtu
Dry, condensed, and evaporated dairy product manufacturing	5.5 TBtu
Ice cream and frozen desserts	4.4 TBtu
Total	35.8 TBtu

Site fuel use (2008)	
Fluid milk manufacturing	24.6 TBtu
Creamery butter manufacturing	
Cheese manufacturing	30.3 TBtu
Dry, condensed, and evaporated dairy product manufacturing	20.6 TBtu
Ice cream and frozen desserts	2.6 TBtu
Total	77.9 TBtu
Top 5 states for industry employment	
1) Wisconsin 2) California 3) New York 4) Texas 5) Pennsylvania	

Sources: U.S. Census Bureau (2008; 2009a; 2009b)

2 The U.S. Dairy Processing Industry

The U.S. dairy processing industry is defined in this guide as facilities involved in the conversion of raw milk into products within the five subsectors defined by the North American Industry Classification System (NAICS) codes listed in Table 2.1. In 2008, approximately 183 billion pounds of raw milk were produced on dairy farms, of which approximately one third was converted directly to fluid milk and cream (USDA 2010).

Table 2.1. NAICS codes and key products of the U.S. dairy processing industry

NAICS Code	Sector description	Key products
311511	Fluid milk manufacturing	Fluid milk (whole, skim, 1%, 2%, flavored), cream (half and half, light, heavy), sour cream, yogurt, cottage cheese, eggnog
311512	Creamery butter manufacturing	Butter (salted, unsalted)
311513	Cheese manufacturing	Processed cheese, cheddar, mozzarella, provolone, romano, parmesan, swiss, ricotta
311514	Dry, condensed, and evaporated dairy manufacturing	Evaporated milk, sweetened condensed milk, dry milk powder, ice cream mixes
311520	Ice cream and frozen dessert manufacturing	Ice cream (lowfat, regular), sherbet, frozen yogurt

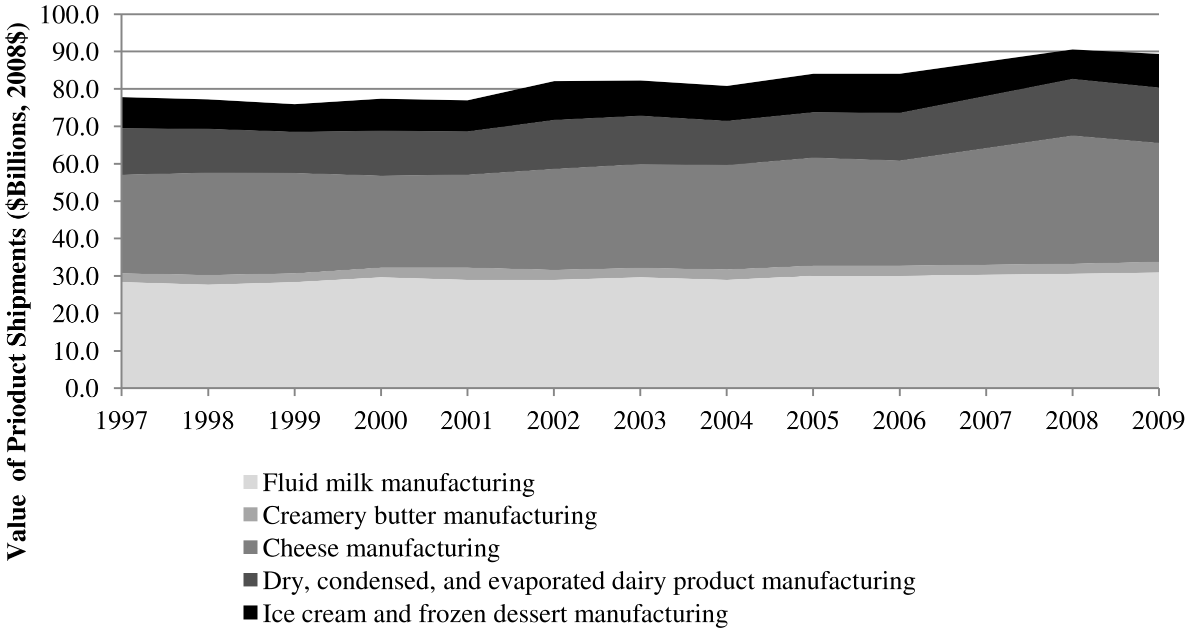
2.1 Economic Trends

In 2008, the dairy processing industry generated just over $90 billion in product shipments, accounting for approximately 15% of the entire U.S. food industry's economic output. As shown in Figure 2.1, in inflation adjusted dollars (adjusted to 2008 dollars[1]) the dairy processing industry grew about 15% over 12 years, from $77.8 billion in 1997 to $89.4 billion in 2009. The largest growth over this period occurred in the cheese manufacturing (311513) and the dry, condensed, and evaporated dairy manufacturing (311514) subsectors (U.S. Census Bureau 2009a).

As shown in Figure 2.2, on a product weight basis, the production of all subsectors of the dairy industry has also grown over this period, except for the ice cream and frozen dessert subsector, which declined very slightly since 1997 (around -1.2%). This decline was due to a significant drop in frozen yogurt production (-40%), along with a slight decrease in ice cream production (-3.3%), offsetting slight growth in sherbet production (4.1%) and large growth in "other frozen desserts" (109%). The two subsectors with the most growth have been butter (37%) and cheese (29%), fueled primarily by growth in non-American style (i.e. non-processed) cheese (USDA 2010). Note that Figure 2.2 has two vertical axes, due to the much higher production volume of fluid milk compared to other dairy products. The right axis corresponds to production volume of fluid milk only, and the left axis corresponds to production volume of the rest of the dairy products shown.

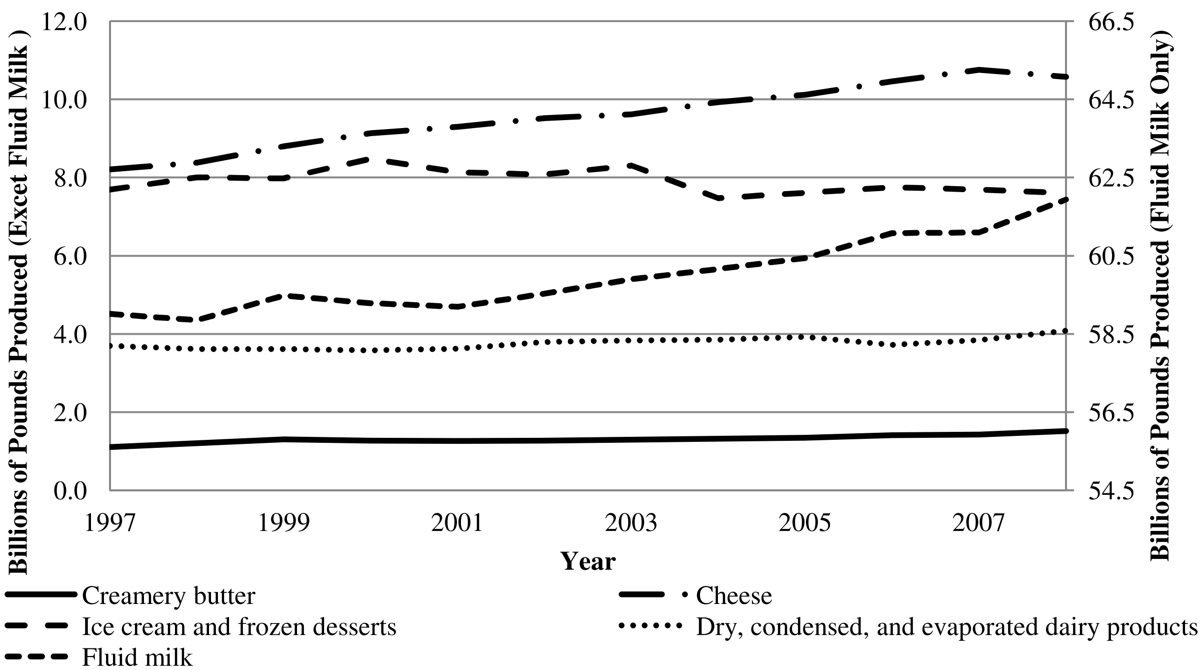
[1] Value of product shipments data in Figure 2.1 and on were adjusted for inflation using producer price index data for the U.S. dairy processing industry from the U.S. Bureau of Labor Statistics (2011).

Figure 2.1. Industry value of product shipments by subsector, 1997-2009



Source: U.S. Census Bureau (2009a)

Figure 2.2. Pounds of dairy products produced in the U.S., by subsector, 1997-2008



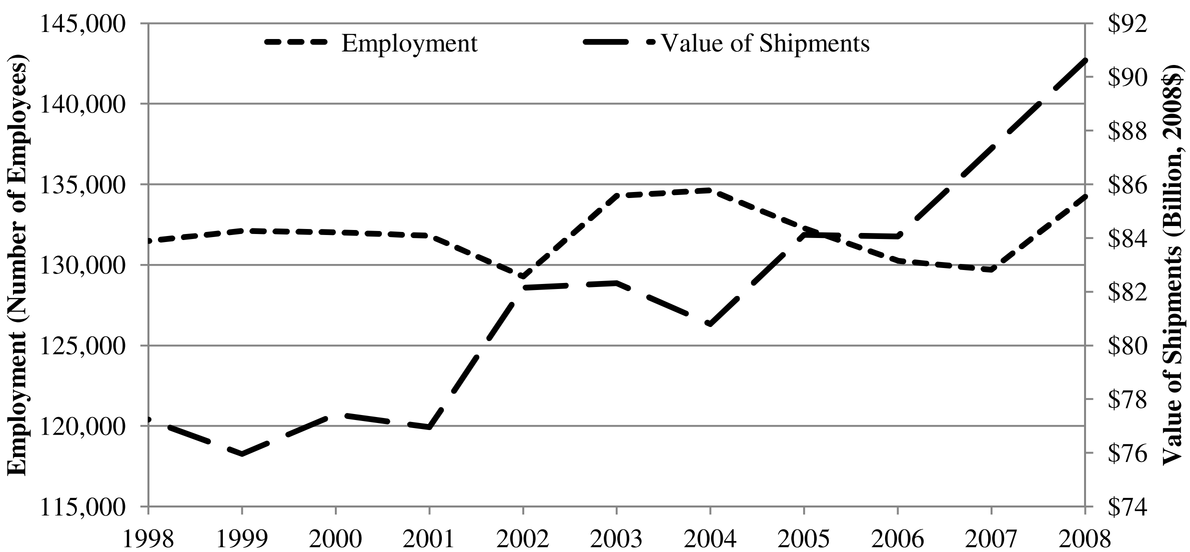
Source: (USDA 2010)

2.2 Employment

Although the dairy industry has been growing in production volume and value of product shipments, its employment has fluctuated over the years, and has grown only slightly from 1998 to 2008. Despite the slight increase in employment, the number of establishments in the U.S declined from 1,837 to 1,583, a decrease of about 14%, indicating a trend toward consolidation in the U.S. dairy industry. Figure 2.3 plots both employment and value of product shipments by subsector over the period 1998-2008.

Geographically, employment for the dairy industry is broadly distributed across the United States. However, the states of California, Wisconsin, New York, Pennsylvania, and Texas are the highest employers in the dairy industry, accounting for around 42% of the industry's employment. California and Wisconsin alone account for over a quarter of industry employment. In Figure 2.4, the five most prominent states with respect to employment in the dairy are broken down to show the relative proportion of employment and number of establishments of each dairy subsector. These charts show the large importance that cheese manufacturing has for each state, most especially Wisconsin. When comparing the relative proportions of employment versus number of establishments for each subsector, a couple of interesting patterns emerge. First, for most states, fluid milk accounts for a larger proportion of the employment than the number establishments, indicating that the average fluid milk plant in these states is larger than the rest of the industry. Second, the creamery butter and ice cream & frozen desserts subsectors account for a much larger proportion of the number of establishments than they do in the number of employees, indicating that the average plants for these subsectors in these states were smaller than the rest of the industry.

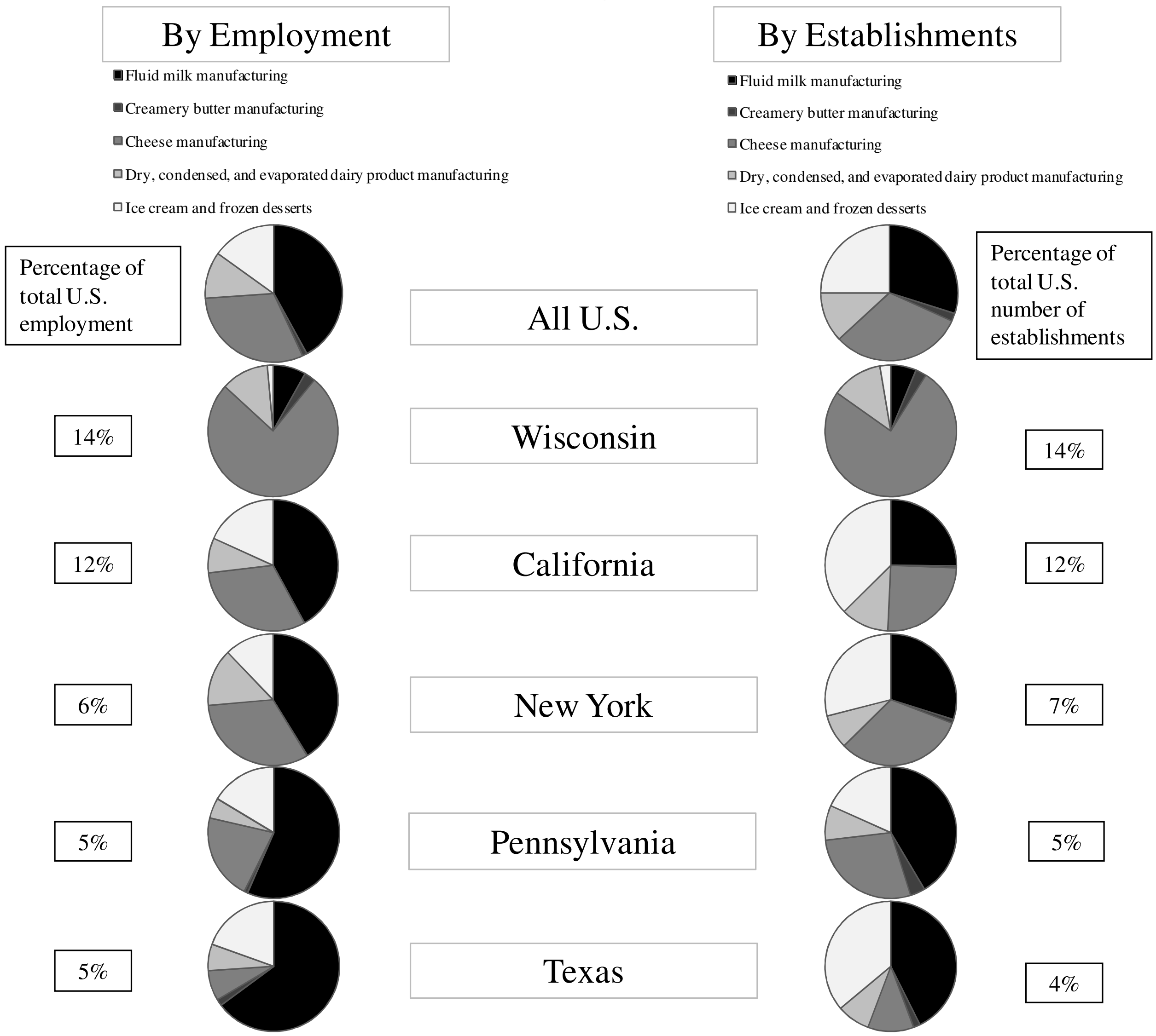
Figure 2.3. Trends in industry value of product shipments and employment, 1998-2008



Source: U.S. Census Bureau (2008; 2009a)

Table 2.2 shows U.S. dairy processing industry consolidation data for 2007, the latest year for which such data are available. The highest degree of consolidation can be seen in the butter subsector, where only 4 companies account for nearly 80% of U.S. value of shipments. Other subsectors are less consolidated. Of note is that at the industry level, 75% of the industry value of shipments is attributable to only its 50 largest companies. The remaining 25% is dispersed among roughly 1,000 smaller companies, which indicates that the industry contains many small companies and manufacturing plants with small, regional market shares. (U.S. Census Bureau 2007).

Figure 2.4. 2008 distribution of employment and establishments by subsector for major dairy processing industries



Source: U.S. Census Bureau (2008)

Table 2.2. 2007 U.S. dairy processing industry consolidation

Sector	NAICS	Total Number of Companies	Total Value of Shipments (Billions)	Percent of 2007 Value of Industry Shipments Accounted for by:			
				4 Largest Companies	8 Largest Companies	20 Largest Companies	50 Largest Companies
Dairy product manufacturing	3115	1,073	$91.6	24%	35%	56%	75%
Fluid milk	311511	280	$33.5	46%	58%	72%	87%
Creamery butter	311512	23	$2.1	79%	95%	Unavail.	100%
Cheese	311513	341	$33.2	32%	47%	71%	89%
Dry, condensed, and evaporated dairy product	311514	141	$13.9	42%	62%	81%	96%
Ice cream and frozen dessert	311520	347	$8.8	53%	66%	84%	94%

Source: U.S. Census Bureau (2007)

Table 2.3 shows the major employers for each subsector of the dairy processing industry along with the locations of their headquarters. The companies are listed in no particular order (Hoover's 2011).

Table 2.3. Major employers in the U.S. dairy processing industry

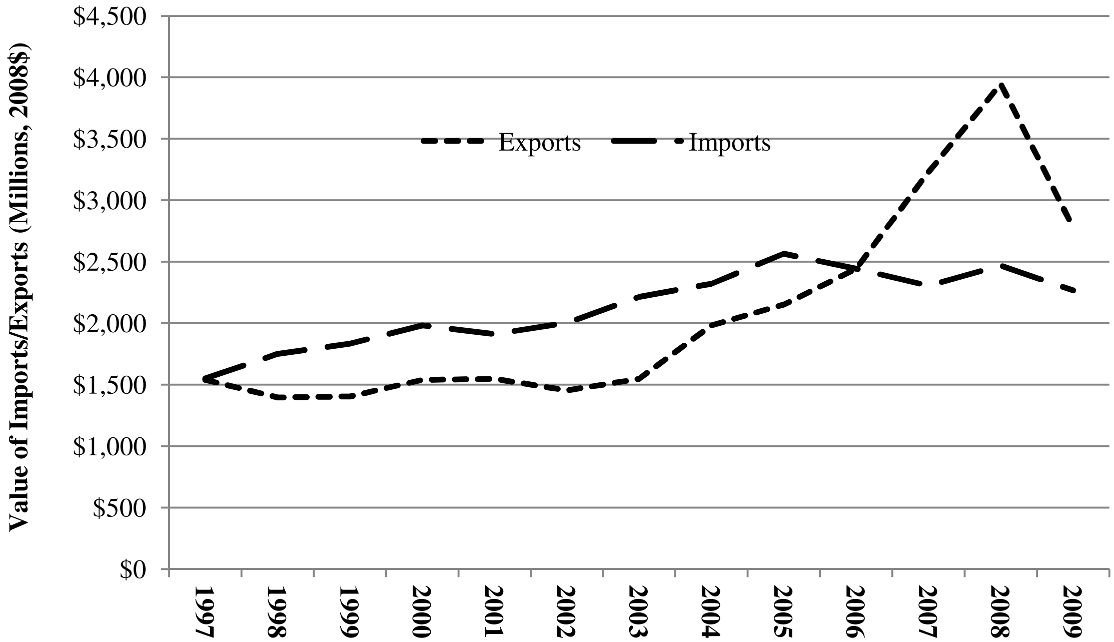
Subsector	NAICS	Company	Headquarters Location
Fluid milk manufacturing	311511	Dean Foods	Dallas, TX
		The Dairy Farmers of America	Kansas City, MO
		Foremost Farms	Baraboo, WI
		Northwest Dairy Association	Seattle, WA
Creamery butter manufacturing	311512	The Dairy Farmers of America	Kansas City, MO
		Foremost Farms	Baraboo, WI
		Michigan Milk Producers Association	Novi, MI
		Bongards' Creameries	Norwood, MN
Cheese manufacturing	311513	Kraft Foods	Northfield, IL
		The Dairy Farmers of America	Kansas City, MO
Dry, condensed, and evaporated dairy product manufacturing	311514	Abbot Labs	Abbot Park, IL
		Dean Foods	Dallas, TX
		The Dairy Farmers of America	Kansas City, MO
Ice cream and frozen desserts manufacturing	311520	Unilever	Englewood Cliffs, NJ
		The Dairy Farmers of America	Kansas City, MO
		Hiland Dairy Foods	Springfield, MO

Source: Hoover's (2011)

2.3 Imports and Exports

Although U.S. dairy processing industry exports have historically only accounted for approximately 2% of value of shipments, in recent years exports have grown to as high as 4% of value of shipments. This growth seems to have been mainly fueled by a large increase of exports to Canada and to the growing economies of Mexico and China. In 2006 this growth turned the U.S. from a net importer of dairy products to a net exporter of dairy products. Cutting energy costs by implementing energy efficiency measures can be an effective way to keep American dairy product prices competitive in the global market and retain this net export advantage in the coming years (U.S. Department of Commerce 2011).

Figure 2.5. US import/export of dairy products



Source: U.S. Department of Commerce (2011)

3 Overview of Dairy Processing Methods

The processing techniques that are employed by U.S. dairy processors are as diverse as the variety of products manufactured by the industry. The choice of individual processes and process sequence will depend heavily on the end product being manufactured. In addition, for any given product, the choice of processes and process sequence can vary from facility to facility.

However, there are many unit processes (i.e., discrete processing steps) that are common across the industry. Unit processes such as pasteurization, homogenization, and cold storage can be found in nearly every dairy processing facility in the United States. Furthermore, there are many unit processes that are common across individual subsectors, such as evaporation in the dry, condensed, and evaporated dairy products subsector. 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. dairy processing facility.

Section 3.1 provides a brief overview of the most significant unit processes employed in the U.S. dairy processing industry. Section 3.2 presents process flow diagrams for several key products manufactured by the U.S. dairy processing industry, which illustrate how unit processes are typically sequenced within the various industry subsectors.

3.1 Unit Processes

All dairy products start with receiving of raw milk from the farm. The raw milk generally is transported by way of tanker trucks, and is typically already refrigerated to 7° centigrade (C). When the raw milk is unloaded into the processing facility, it is sometimes also sent through a centrifuge to remove particulates, a process known as **clarification**, and cooled to 4°C via a heat exchanger on its way to a refrigerated storage tank. Stored raw milk is kept at a 4°C prior to processing, usually by way of a jacketed storage tank and agitation (Hui et al. 2007)

The first step of all dairy processes is **standardization**, the object of which is to ensure the proper fat content and solids nonfat (SNF) content for the desired finished product. Ensuring the proper fat content can be done one of two ways. Both processes use a centrifuge to separate the very low fat content and dense skim portion from the high fat content and less dense cream portion. One process involves analyzing the raw milk's fat content prior to processing, and calculating the proportion of fat to remove during centrifugation. The other process involves completely separating raw milk as it is unloaded from the tanker truck and individually storing the two phases. These two streams are then recombined in the proportions required by the specific product as the first step of processing. The latter method is used primarily by larger operations with diverse products, giving them the flexibility to quickly switch the product being produced without having to retest the milk and recalculate the degree of separation.

For some dairy products, such as yogurt and cheese, some water must be removed to achieve the solids nonfat content required for later process steps (such as fermentation) and desired finished product attributes. This water removal can be done via a single stage evaporator or ultrafiltration, both of which are described below (Hui et al. 2007). Manufactuers of these products may also add solids in the form of cream or powdered skim milk (the latter of which is quite energy intensive to produce, as discussed in Chapter 4).

Pasteurization is usually, but not necessarily, the next step in most dairy processes. This process can also be substituted with **sterilization** or some other kind of **heat treatment**, depending on the specific product. The object of pasteurization is to inactivate pathogenic microorganisms (in the interest of human health) and a majority of microbes that can spoil the milk. Pasteurization does not kill spores or some thermophilic microorganisms, which leads to the relatively short shelf life and refrigeration requirement of most pasteurized dairy products. Sterilization treats the milk with a more extreme heat treatment to inactivate all microorganisms and spores, leading to a longer shelf life without refrigeration required. Though sterilized milk requires more heat up front for the sterilization, it can save significant energy on refrigeration through the rest of the milk's life. Because it requires more intense heating, though, sterilization significantly changes the flavor of the milk. This type of milk represents a small market share in the U.S. and England, but a large market share in Germany and France (Brennan 2006). Finally, some dairy products, such as yogurt, require a more intense heat treatment than required for pasteurization. In addition to pasteurizing the milk, the heat treatment functions to alter certain milk properties, such as inactivating specific enzymes, in order to obtain the desired finished product attributes (Hui et al. 2007)

Pasteurization, **sterilization**, and other **heat treatments** are occasionally done via a batch process, where a tank of the milk is heated to a specific temperature and held for a specific length of time. However, by far the most common method used is a continuous process. In a continuous process, a gear pump or a flow regulator is used to deliver a constant and accurate flow rate to the pasteurization process. The stream is passed through a heat exchanger, which heats the milk to the desired temperature. It is then pumped through a specific length of piping to hold it at this temperature for a specified period of time, and then it is cooled back down. Most dairy processors use a process called regeneration to cut down on energy costs. Regeneration cools the outlet stream by using it to heat the incoming stream, recovering approximately 85%-90% of the thermal energy. A small amount of steam is used to finish heating the inlet stream, and a small amount of cooling is used to finish cooling the outlet stream (Hui 1993).

Almost all dairy products are subjected to **homogenization** at some point during processing. Milk is composed of a water soluble component and a fat soluble component that will separate if not homogenized, resulting in the phenomenon of "creaming." The purpose of homogenization is to break up the fat globules into smaller sizes and disperse them in the water soluble component, which prevents them from coalescing and forming the separate layer. This is done using a three or five piston pump to create a large pressure drop across a small opening that the milk stream is forced through. Often a two-stage homogenizer is used, where the first stage is primarily used for cavitation to break up the fat globules, and the second stage creates turbulence to break up aggregates and disperse the small fat globules (Hui 1993).

In several dairy products, a **cooking** or **fermentation** step is required to allow the desired biological/chemical changes to occur to the product. Yogurt, sour cream, cottage cheese, and cheese are the primary products that require such a step. The standardized milk or cream is filled into a jacketed tank, along with any enzymes, microbial cultures, and/or other ingredients required. The mixture is then heated to a specified temperature for a specific period of time, usually several hours, to allow the enzymes and microorganisms to perform their biological transformations into cheese curds, yogurt, or sour cream. For yogurt production, an alternative process is sometimes used to create "set yogurt." In this process, packaging occurs immediately after all the ingredients are mixed together. The sealed containers then undergo fermentation in controlled temperature air-blast tunnels (Hui, et al. 2007).

Cheese generally needs **mechanical work** performed on it to achieve its final state. During the cooking step, solid cheese curds are formed, leaving liquid whey as the byproduct. After the cooking step, the liquid whey is drained, leaving the cheese curds. The curds are then washed and pressed together. Though there are several ways to press the curds together into blocks, most modern industrial processes use pneumatic conveyance to transport the dried curds to the top of a tall tower, where the weight compresses the curds at the bottom of the tower into a single block, to be cut with a mechanical cutter. Cheeses with a "stringy" consistency, such as mozzarella, utilize mechanical dough kneaders to stretch the cheese in hot water (Hui 1993).

To create butter, the cream phase of milk must be **churned.** Cream is an oil-in-water emulsion, meaning that small drops of fat soluble components are surrounded by and dispersed in the water soluble component. Churning inverts the emulsion into a water-in-oil emulsion, which means small drops of water soluble component are now surrounded by and dispersed in the fat soluble component. In larger operations, churning is done via a large, mechanical beater. When the water-in-oil emulsion is made, a water phase, known as buttermilk, is released and drained. The curds of butter are then sometimes (but not always) washed with water and allowed to drain. Curds are then pressed together to form a single mass. The single mass is then extruded and cut into the proper shape and size (Hui 1993).

Freezing is a process used in the production of ice cream and other frozen desserts. Batch freezers are commonly used by smaller ice cream manufacturers, where the ice cream mixture is cooled in an agitated, jacketed tank until the mixture is partially frozen. Continuous freezers, usually used in large operations, utilize heat exchangers to achieve the partial freezing. The second step of ice cream freezing is a process called **hardening**. The partially frozen ice cream is packaged and subjected to blast air freezing at temperatures of -20F to -30F to fully freeze the ice cream (Hui et al. 2007).

Evaporation is the process most commonly used to remove water from dairy products. While used to some degree in other products, evaporation is mostly used in the production of evaporated milk, condensed milk, milk powder, and whey powder. While there are several types of evaporators, the most common type of evaporator is a falling film evaporator, due to its higher efficiency, lower operating temperature, easy maintenance, and ability to have more "effects" than other types, which is described below (Carić 1994).

In falling film evaporation, the liquid falls by gravity down the inside surfaces of tubes arranged in a shell-and-tube heat exchanger configuration, with steam generally used as the heating medium. Evaporators are commonly operated under vacuum to lower the required operating temperature. A common approach to energy efficiency for evaporators is to use the hot vapor that boils out of the liquid in one evaporator (or "effect") as the heating medium in another effect, which is operated at a lower pressure. The liquid moves from one effect to the next, becoming more and more concentrated in each effect. This approach is called "multi-effect" evaporation. In practice, up to 5 effects can be used in dairy evaporation (up to 7 are possible if using falling film evaporators) (Carić 1994).

An additional way to improve energy efficiency in multi-effect evaporators is to include a vapor recompression system. The thermal energy of the outlet vapor is increased by injected steam (thermal vapor recompression) or with a turbocompressor (mechanical vapor recompression) before it is used as the heating medium for the next effect (Carić 1994).

Since evaporation can only remove a certain amount of water, **drying** is used to create dry milk powder and whey powder. The most common method for drying is spray drying. Spray drying involves atomizing the liquid and spraying it into a tower or chamber of flowing hot air that removes the moisture, leaving a dry powder at the outlet. Recently, multistage dryers have appeared, in which the powder is mostly dried in the spray dryer and then transferred to a fluidized bed chamber to finish the drying. The fluidized bed step requires less air to finish the drying compared to the spray dryer, making the drying process more efficient. A less common technique is roller drying. In roller drying, the liquid flows over a rotating, heated drum, typically under vacuum, and the dried powder is scraped off of the drum. Although roller dryers tend to be smaller and less costly to operate, the quality of the powder can be affected. Drying processes are quite energy intensive, and measures taken to increase the energy efficiency of such processes can have large energy savings benefits (Carić 1994).

Membrane concentration can be applied to remove water from milk in lieu of or as a precursor to traditional evaporation methods. In membrane concentration, water can be separated from milk solids or cream 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 dairy product concentration. Common types of membrane concentration used in the dairy industry are microfiltration, ultrafiltration, and reverse osmosis, each indicating a different range of pore sizes. The type of filtration recommended for use is highly dependent on the application (Walstra et al. 2006).

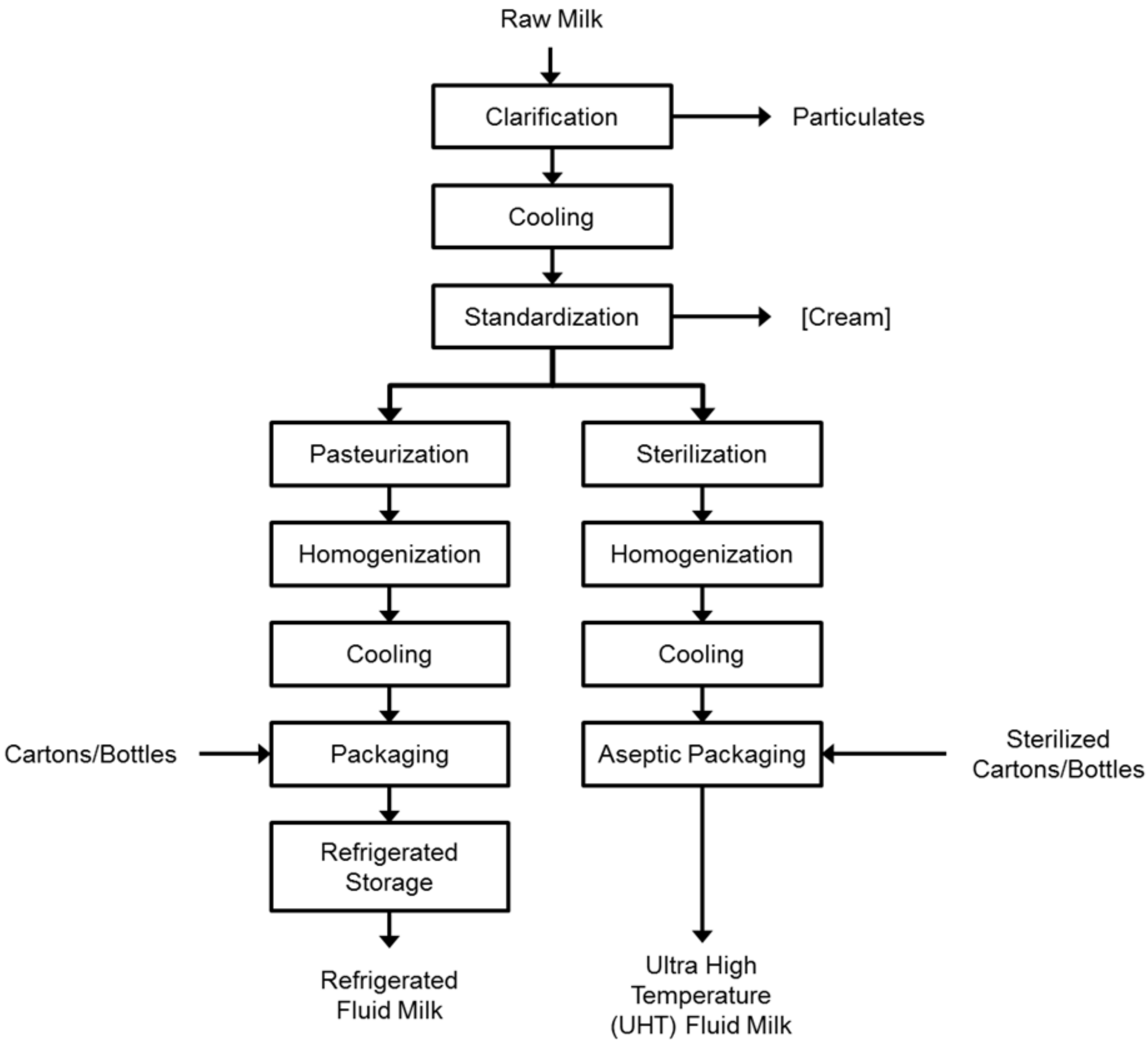
Cold Storage is used for most dairy products after production. Refrigerated storage for fluid milk, yogurt, cheese, butter, and other products is used to delay the growth of microorganisms that can spoil the final products. It is used to also prevent undesirable physical and chemical changes to the products, such as drying, oxidation, or melting/deformation of butter and soft cheeses. Frozen storage is used to keep ice cream and other frozen desserts in their desired frozen state, since thawing and refreezing will change the product attributes. Sterilized, concentrated, and dry dairy products generally do not need or use cold storage after production.

3.2 Process Flow Diagrams

This section presents representative process flow diagrams for several key products in the dairy processing industry. While not inclusive of all processes employed and all products manufactured in the dairy industry, Figures 3.1 through 3.7 depict process flow diagrams for the major products manufactured in the dairy processing industry: 1) Fluid milk; 2) yogurt; 3) butter; 4) cheese; 5) dry, sweetened condensed, and evaporated milk; 6) dry whey powder; and 7) ice cream. The process flows depicted in Figures 3.1 to 3.7 are meant to be representative of the process sequences employed at typical U.S. dairy processing facilities, but might not be representative of the exact process flows at any individual plant.

Figure 3.1 illustrates the typical process for producing fluid milk. Upon entering the facility, raw milk is (sometimes) clarified and then cooled a few degrees prior to being transferred to cooled storage tanks. To produce pasteurized milk, the most common type of milk in the U.S., the milk is standardized and pasteurized, with the homogenization step usually occurring prior to the milk being cooled back down (Brennan 2006). The cooled milk is then packaged and kept in refrigerated storage until shipment. Ultra high temperature milk (UHT), which is quite common in Europe, replaces the pasteurization step with a sterilization step. The milk is then aseptically packed into sterilized packaging. Due to its long shelf life, UHT milk is commonly stored at room temperature (Walstra et al. 2006).

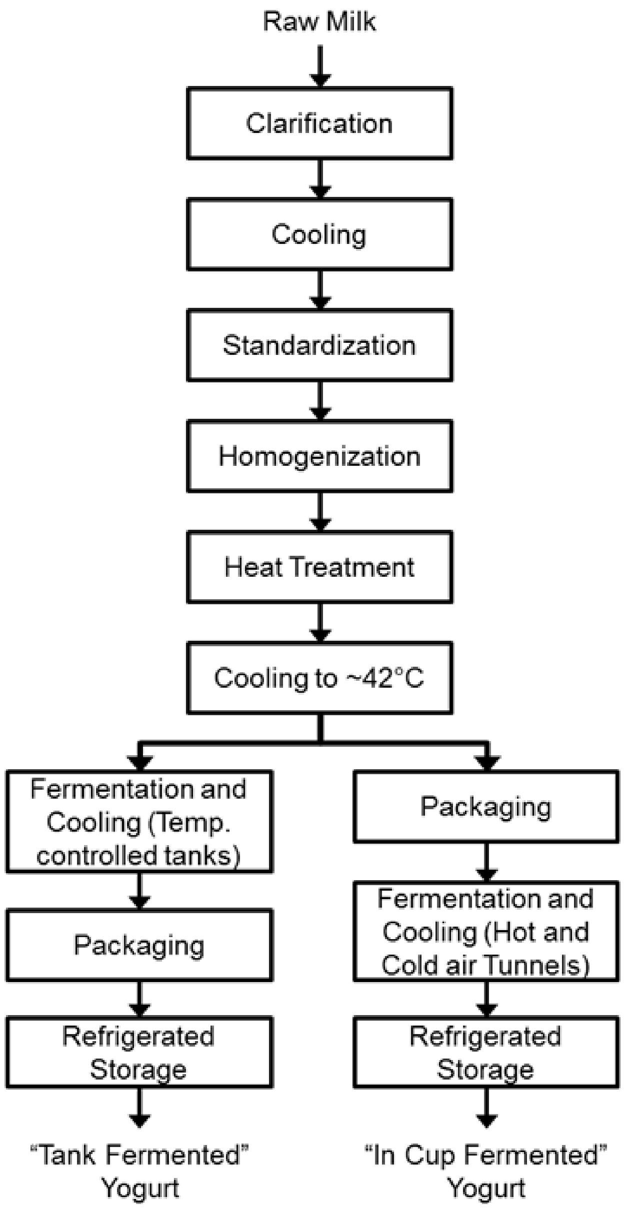
Figure 3.1. Process diagram for fluid milk production



Source: Walstra et al. (2006)

Figure 3.2 depicts the typical process for yogurt production. As with other milk products, the raw milk is (sometimes) clarified and then cooled prior to processing. Different types of yogurt require a wide range of compositions, which are achieved by standardization. In addition, some yogurts may require a solids nonfat level higher than normal milk contains. For these situations, the milk may be concentrated by water removal via ultrafiltration or evaporation. After standardization, the milk is homogenized at an elevated temperature (typically around 70C), and then subjected to a heat treatment process that also serves as pasteurization. The more intense heat treatment denatures and breaks down certain milk proteins to encourage fermentation. The milk is then cooled to fermentation temperature (typically around 42°C), and inoculated with the proper bacterial cultures. “Tank fermented” yogurt is then held at the fermentation temperature and allowed to ferment in the tank before being cooled and packaged. “In cup fermented” yogurt is first packaged, and then placed in blast-air tunnels which hold at fermentation temperature before cooling. Both types are then held in refrigerated storage until shipment (Hui et al. 2007)

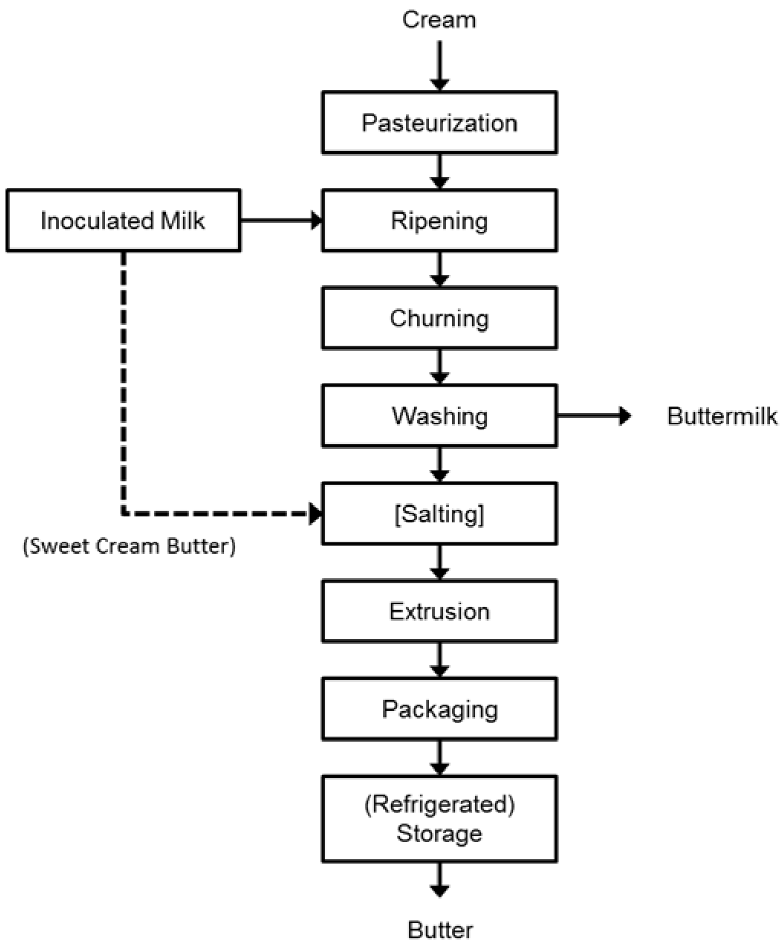
Figure 3.2. Process diagram for yogurt production



Source: Hui et al. (2007)

A typical butter manufacturing process is depicted in Figure 3.3. Cream is harvested from the standardization process of other milk products. After the cream is pasteurized, it is held at high temperature to “ripen.” This allows for proper crystallization of the milkfat, which makes churning easier and reduces fat lost in buttermilk. The cream is then churned to air break open the milkfat globule membrane and create the primarily fat phase that becomes butter, releasing the aqueous phase as buttermilk. The butter curds are then washed to remove excess buttermilk. An optional salting step is performed, and the butter curds are pressed and extruded into the proper sizes prior to packaging and storage (Walstra et al. 2006).

Figure 3.3. Process diagram for butter production



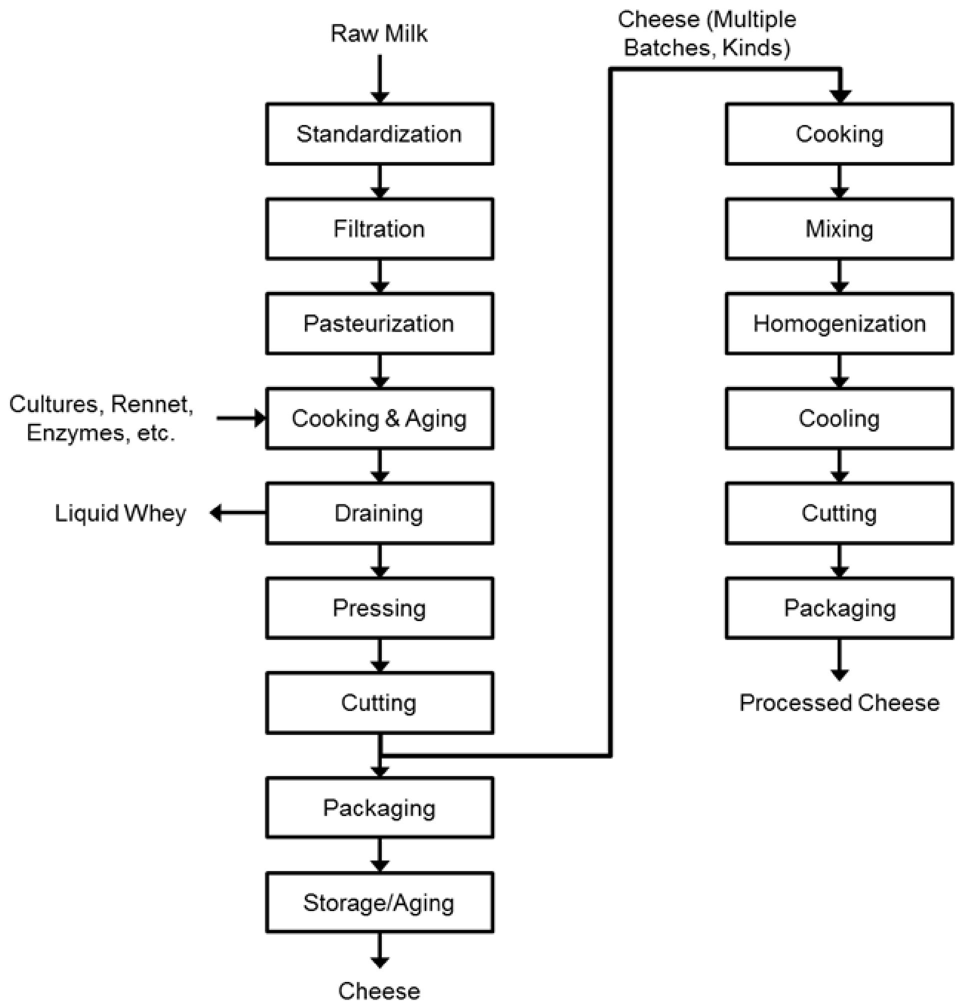
Source: Walstra et al. (2006)

There are an astonishing number of cheese varieties. The difference between the varieties is dependent upon several factors, including the proportions of milkfat, solids nonfat, and water, strains of bacteria used, and the parameters of each processing step. Hence, Figure 3.4 depicts a generic process for cheese production. Specific cheese types may have specified resting/aging times, or repeated steps not depicted in this process flow diagram (Walstra et al. 2006).

Similar to yogurt, raw milk is standardized via centrifuge to achieve the specified level of milkfat. In some cheeses, a higher solids nonfat content is required, and ultrafiltration is commonly used as part of the standardization process to remove water. Other concentrated dairy ingredients may be added such as skim milk powder or cream. Once the desired composition is attained, the milk is pasteurized and filled into a cheese vat. In the cheese vat, rennet, enzymes, and/or bacterial cultures are added, depending on the type of cheese to be made. In the United

States, cheeses such as cheddar, colby, and gouda may have natural color added. The mixture is then cooked to facilitate the biological processes that create cheese curds. Additional cooking is commonly used to “age” the cheese to the desired taste and attributes. After the cooking step, the curds are drained from the liquid whey byproduct of the cheesemaking process. After draining, the curds are pressed together to give solid blocks. Some cheeses, such as mozzarella, are also stretched to give a “stringy” texture. The cheese is then packaged, aged, and stored (Walstra et al. 2006).

Figure 3.4. Process diagram for generic cheese production



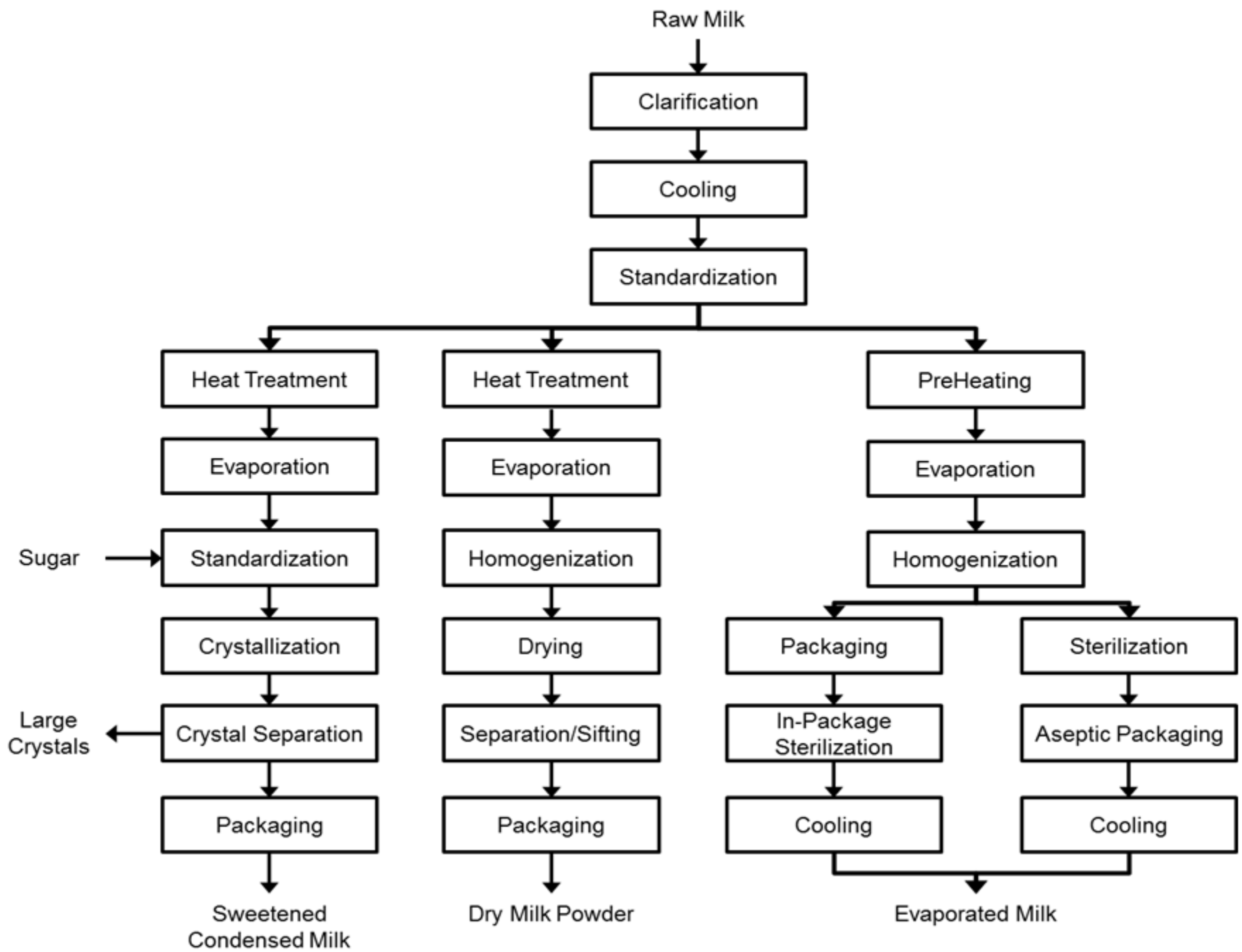
Source: Walstra et al. (2006)

Commonly, cheese with visual defects is diverted to be used in the manufacture of processed cheese. The cheese is combined with additives, such as melting/emulsifying salts, into a single vat, and cooked to a greater extent than the cooking step earlier in the process. This process promotes protein denaturing—predominantly through loss of divalent calcium linked bridges and other changes—to achieve the desired attributes. During the cooking step, the product is mixed to ensure homogeneity. After cooking, the cheese is cooled, cut into the appropriate size and shape, and, finally, packaged (Walstra et al. 2006).

Figure 3.5 illustrates the process flow diagram for dried, condensed, and evaporated milk. Evaporated milk is milk that is concentrated and sterilized for a long shelf life. After clarification and cooling upon entering the facility for storage, the milk is standardized and preheated to prepare for evaporation. Water is then evaporated off using the evaporation process described earlier, and the concentrated milk is homogenized. It is then either packaged into cans, and sterilized "in-package," or sterilized via heat exchanger, then aseptically filled into sterilized cans (Carić 1994).

Sweetened condensed milk is similar, except that sugar is added to the concentrated milk, which lowers the water activity of the milk to the point that microorganisms cannot grow, giving it its long shelf life. The milk is first subjected to a heat treatment to kill certain types of microorganisms, and then evaporated similar to evaporated milk. Sugar is then added, and the product is subjected to a specific cooling process designed to achieve desired lactose crystallization. Lactose crystals that are too large are then centrifuged out, and the remaining product is packaged (Carić 1994).

Figure 3.5. Process diagram for concentrated and dried milk production



Source: Carić (1994)

Dry milk powder is also subjected to heat treatment to kill microorganisms. Evaporation, while not required, is often utilized prior to drying, as it is a much less energy intensive way to remove most of the water than by spray drying alone. The product is then homogenized and dried via spray, roller or vacuum drying. The resulting powder is sifted for desired particle size, and packaged (Carić 1994).

A byproduct of the cheesemaking process is liquid whey. Due to its high biochemical oxygen content (BOC), whey is expensive to dispose of in liquid form. Because liquid whey is also perishable, the most common method of handling whey is to dry it into a powder. In powder form, whey can be used for various nutritional supplement applications due to its high protein content. This process, however, requires both high capital investment and high operational energy costs. Figure 3.5 depicts the typical processes used to dry liquid whey (Carić 1994).

Prior to water removal processes for whey, whey typically will contain small bits of cheese (termed fines) which are removed from the whey typically with screens. Additionally, there is free milkfat in the whey which is removed with the use of a continuous separator. The less dense portion from the whey seperator is called whey cream and the more dense portion is termed clarified whey. Both screening and separating require non-trivial amounts of energy.

Originating from the cheesemaking process, liquid whey is often first subjected to reverse osmosis filtration, microfiltration, ultrafiltration, or some other non-thermal process to remove some of the water content (which are both less expensive and more energy efficient). After filtration, the liquid is pasteurized and subjected to evaporation, similar to other dried milk products. At this point, multiple methods can be used to create the final product.

The most basic (leftmost process), and most energy intensive, involves spray drying the effluent from the evaporation step to the desired moisture content.

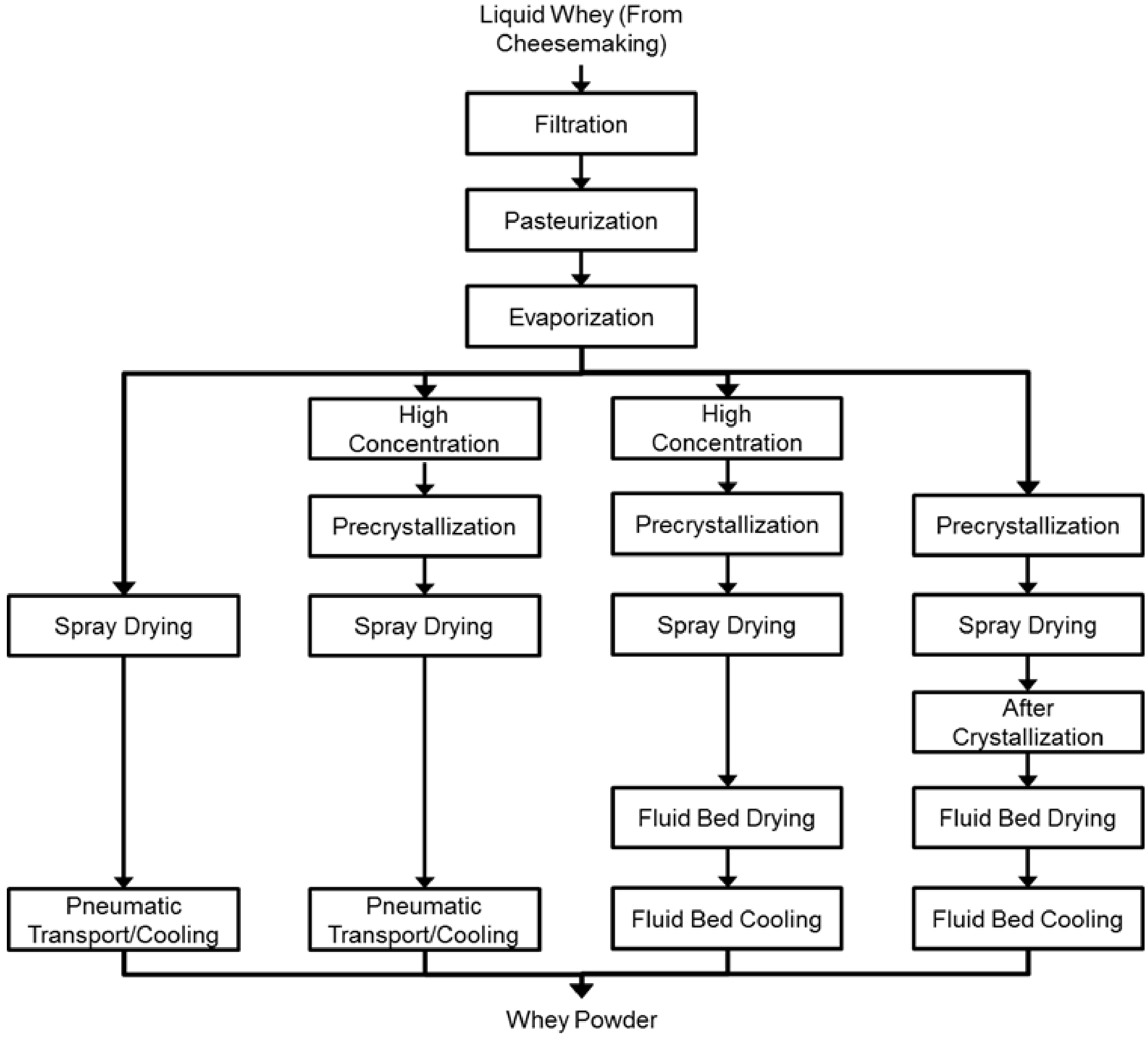
An added lactose crystallization step (second to left process) allows more water to be evaporated prior to spray drying. This step, while decreasing energy use, requires additional process time to perform a cooling/crystallization step.

To reduce operating costs even more, a fluidized bed drying step can be added (second to right process). This allows the powder to leave the spray drying step at a higher moisture content, and finish drying in a less intensive fluidized bed dryer.

Finally, an alternate way (rightmost process) to exploit whey crystallization for increased water removal is to allow the whey to only partially crystallize prior to spray drying. The whey can exit the spray drier at a much higher moisture content and finish crystallization on a conveyor. The remaining moisture is then dried off in a fluidized bed dryer.

The steps involving a crystallization step and a fluidized bed step require more equipment and processing time, but use significantly less energy. The leftmost process will use approximately 30% more steam per kilogram of whey than the two processes on the right (Carić 1994).

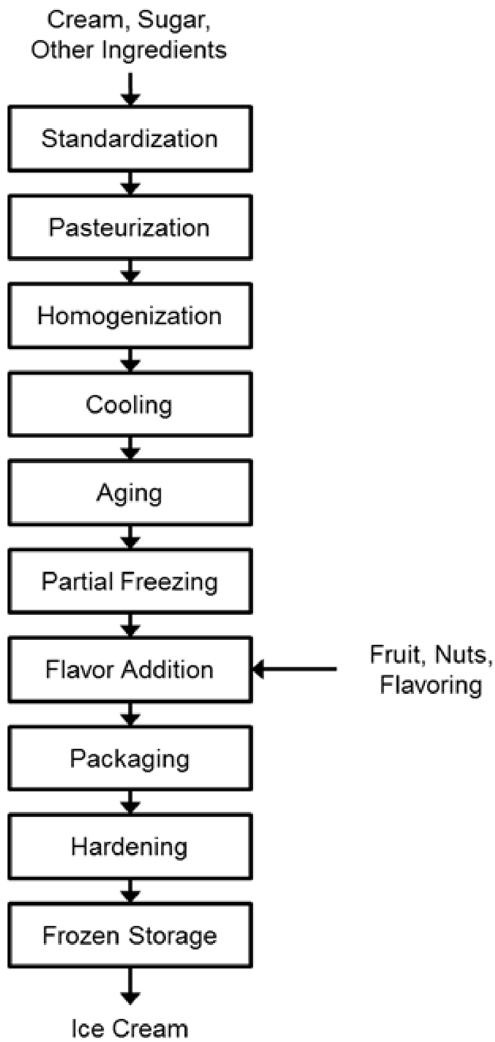
Figure 3.6. Process diagram for powdered whey production



Source: Carić (1994)

The typical process for ice cream production is depicted in Figure 3.6. The ice cream production process starts out with standardization, as with other dairy product processes. However, most ingredients for the ice cream, such as sweeteners, stabilizers, and emulsifiers, are combined at the beginning as part of the standardization step. The only ingredients not added at the beginning are fruit, nuts, and flavoring, which are added prior to packaging. Following standardization, the mixture is pasteurized and homogenized similar to other dairy products. After being cooled, the ice cream mixture is commonly "aged" in a tank at ~5C for some hours to allow the fat to crystallize and the stabilizers to hydrate. The ice cream is then partially frozen using a batch or continuous freezer and air is incorporated into the mixture to give a creamy texture. The packages of partially frozen ice cream are then "hardened" in blast freezing tunnels to finish the freezing process and then moved to frozen storage to await shipment (Hui et al. 2007).

Figure 3.7. Process diagram for ice cream production



Source: Hui et al. (2007)

4 Energy use in the Dairy Processing Industry

4.1 Energy Expenditures

In 2008, the dairy processing industry spent close to $1.5 billion on purchased fuel and electricity, or roughly 1.7% of the industry's value of product shipments. This percentage is even higher in the dry, condensed, and evaporated dairy products subsector—over 2.1%—due its heavy use of natural gas. Of this $1.5 billion, $726 million was spent on electricity and $731 million was spent on purchased fuel (primarily natural gas) (U.S. Census Bureau 2009b).

Electricity is used throughout the dairy processing industry to drive process motors, fans, pumps and compressed air systems, as well as building lighting and HVAC systems. In addition to machine drives, one of the primary uses of electricity in the dairy processing industry is for process cooling, freezing, and cold storage. In all, the U.S. dairy industry consumed over 10.1 terawatt-hours (TWh) of electricity in 2006, accounting for 13% of the entire U.S. food industry electricity use (U.S. DOE 2006b).

The largest share of fuel consumed by the dairy industry (80%) is used for direct process heating and steam generation via boiler systems. The remaining 20% is used for miscellaneous process and building demands, such as HVAC systems. Although coal, residual oil, and distillate oils can be used as fuels, the dairy processing industry uses almost exclusively natural gas. In 2006, the dairy processing industry consumed 80 billion cubic feet of natural gas, accounting for 13% of the entire food processing industry's natural gas consumption (U.S. DOE 2006b).

Figures 4.1 and 4.2 show the rise in expenditures on electricity and fuels in the dairy processing industry from 1997 to 2009. The rise in energy expenditures have been dramatic, especially the rise in natural gas expenditures. In one decade (from 1998-2008), expenditures on electricity increased by 46%, as seen in Figure 4.1, and expenditures on natural gas have increased by 171%, as seen in Figure 4.2. The combination of rising expenditures on electricity and natural gas in the dairy processing industry have resulted in an increase of 89% in total energy expenditures from 1998 to 2008 (U.S. Census Bureau 2009b).

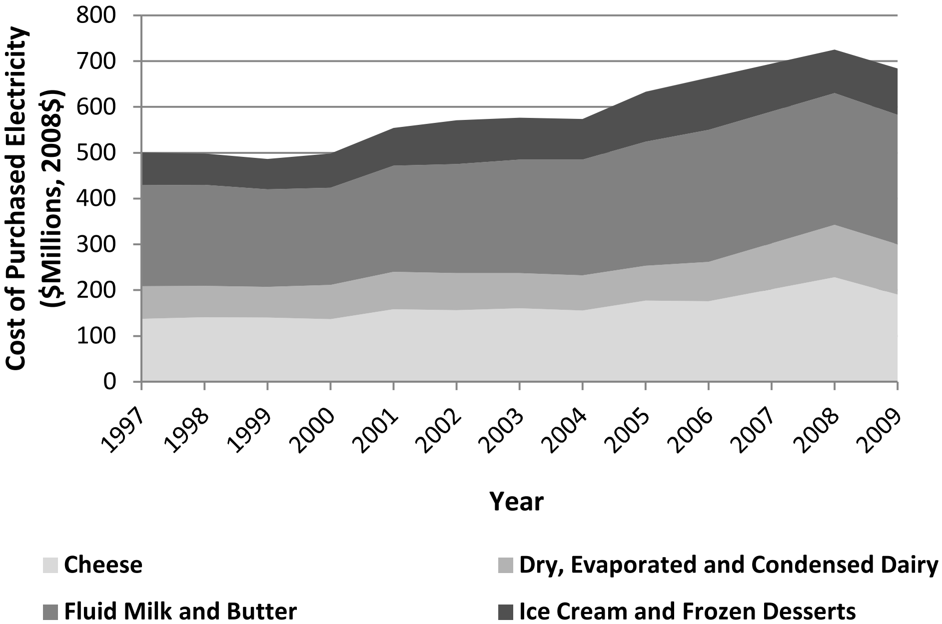
In addition, these charts illustrate the effect of two well documented spikes in the price of energy, especially natural gas. In 2001, strong winter demand for natural gas and low supply caused prices to more than double in some parts of the United States. In 2008, several factors, such as the rising cost of oil and speculation in the natural gas market drove up the price of natural gas by as much as 70%. Improving energy efficiency is an effective way to curb these rising energy costs and to buffer the effect of similar spikes in energy prices (Roesser 2009).

Since 1998, electricity and natural gas prices have continued to rise dramatically, adding to the economic pressures on the U.S. dairy processing industry. Nationwide, the average industrial price of natural gas over the past 10 years more than tripled, from $3.14 per thousand cubic feet in 1998 to $9.65 per thousand cubic feet in 2008. In New York, a major dairy producing state, the price of natural gas was even higher, at $12.30 per thousand cubic feet in 2008 (U.S. DOE 2011a).

Though not as dramatic, the national average industrial price of electricity increased by over 50%, rising from $4.48 per kilowatt-hour (kWh) in 1998 to $0.068 per kWh in 2008. In California, one of the top two dairy processing states, the price of electricity was even higher, at

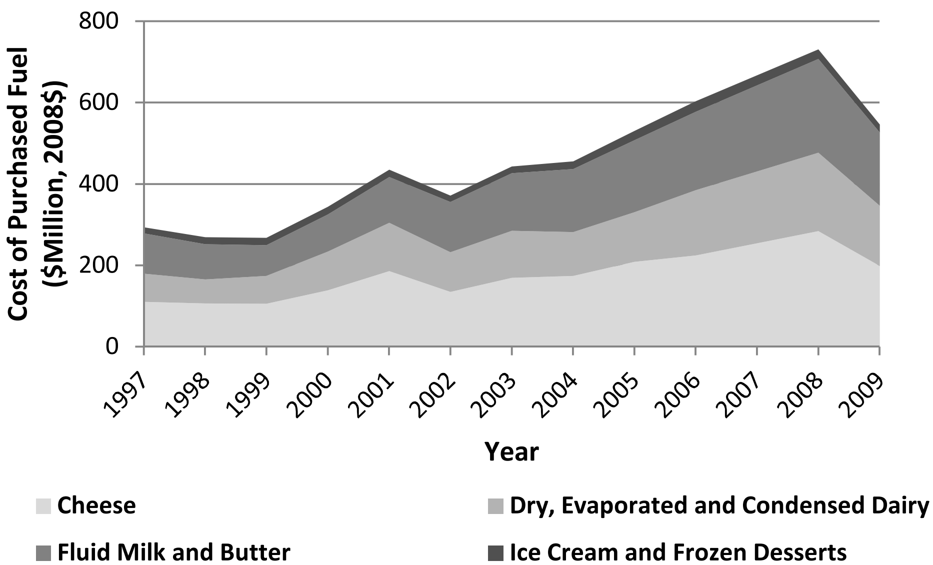
$0.10 per kWh in 2008. Given the increases and volatility in industrial natural gas and electricity prices in the United States, the need for improved energy management and energy efficiency in the U.S. dairy processing industry is perhaps stronger now than ever (U.S. DOE 2011b).

Figure 4.1. Cost of purchased electricity by subsector



Source: U.S. Census Bureau (2009b)

Figure 4.2. Cost of fuel by subsector

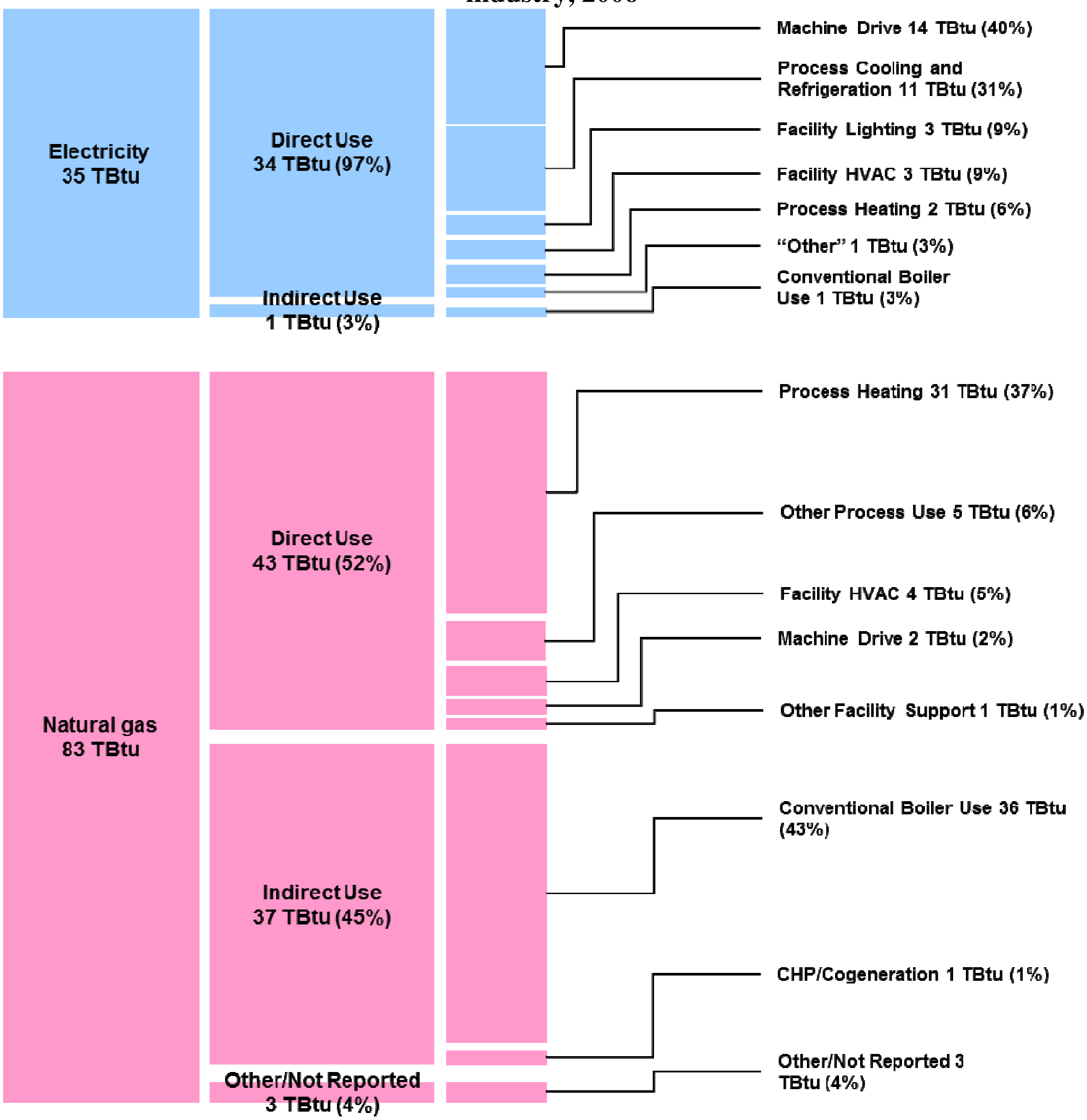


Source: U.S. Census Bureau (2009b)

4.2 Energy Consumption and End Use

In 2006, the U.S. dairy industry consumed about 10.1TWh of electricity, equating to roughly 35 trillion Btu (TBtu) of final (i.e., site) energy. Approximately 18% of this electricity was used for facility lighting and facility HVAC. Around 40% of electricity usage was used for machine drive applications to power pumps, motors, fans, and compressors, and 31% was used for process cooling, freezing, and cold storage (U.S. DOE 2006b).

Figure 4.3. Estimated energy consumption and end uses in the U.S. dairy processing industry, 2006



Source: U.S. DOE (2006b)
Note: end use percentages may not total to 100% due to rounding

In terms of fuel consumption, the industry combusted approximately 85 trillion Btu worth of natural gas in 2006. A large majority of this, 47 TBtu (80%), was used for direct process heating or to create steam in a boiler, which is generally then used for process heating applications. Other applications include facility HVAC and combined heat and power (CHP), also referred to as cogeneration. Figure 4.3 depicts a breakdown of how the dairy processing industry as a whole used energy (U.S. DOE 2006b).

For insight into an individual subsector's fuel and electricity uses, the relative amount of fuel and electricity expenditures (Figures 4.1 and 4.2) versus the value of product shipments (Figure 2.1) can be compared across the subsectors. For example, the ice cream and frozen desserts subsector, despite accounting for only 8% of the value of product shipments in the dairy processing industry, accounts for 13% of the amount spent on purchased electricity. This is likely fueled by the electricity-intensive freezing process for ice cream. On the other hand, dry and concentrated dairy products, while only accounting for 15% of the total value of product shipments, accounts for 26% of the dairy industry's fuel purchases. This is likely due to the steam and heating intensive processes of evaporation and drying used to make these products (U.S. Census Bureau 2009b)

4.3 Process Energy Intensity

Tables 4.1 through 4.6 provide manufacturing energy intensity data for several key products in the U.S. dairy processing industry. These data are meant to provide representative breakdowns of processing steps and process energy use in typical U.S. facilities. However, they may not be representative of the operating conditions at any single facility. Where applicable, each figure provides energy intensity data (in Btu/lb of product output) for steam, refrigeration, electricity, and direct fuel used, as well as total energy intensity. For ease of data interpretation, the relative magnitudes of the total energy intensities in each figure are illustrated graphically via a bar graph (not to scale) in the rightmost column. All data are on a site (i.e., not primary) energy basis. These tables do not include the energy used for CIP, which can account for a significant portion of the energy use in a typical process. For example, Ramirez et. al (2006) estimates that in the Dutch dairy industry, CIP accounts for 9.5% of energy use in fluid milk processing, 26% of energy use in butter processing, and 19% of energy use in cheese production.

Figure 4.4. Estimated representative process energy intensities of several dairy products

Fluid Milk

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Final Storage			18		18
Packaging		15			15
Pre-Packaging Storage			9		9
Deoderization	25				25
Cooling			85		85
Homogenization				10	10
Pasteurization	92				92
Separation				18	18
Clarification/Standardization				9	9
Receiving and Storage		13	18		30

Figure 4.5. Estimated representative process energy intensities of several dairy products (cont.)

Cottage Cheese and Yogurt

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Storage			7		7
Packaging				1	1
Creaming				2	2
Drier		4			4
Drawing, Washing, Cooling				2	2
Cooker	41				41
Pasteurization, Cooling	2		2		4
Separation				18	18
Clarification/Standardization				9	9
Receiving and Storage		13	18		30

Creamery Butter

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Pasteurization	359				359
Mechnical Power				18	18
Refrigeration			175		175

Cheese

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Cooking, Pasteurization	92				92
Finishing Vat	8				8
Make Vat	178				178
Starter Media	6				6
Pasteurization	72				72
Motors, Pumps			193	648	841

Dry Whey

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Spray Dryer		1115			1115
Whey Evaporators	3881				3881
Motors, Pumps			193	648	841

Figure 4.6. Estimated representative process energy intensities of several dairy products (cont.)

Canned Evaporated Milk

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Sterilization	49				49
Canning	58			62	120
Homogenizing Pumps				16	16
Concentration	141			31	172
Pasteurization or Stabilization	64				64
Clarification				23	23

Powdered Dry Milk

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Evaporative Cooling				31	31
Spray Drying		115			115
Homogenizing Pumps				16	16
Concentration	141			31	172
Pasteurization or Stabilization	64				64
Clarification				23	23

Source: Sikirica et al. (2003)

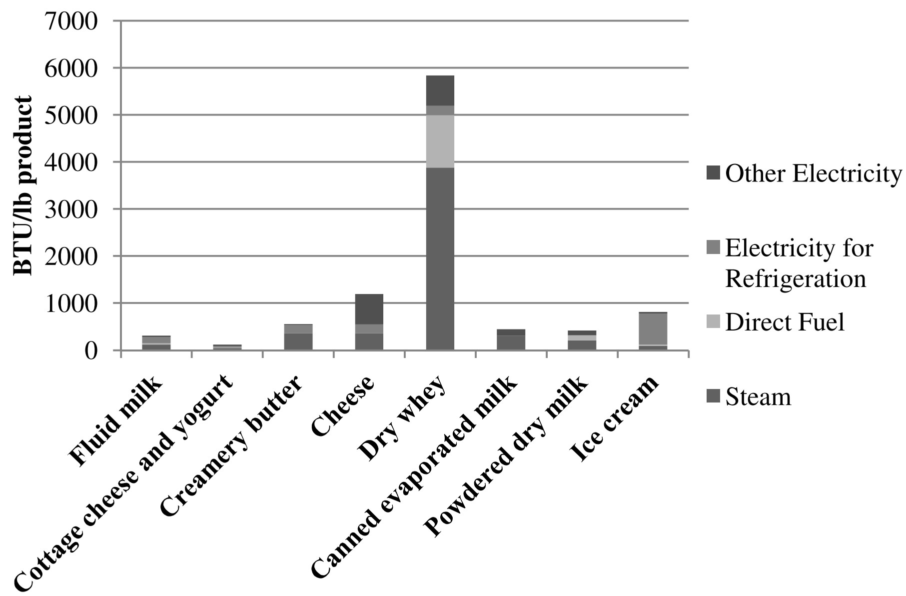
Ice Cream

Process	Energy Intensity (BTU/lb)				
	Steam	Direct Fuel	Electricity for Refrigeration	Other Electricity	Total
Final Storage			18		18
Packaging		15			15
Cooling			85		85
Homogenization				10	10
Pasteurization	92				92
Separation				18	18
Clarfication/Standardization				9	9
Freezing			538		538
Receiving and Storage		13	18		30

Note: Estimated from fluid milk energy intensity data, with freezing and final storage data estimated from frozen juice energy intensity data from Sikirica et al. (2003)

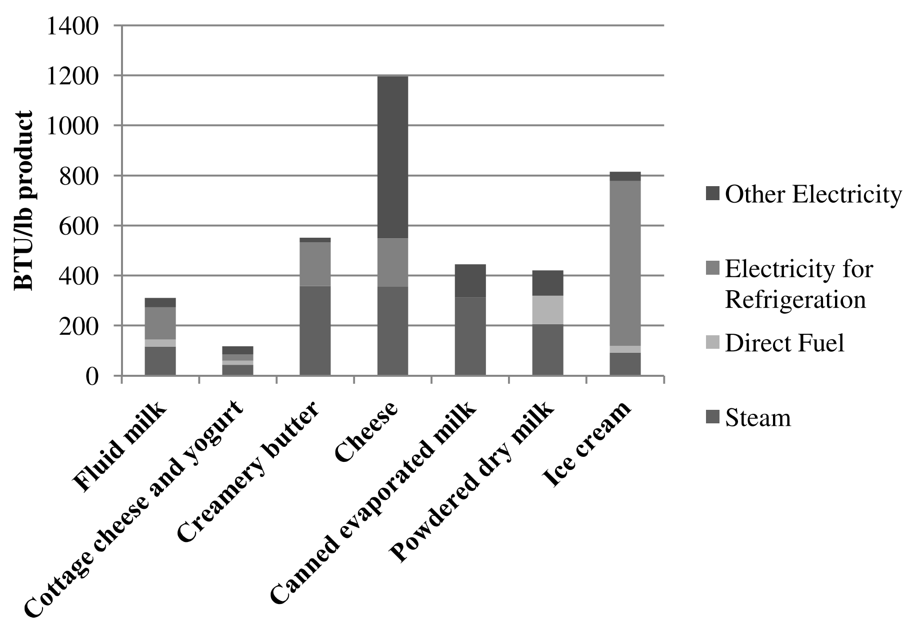
From these process intensities, one can compare the relative energy intensities of the various products in the dairy industry, as shown in Figures 4.5 and 4.6. Dry whey powder is clearly the most energy intensive dairy product, primarily due to evaporation and spray drying. Since drying whey is a necessary part of the cheesemaking process, finding ways to improve whey drying energy efficiency can significantly decrease energy costs in cheesemaking. Because dry whey has such a large process intensity, figure 4.6 displays the cumulative process intensities without dry whey, to give better resolution of the remaining dairy products. After dried whey, the next most energy intensive product is cheese, followed by ice cream.

Figure 4.7. Comparison of process energy intensities of several dairy products



Source: Sikirica et al. (2003)

Figure 4.8. Comparison of process energy intensities of several dairy products, excluding dry whey



Source: Sikirica et al. (2003)

5 Energy Efficiency Opportunities

Various opportunities exist within the diary processing industry to reduce energy consumption while maintaining or enhancing production. As part of the dairy industry's aggressive move to reduce the carbon footprint and energy consumption of the industry as a whole, energy efficiency improvements to dairy processing facilities are key to attaining this goal.[2]

The most effective method to improving energy efficiency in a dairy processing facility is to implement energy saving techniques across various levels of production. At the component and equipment level, energy efficiency can be improved by preventative maintenance, proper loading and operation, energy efficient choices for new equipment, and the replacement of older components and equipment with higher efficiency models when feasible.

At the process level, process control, optimization, and integration can ensure maximum efficiency. In addition, implementation of new or alternate process systems can improve efficiency and reduce operating costs.

On the facilities level, efficient lighting, heating, and cooling can reduce energy loads, and implementation of combined heat and power or process integration systems can improve efficiency.

Finally, on the organizational level, a strong company commitment to energy management, augmented by energy monitoring, target setting, employee involvement and continuous improvement, is essential to the long term success of energy efficiency improvements and its associated cost benefits.

The following chapters in this Energy Guide discuss some of the most pertinent energy efficiency measures applicable to the dairy processing industry today. This guide focuses on measures that are proven, cost effective, and available for implementation today. However, this guide also includes a short chapter on emerging energy efficient measures that show promise for applications in the dairy processing industry. For most measures, references to technical literature and online resources are provided, and may be consulted for further information.

Based on the energy expenditure and end use data presented in Chapters 3 and 4, this Energy Guide focuses primarily on the following major areas of opportunity for energy efficiency: steam systems, motor and pump systems, refrigeration systems, compressed air systems, building facilities, self generation, pasteurization processes, evaporation processes, and drying processes. As such, the measures described in this Energy Guide address the end uses that, collectively, account for over 90% of the energy used in the dairy processing industry.

Whenever possible, this guide includes case studies of dairy processing facilities that have successfully implemented a specific measure. When a case study from a dairy processing facility is not available, this guide often cites case studies from other food processing facilities and occasionally from non-food industries. In most instances, these case studies include typical payback periods or specific energy or cost savings data. The applicability of measures, and their associated payback periods and savings will vary from facility to facility and from process to

[2] In 2009, the Innovation Center for U.S. Dairy announced its commitment to a roadmap for reducing the GHG emissions of fluid milk by 25 percent by 2020. (For more information, visit http://www.usdairy.com/.)

process. As such, the values provided in this guide should be regarded only as guidelines. Further economic research of all measures is needed to assess their cost effectiveness at individual plants.

While this guide focuses primarily on reducing energy usage, the dairy industry consumes significant amounts of water in CIP and other systems. Given water's rising importance as a resource, as well as the energy use associated with heating and pumping water, this guide includes a chapter on basic water efficiency measures applicable to the dairy processing industry.

The chapters of this Energy Guide are organized into specific areas of opportunity for energy and water efficiency improvement. Table 5.1 summarizes the chapter themes and measures associated with each energy use area.

Chapter 6 provides an overview of implementing an effective organizational energy management program. Chapters 7 through 12 focus on "cross cutting" measures, which are applicable across most manufacturing industries. Chapter 13 focuses on energy efficiency measures that are applicable specifically to dairy processes, such as pasteurization, evaporation, and cheesemaking. Chapter 14 gives an overview of promising emerging technologies that have the potential to improve dairy processing energy efficiency in the future. Chapter 15 provides an overview of water efficiency measures, related both to CIP systems and general housekeeping.

Table 5.1 Summary of efficiency measures presented in this Energy Guide

Steam Systems (Chapter 7)	
Boilers	
Boiler process control	Boiler replacement
Reduction of flue gas quantities	Direct contact with water heating
Reduction of excess air	Condensing economizer
Properly sized boiler systems	Segregate hot water system according to temperature
Improved boiler insulation	Boiler maintenance
Condensate return	Flue gas heat recovery
Blow down steam recovery	
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

Table 5.2 Summary of efficiency measures presented in this Energy Guide (cont.)

Motor Systems and Pumps (Chapter 8)	
Motor Systems	
Motor management plan	Adjustable-speed drives
Strategic motor selection	Power factor correction
Maintenance	Minimizing voltage imbalances
Properly sized motors	
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
Refrigeration Systems (Chapter 9)	
Refrigeration System Management	
Good housekeeping	Efficient piping design
Monitoring system performance	Thermal storage
Ensuring proper refrigerant charge	Checking for refrigerant contamination
Refrigeration system controls	Segregation of refrigeration systems
Cooling Load Reduction	
Piping insulation	Geothermal cooling
Minimizing heat sources in cold storage areas	Tank Insulation for storage tanks
Reducing heat infiltration in cold storage areas	Mixing in storage tanks
Reducing building heating loads	Properly sized motors
Free cooling	Optimized air flow pattern
Cooling towers	
Compressors	
Compressor control systems and scheduling	Compressor heat recovery
Floating head pressure control	Dedicating a compressor to defrosting
Indirect lubricant cooling	Adjustable-speed drives
Raising system suction pressure	Using an economizer with a single stage, low temperature compressor
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

Table 5.3 Summary of efficiency measures presented in this Energy Guide (cont.)

Compressed Air Systems (Chapter 10)	
System improvements	Pressure drop minimization
Maintenance	Inlet air temperature reduction
Monitoring	Controls
Leak reduction	Properly sized pipe diameters
Turning off unnecessary compressed air	Heat recovery from compressors
Modification of system in lieu of increased pressure	Natural gas engine-drive compressors
Replacement of compressed air by other sources	Buffer tank to regulate compressor duty cycle
Improved load management	
Building Energy Efficiency Measures (Chapter 11)	
HVAC systems	
Energy-efficient system design	Efficient exhaust fans
Recomissioning	Use of ventilation fans
Energy monitoring and control systems	Infrared heating
Non-production hours set-back temperatures	Solar air heating
Duct leakage repair	Building reflection
Variable-air-volume systems	Building insulation
Adjustable-speed drives	Low-emittance windows
Heat recovery systems	Air curtains
Fan modification	
Lighting	
Turning off lights in unoccupied areas	Replacement of T-12 tubes with T-8 tubes
Lighting controls	High-intensity discharge voltage reduction
LED Exit signs	High-intensity florescent lights
Electronic ballasts	Daylighting
Self-Generation (Chapter 12)	
Combined heat and power	Photovoltaic panels
Tri-generation	Solar thermal water preheating
Backpressure turbines	

Table 5.4 Summary of efficiency measures presented in this Energy Guide (cont.)

Process Specific Energy Efficiency Measures (Chapter 13)	
Pasteurization/Sterilization/Heat Treatment	
Reclamation/adding plates	Induction heating of liquids
Compact immersion tube heat exchangers	Heat exchanger enhancement techniques
Helical heat exchangers	
Evaporation	
Maintenance	Mechanical vapor recompression
Multiple effect evaporators	Concentration using membrane filtration
Thermal vapor recompression	
Spray Drying	
Operating temperature optimization	Exhaust heat recovery
Strategic placement of air intake	Use of multiple stage drying
Inlet air monitoring	Use of crystallization (dry whey only)
Heat recovery from product	Using other concentration techniques
Miscellaneous measures	
Good mixing in cooking tanks	Creating 80% whey instead of powdered whey
Cave aging (with use of heat pumps)	Use whey permeate to feed biogas reactor
Emerging Technologies (Chapter 14)	
Heat pumps for waste heat recovery	High hydrostatic pressure pasteurization
Pulsed electric field pasteurization	UV pasteurization
Geothermal heat pumps	Microfiltration
Advanced rotary burners	LED Lighting
Water Efficiency Measures (Chapter 15)	
CIP Improvements	
Reuse or recovery distribution systems	Pulse rinse on tanks
Single phase cleaning	RO or evaporative water use in CIP
Over-ride procedure	Air blows
Optimization of phase separation	
General Techniques	
Good housekeeping	Reducing cooling tower bleed-off
Wastewater treatment	High pressure low volume sprays
Recycling of milk waste as fertilizer	Low pressure foam cleaning
Use of water efficient building fixtures	Pre-soaking of floors and equipment
Use of small diameter hoses	Membrane filtration
Use of automated start/stop controls	

6 Energy Management Programs and Systems

6.1 Strategic Energy Management Program

Improving 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 and a formal energy program is in place. 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, worked with leading industrial manufacturers to identify the fundamental aspects of effective energy management programs.[3] Through this process, the major elements in a strategic energy management program were identified and are depicted in Figure 6.1, which illustrates the steps of the ENERGY STAR Guidelines for Energy Management.

Further recognition of the value and importance of energy management programs focused on continuous improvement is reflected in the development of ISO 50001, the International Standards Organization's standard for energy management. This new management standard follows the same framework of the ENERGY STAR Guidelines for Energy Management.[4]

As shown in Figure 6.1, 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 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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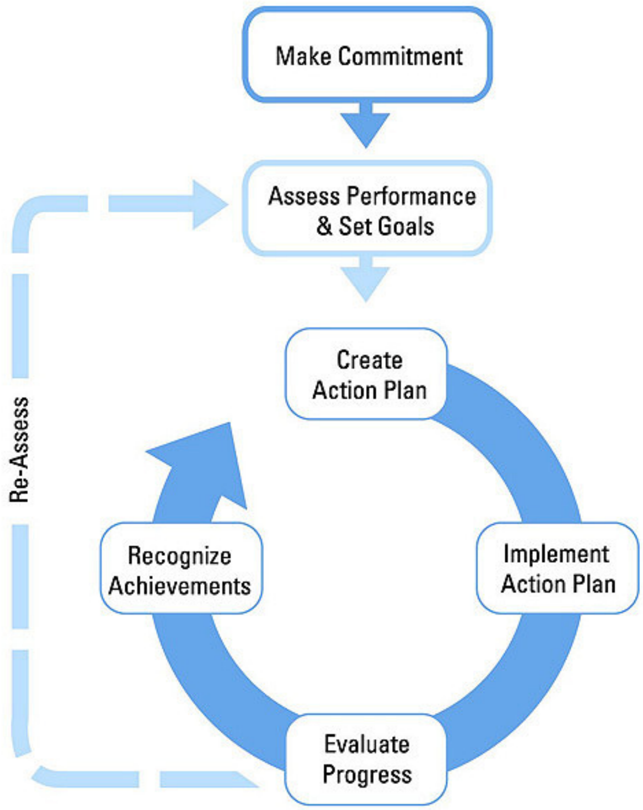
[3] Read more about strategic energy management at http://www.energystar.gov/industry

[4] ISO 50001 was published on June 15, 2011. Copies of the standard can be purchased at http://www.iso.org/

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 perform are outlined in Appendix A. In addition, performance results should be regularly evaluated and communicated to all personnel and high achievement should be rewarded and recognized.

Figure 6.1. ENERGY STAR Guidelines for Energy Management



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 B.

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.

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.[5] 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).

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

[5] 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)

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 C.

The value of establishing energy teams—or at a minimum, designating a site energy champion—has been examined by the Focus on Energy program in Wisconsin. Through this program, funding was provided to place full time energy champions in twenty pulp and paper mills that previously lacked dedicated energy management personnel. Based on energy initiatives, projects, and other activities undertaken by these new site energy managers, Focus on Energy found, at minimum, for every $100,000 spent for staffing an energy manager, $1 million dollars in energy savings were realized. Given the energy intensive nature of pulp and paper mills, this cost to benefit ratios is most likely industry specific. However, the experience of the Focus on Energy program illustrates the value of staffing an energy manager or making energy management a key aspect of existing personnel (Wroblewski 2011).

6.3 Energy Monitoring and Control 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).

In a case study of energy monitoring in the dairy industry, one facility reported that by installing a system to track its real-time energy usage and emissions, significant opportunities were identified for no-cost behavior modification (staggered boiler start-ups) and low-cost energy savings projects (compressed air, boiler system, and refrigeration system improvements). The estimated savings associated with these collective improvements amounted to over 2.8 million kWh in electricity use per year and over 450 tons of CO_2 emissions per year. The simple payback period for the investments was estimated at 1.2 years (EPS 2011; Bunton 2011).

Process control systems can reduce the time required to perform complex tasks, often improve product and data quality and consistency, and can optimize process operations.

Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems. These savings apply to plants without updated process control systems; many facilities may already have modern process control systems in place to improve energy efficiency. A variety of process control systems are available for virtually any industrial process, and a wide body of literature is available assessing control systems in most industrial sectors.

Modern control systems are often not solely designed for energy efficiency, but rather for improving productivity, product quality, and the efficiency of a production line. Applications of advanced control and energy management systems are in varying development stages and can be found in all industrial sectors. Control systems result in reduced downtime, reduced maintenance costs, reduced processing time, and increased resource and energy efficiency, as well as improved emissions control. Many modern energy-efficient technologies depend heavily on precise control of process variables, and applications of process control systems are growing rapidly. Modern process control systems exist for virtually any industrial process. Still, large potentials exist to implement control systems and more modern systems enter the market continuously.

Process control systems depend on information of many stages of the processes. A separate but related and important area is the development of sensors that are inexpensive to install, are reliable, and will analyze in real-time. Information from the sensors is used in control systems to adapt the process conditions, based on mathematical ("rule"-based) or neural networks and "fuzzy logic" models of the industrial processes.

Neural network-based control systems have successfully been used in the cement (kilns), food (baking), non-ferrous metals (alumina, zinc), pulp and paper (paper stock, lime kiln), petroleum refineries (process, site), and steel industries (electric arc furnaces, rolling mills). New energy management systems that use artificial intelligence, fuzzy logic (neural network), or rule-based systems mimic the "best" controller, by using monitoring data and learning from previous experiences.

Process knowledge based systems (KBS) have been used in design and diagnostics, but are still not widely used in industrial processes. KBS incorporates scientific and process information and applies reasoning processes and rules in the management strategy. A recent demonstration project in a sugar beet mill in the UK using model based predictive control system demonstrated a 1.2% reduction in energy costs, while increasing product yield by almost one percent and reducing off-spec product from 11% to 4%. This system had a simple payback period of 1.4 years (CADDET 2000a).

Research for advanced sensors and controls is ongoing in all sectors, and is funded with both public and private research funds. Several projects within U.S. DOE's Industrial Technologies Program (ITP) are attempting to develop more advanced control technologies. Outside the United States, there is much attention in Japan and Europe to the development and demonstration of advanced controls. Future steps include further development of new sensors and control systems, demonstrations at a commercial scale, and dissemination of the benefits of control systems in a wide variety of industrial applications.

7 Steam Systems

As discussed in Chapter 4, steam systems are the most significant end use of energy in the U.S. dairy 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. dairy processing industry use natural gas as a boiler fuel, improving steam system efficiency is also an important strategy for controlling energy costs in the face of volatility in industrial natural gas prices. According to the U.S. Department of Energy, 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 primarily used in process heating applications in the dairy industry, including pasteurization, cooking, and evaporation. This chapter describes some of the most significant opportunities available for improving steam system efficiency in a typical industrial plant.[6]

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).

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

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[6] 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.

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 (NOx), 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.

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. Several dairy plant case studies have shown a payback of less than 1 year for improved boiler insulation (IAC 2011).

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 or gas 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).

A Meadow Fresh dairy plant in New Zealand hired an energy efficiency consulting company to evaluate its boiler systems. After about 3 hours of the consultant's work, the resulting boiler system "tune-up" netted the company approximately $45,000 a year in energy savings (EECA 2010).

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).

A large survey of dairy plant case studies gives several instances of flue gas heat recovery systems having paybacks of less than 2 years (IAC 2011). 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 MMBtu of boiler fuel per year (U.S. DOE 2002a). Odwalla's expected payback period for the economizer was just 10 months.

Going a step further, using a **condensing economizer** can extract even more heat from the outgoing flue gas. A condensing economizer can improve steam system efficiency and heat recovery by up to 10% (DOE 2007). A condensing economizer cools the flue gas below its dew point, which allows it to extract latent heat from the condensation of the flue gas vapor. Because the vapor is acidic, the condensing economizer must be resistant to corrosion, and any recovered water usually needs to be treated prior to reuse or discharge to the waste stream.

A Unilever Canada margarine plant installed a condensing economizer as their first project in an ongoing energy efficiency improvement effort. The $500,000 project saves the company about $378,000 a year, giving a simple payback period of 1.32 years (CIPEC 2008).

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 study of a Lithuanian dairy plant estimated that condensate return would reduce the boiler energy use by 8% (Makaliunas and Nagevicius 1998). 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, when an inefficient coal-fired boiler is replaced with a natural gas-fired boiler, both boiler fuel costs and emissions of air pollutants can be reduced.

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).

Segregate hot water systems according to temperature. In some cases where multiple hot water temperatures are required, using separate boilers for the different temperature streams can save energy. Higher temperatures cause greater potential for heat loss, and less efficiency. Multiple boilers allows some water to be heated to lower temperatures, which reduces the amount of water heated to the highest required temperature. In the same regard, steam is sometimes used in processes where hot water is more appropriate, leading to unnecessary heat loss. An analysis of energy efficiency measures for the dairy industry in Canada estimates that using multiple boilers can have a simple payback period of 2-4 years (Wardrop 1997).

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 dairy 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 dairy plant case studies indicate that the payback period for improved insulation is typically less than one year (IAC 2011). In addition, improved insulation can reduce the amount of heat inadvertently released to the plant's interior (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). Implementing an insulation maintenance program has given payback periods of less than one year in several U.S. dairy plant case studies (IAC 2011).

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). Several U.S. dairy plant case studies have shown simple payback periods are often less than 6 months (IAC 2011).

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 MMBtu 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 dairy 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 MMBtu) per year with a payback period of around 2.5 years (Das 2000).

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 dairy processing facility to drive process equipment (e.g., for mixing, beating butter, cheese pressing and cutting, 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 dairy processing plants. Pumps are used extensively to pressurize and transport water in cleaning and wastewater handling operations, for transporting milk and other liquid dairy products between processes, and for circulating 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 2002e).

This chapter presents some of the most significant energy efficiency measures available for motors and pumps in industrial applications.[7]

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).

[7] 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):

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

The Motor Decisions MatterSM 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 D) 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 D). 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℠ 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).

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). An IAC case study of a U.S. dairy plant found that implementing a motor maintenance plan resulted in a simple payback period of about 4 months (IAC 2011).

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. Several IAC case studies showed that dairy plants that replaced an inappropriately sized motor with a properly sized one gave payback periods of about 3 years (IAC 2011).

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 D) can aid in proper motor selection.

Adjustable speed drives (ASDs).[8] 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%.

[8] 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 guide for consistency.

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; it may also result in fees or higher rates from the electrical utility company. 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. A study on energy efficiency in the Canadian dairy industry estimates that implementing power factor correction measures has a payback period of 2-3 years (Wardrop 1997).

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.

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 2005a).

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 2005a). 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. dairy processing industry. The major applications of refrigeration systems in the industry are in the process cooling of milk and other dairy products, the cold bulk storage of raw and pasteurized milk, the freezing of ice cream, and the in generation of cold air for cold storage of almost all dairy products.

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, brine, or glycol, 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. dairy 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).

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.

Thermal storage for running at off-peak hours. Thermal storage systems are a way to store cooling energy for use at a later time. Often this is done by cooling a working component—for example, chilling water or creating ice—and storing it in a highly insulated vessel. There are several ways to take advantage of this type of system. One way is to run the refrigeration system at a constant rate, using the thermal storage system as a "buffer" that stores cooling energy when demand is less than production, and releasing the cooling energy when demand exceeds production. This minimizes the need to run the refrigeration system on its less efficient high and low ends of capacity. Another strategy is running the refrigeration system completely during the cheaper "off-peak" hours, and using stored cooling energy during peak hours. Finally, some facilities use some combination of both techniques (Dincer 2002). A review of energy efficiency in the Canadian dairy industry estimates that the installation of a thermal storage system can have a simple payback period of 1-3 years (Wardrop 1997).

Segregation of different cooling temperature requirements. Similar to steam/hot water segregation, if there are multiple cooling temperature requirements, such as in an ice cream facility that needs to cool both milk and frozen ice cream, it can be beneficial to have multiple cooling systems to service these different temperatures. This allows some of the cooling energy to be moved from a less efficient low-temperature refrigeration system to a more efficient high-temperature refrigeration system. A review of energy efficiency in the Canadian dairy industry estimates payback periods of 1-3 years for segregating multiple temperature loads (Wardrop 1997).

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). Several industrial case studies have shown a payback period of less than 6 months in dairy plants that have implemented measures to reduce heat sources in cold storage areas (IAC 2011).

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). In IAC audits of U.S. dairy plants, those that implemented heat infiltration reduction measures have achieved simple payback periods of less than 6 months (IAC 2011).

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 more 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 degrees Fahrenheit, and has led to energy savings of up to 15% in some Canadian facilities. 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). Several U.S. dairy plants that have implemented free cooling systems report simple payback periods of less than 4 years (IAC 2011).

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 over-sizing can save 1.2% of motor electricity consumption (Xenergy, 1998).

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.

A skim milk powder plant operated by Gay Lea Foods uses an underground water well for non-contact cooling water, returning all water back to the ground with no change in water chemistry. The project has decreased energy consumption by 35%, leading to savings of $180,000 per year (CIPEC 2009b).

Mixing product in cooled storage tanks. Often both raw milk and pasteurized milk storage tanks are equipped with an agitator. Keeping milk well mixed in storage tanks reduces temperature gradients and allows for more efficient heat transfer. As an added benefit, keeping milk well mixed reduces physical separations and ensures a homogeneous product (Wardrop 1997).

Optimized air flow pattern. In cold storage areas and blast air units, air flow patterns are often not optimized, creating temperature gradients, dead zones, and by-pass flow patterns, all of which decrease heat transfer efficiency. A simple project to measure air flow rates in different sections of a room or blast air unit can illuminate these dead zones and by-pass flows. Installation of baffles and other air flow enhancers can then be installed to increase heat transfer efficiency. A study of a Pacific Seafood Group frozen sardines manufacturer found that installing baffles and lowering the ceiling of blast freezers led to an estimated 12% energy savings (Kolbe, Ling et al. 2004).

Cooling towers. Using cooling tower water instead of chilled water can lead to significant energy savings, with a payback period of less than 4 months (IAC 2011). 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 (RACCP 2001).

The U.S. DOE (2006a) 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 side stream 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.

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 2004). 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).

Using an economizer with a single stage, low temperature compressor. The most efficient way to run a low temperature refrigeration unit is to use a two-stage compressor system. However, if the unit is just a single-stage compressor unit, using an economizer is an effective way to improve the energy efficiency of the refrigeration unit (Cascade 2007).

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). Several industrial dairy case studies have shown that the simple payback period for reducing condensing pressure is close to zero (IAC 2011).

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). Case studies from the IAC database indicate payback periods of less than 2 years for implemented system improvement projects (IAC 2011).

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 six months (IAC 2011).

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. Several industrial case studies of dairy plants have shown implemented system modification projects, in lieu of increased pressure, having payback periods of less than 2 years (IAC 2011).

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 in U.S. dairy plants is less than 2 years (IAC 2011).

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 2005a). 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 2011).

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). Furthermore, 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). A Unilever Canada plant recovered heat from its compressors to completely heat its loading docks. The simple payback period for the project was about 2.5 years (CIPEC 2008).

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).

Using a buffer tank to regulate compressor duty cycle. Older compressor units tend to be inefficient at regulating their duty cycle. Adding a buffer tank to help regulate the compressor duty cycle can be a wise investment. Payback periods are estimated at 1-3 years (Wardrop 1997).

11 Building Energy Efficiency Measures

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

Lighting systems and HVAC systems are significant consumers of electricity at many dairy processing facilities, together accounting for approximately 18% of total electricity use (see Figure 4.3). 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 dairy processing facility, including manufacturing areas, offices, 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, dairy 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 (also known as retrocommissioning) 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).

An energy audit of Schneider Foods of Kitchener, Ontario found improvements that allowed the plant's main ventilation rate to be reduced significantly. The change resulted in savings of $125,000 per year (CIPEC 2002).

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 2011).

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.

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 1997). 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.[9]

Use of air curtains between ambient and temperature controlled areas. Dairy plants almost always have sections of the plant that are at ambient temperature conditions (such as main processing area), and sections that are temperature controlled (such as cold storage for packaged product). Using air curtains and other barriers (rollup doors) reduce heat infiltration, which reduces the cooling load in the cold storage areas (Makaliunas and Nagevicius 1998).

Infrared heating. Using infrared heaters can be an economical decision for heating open areas. Instead of heating air, like conventional heaters, infrared heaters emit infrared light, which heats only surfaces and people, not the air in the room. A study for improving energy efficiency in the Canadian dairy industry estimates that the simple payback period for installing an infrared heating system is 1-3 years (Wardrop 1997).

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 2011).

Unilever Canada installed motion detectors in their office space, storage rooms, and meeting rooms. The project cost $4,000, but generated savings of approximately $3,900 per year, giving a simple payback period of about 1 year (CIPEC 2008).

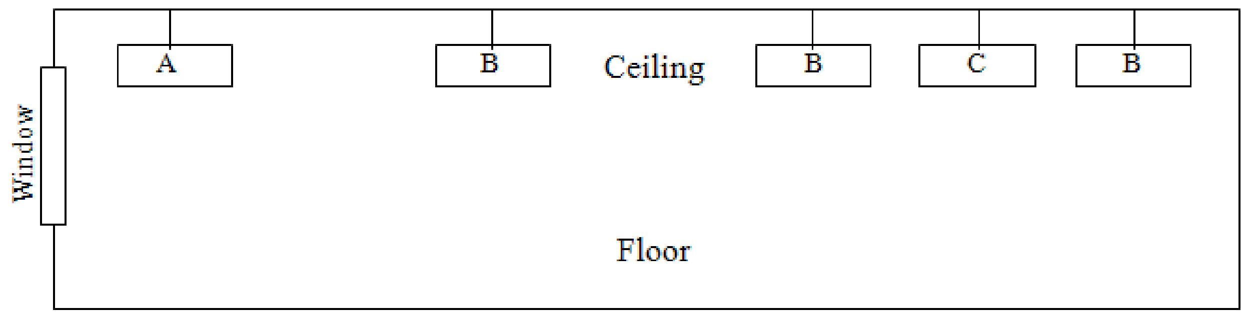
Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control

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

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 (which is particularly important in refrigerated spaces, from which heat generated by lighting must be removed) (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). Even more efficient T-5 type lights are emerging on the market, but data on widespread use in the industry were not available at the time of this writing.

As part of a large energy efficiency initiative at Unilever Canada, a lighting retrofit allowed 44 of their T-12 ballasts to accommodate T-8 lights at their Rexdale plant. In addition to a 2.6 year payback period and $1,400 annual savings, the T-8 lights delivered higher quality lighting, increasing color rendition accuracy by 28% (CIPEC 2008).

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). However, their use may be limited in cold storage areas with very low temperatures; facilities should check the low-temperature rating on this type of light, and possibly test it, to ensure that its performance is adequate in very cold temperature areas (Morrison 2011).

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. dairy processing industry. In 2009, only 1% of the industry's consumed electricity was generated at individual facilities (U.S. Census Bureau 2009b), accounting for only 1% of natural gas consumed (U.S. DOE 2006b).

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. dairy processing industry.

Combined heat and power (CHP). For industries like dairy 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 dairy 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 NOx, 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 D).

Schneider Foods of Kitchener, Ontario, discovered in an energy audit that a natural gas cogeneration unit could provide significant cost savings. With a payback period of 4 years, the plant estimated an annual savings of $1.5 million (CIPEC 2002).

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. Because of the significant need for electricity, steam and refrigeration, the dairy industry may be in a prime position to take advantage of tri-generation.

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 CO2 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.

Solar thermal water preheating. Solar thermal water preheating also involves installing solar panels to harness the sun's energy. Instead of generating electricity, though, the panels absorb the sun's heat, which is transferred to water running through piping in the panels, heating the water up to 110F before being sent to the water heater. This preheating reduces the heating load required to heat process or HVAC hot water. Oakhurst Dairy of Portland, Maine, installed a solar thermal preheating system, a project with a payback period of 8 years. However, the company claims that significant benefits also include an increase in employee morale from pride in the project, as well as positive public relations and marketing (D-CREE 2009).

13 Process Specific Efficiency Measures

Chapters 6 through 12 focused on a number of cross-cutting efficiency measures applicable to dairy processing facilities. In addition to these measures, there are several measures applicable to specific unit processes employed in the dairy processing industry. In this chapter, the most significant of these process-specific energy efficiency measures are discussed. Measures are grouped under one of the following four categories, based on the process to which they apply: 1) pasteurization, sterilization and other heat treatments, 2) evaporation, 3) drying, 4) miscellaneous processes.

13.1 Energy Efficiency Measures for Pasteurization, Sterilization, and Other Similar Heat Treatments

Using heat reclamation or adding plates to an existing reclamation unit. Heat reclamation is a widely used technique that cools the outgoing pasteurized hot milk by using it to heat the incoming cold raw milk. Heat recovery of a reclamation process can be upwards of 95%, with a small amount of steam used to finish heating the incoming raw milk and a small amount of refrigerant used to finish cooling the outgoing pasteurized milk. Installing a reclamation process where one does not exist can lead to significant cost savings. For plants with reclamation processes, adding plates to the existing heat exchanger can be an economical way to increase the heat recovery of the unit. An energy audit of the Lithuanian dairy plant Kupiskio pienas found that installing a heat exchanger for reclamation had a payback period of 1.5 years (Makaliunas and Nagevicius 1998).

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. Although most dairy facilities use plate-and-frame heat exchangers, some applications utilize shell-and-tube heat exchangers. For these, 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 dairy 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).

Heat exchanger enhancement techniques. There are several ways to increase the heat transfer efficiency of heat exchangers. Plates for plate-and-frame heat exchangers can come with features such as rough surfaces that increase turbulence or geometries that induce a specific fluid flow profile. Both of these features increase heat transfer efficiency, and therefore, overall energy efficiency. Because there are a variety of heat exchanger models and designs, determining the options available for a particular model and associated savings compared to the existing plates is highly plant-dependent.

One of the most effective ways of enhancing heat transfer efficiency is to eliminate fouling. Fouling is a common occurrence in the dairy processing industry, and involves a buildup of denatured whey proteins and insoluble calcium phosphate salts on piping and heat exchanger surfaces. If not addressed, fouling can increase energy consumption of a dairy plant by up to 8% (Ramírez, Patel et al. 2006). A fouling layer can be removed during the CIP stage, if the proper cleaning chemicals and techniques are used. Ensuring that a plant's CIP system removes this fouling layer can significantly reduce energy consumption.

13.2 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 1997):

- 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 vapor that boils out of the liquid in one evaporator (or "effect") is 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, to evaporate 1 lb of water, 1.2 lb of steam is required for an evaporator with one effect, 0.6 lb steam for one with 2 effects, 0.3 lb for one with 4 effects, and less than 0.1 lb steam for one with seven effects (Carić 1994).

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 dairy processing, but even up to seven effects are possible (Maroulis and Saravacos 2003; Carić 1994). For whey production, a good rule of thumb is that each additional effect increases investment cost by 15% and decreases steam consumption by 25% (Carić 1994).

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 dairy products, both as replacing single-effect evaporators in the standardization step of yogurt and other products and in pre-concentrating products prior to evaporation (Carić 1994; Hui et al. 2007). 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 dairy 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).

13.3 Energy Efficiency Measures for Drying

Use of evaporation and other concentration techniques prior to drying. Although it is possible to dry dairy products without any prior concentration processes, this practice is not recommended. Drying is far less efficient at removing water than membrane concentration or evaporation, using up to 6 times as much steam per pound of water removed. Utilizing membrane concentration or evaporation to remove as much water as possible prior to drying is an effective method for reducing energy use (Carić 1994).

Temperature optimization for spray drying. For the most efficient operation of a spray dryer process, the inlet drying air temperature should be as high as possible and the outlet drying air temperature should be as low as possible. The limits for these temperatures are based on desired finished product attributes. An inlet temperature that is too high will damage or denature the product. An outlet temperature that is too low will give a sticky product with too much moisture content. A first step in improving the efficiency of a spray dryer is to determine why a spray dryer's limits were set at their current levels. If the limits were historically set arbitrarily, without experimentation, or for a different product, it may be worthwhile revisiting the operating conditions and temperature limits of the spray dryer. A spray dryer whose inlet temperature is increased from 160C to 240C can decrease its steam consumption by 29% and overall energy consumption by 50% (Carić 1994).

Strategic placement of air intake. The quality of the incoming drying air can have a significant effect on the efficiency of the spray dryer. Obviously, hot inlet air is better than cool inlet air, since it takes less energy to heat the air to operating temperature. But the moisture content (i.e. the humidity) of the inlet air also plays an important role. Not only does dry air improve the drying efficiency of the air, but dry air also requires less energy to heat up to operating temperature. For these reasons, it is best to pull the inlet drying air from a warm dry area, such as near the ceiling and away from processes where steam and water are used (Carić 1994; McLeod 2007),

Inlet air monitoring. Often the incoming temperature and humidity of the inlet air varies, but the operating settings of the spray dryer stay relatively constant. Because of this, the dryer settings are often not optimally set for the current ambient air conditions. Installing instruments that measure inlet air temperature and humidity can indicate when ambient air conditions change.

This allows the plant and operators to adjust the dryer settings to operate at optimal conditions for the inlet air being used (McLeod 2007),

Multiple stage drying. Recently, two- and three-stage drying has come into mainstream industrial processes. Multiple stage drying allows the powdered product to exit the drying chamber at a higher moisture content than is specified for the finished product. The still-moist powder is then dried the rest of the way in a fluidized bed chamber. Unlike a spray dryer, where the powder is dried with a large excess of air, fluidized bed driers contain a large amount of powder with a relatively little amount of air bubbled through the powder. Although fluidized bed dryers are much more efficient than spray dryers, they can only dry powder below a certain moisture content to avoid clumping, and are therefore only applicable to the last stage of drying. The use of multiple stage drying can lead decrease steam usage by an estimated 10% (Carić 1994).

Using crystallization process in whey powder production. Whey powder is an extremely energy intensive product, as illustrated in Chapter 4. There are a few different ways to produce whey powder, as indicated in Chapter 3. The most straightforward way is simply to concentrate the liquid whey via evaporation to approximately 45% moisture content followed by spray drying. However, the lactose in the liquid whey can be crystallized, which reduces the hygroscopic properties of the whey. This process, also called high concentration, allows more water to be removed from the liquid whey via evaporation prior to drying. Although the inclusion of the crystallization step adds 4-24 hours to the process time, it reduces the steam intensity of the process, compared to just drying, from 6.6 kg steam/kg product to 5.5 kg steam/kg product. The inclusion of multiple-stage drying as well brings the steam intensity down even further, to 5.0 kg steam/kg product. This is a 24% reduction in steam intensity compared to single stage drying without a crystallization step. As an added benefit, whey with crystallized lactose is often considered higher quality, due to its superior resistance to caking (Carić 1994).

Exhaust heat recovery. Often, the outlet air from a dryer is still quite hot, and waste heat can be recovered from it. It is estimated that up to 30% of the heat from the dryer exhaust can be recovered. However, the dryer exhaust is generally contaminated with small particulates of dairy product that must be filtered out to prevent contamination and fouling of the heat recovery system (Carić 1994).

13.4 Energy Efficiency Measures for Miscellaneous Processes

Good mixing in cooking tanks for cheese, yogurt, and other products. For products that require a cooking process step, such as cheese, yogurt, sour cream, and others, good mixing during the cooking step can have multiple benefits. In addition to a more homogeneous product, and better control over product quality, good mixing reduces temperature gradients, and increases heat transfer efficiency to the product (Wardrop 1997).

Cave aging with ground source heat pumps for cheese aging. Cheese manufacturers can take advantage of caves and underground storage areas that maintain a constant, cool temperature from the earth. The Fifth Town Artisan Cheese Co. in Picton, Ontario uses the caves along with a ground source heat pump to keep the cheese aging at a constant 15°C year round. This was part of a larger energy efficiency improvement effort that ended up saving the company $12,000 per year (CIPEC 2009a).

Using whey permeate to feed biogas reactor to generate fuel. In cheese manufacturers that use ultrafiltration to concentrate liquid whey, the whey permeate can be combined with other wastewater and fed into a biogas reactor. In the reactor, the permeate and wastewater are anaerobically digested to create biogas that can then be used to fuel boilers in the plant. Norrmejerier, a dairy producer in Sweden, installed such a system in one of their plants. The project, which also involved switching the final form of the whey protein, had a payback period of less than 6 years, and produced so much biogas that much of it has to be flared because it exceeds boiler demand (SET at Work 2009).

Producing 80% whey protein concentrate (WPC80) instead of dry whey powder. WPC80 is a product that can be manufactured using just ultrafiltration and evaporation, eliminating the need for the energy intensive drying process step. Although the final form of the whey is ultimately decided by the customer buying the whey, WPC80 often has a large demand as a food production raw material, and current customers may be interested in switching to a "greener" and potentially less expensive raw material. Norrmejerier, a dairy producer in Sweden, switched from dry whey powder to WPC80 and installed a biogas reactor fed by whey permeate. The entire project had a payback period of 6 years (SET at Work 2009).

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. dairy 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 dairy 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 dairy 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.

Heat pumping of waste process heat. 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). Dairy plants generally release a large amount of this low-quality waste heat, making it a possible candidate industry to take advantage of this emerging technology; for example, in recovery of wastewater effluent heat.

Pulsed electric field pasteurization. The use of pulsed electric fields to pasteurize liquid food products is showing promise as an emerging technology. In the pulsed electric field process, liquids are exposed to high voltage pulses of electricity to inactivate harmful micro-organisms as well as some enzymes in milk that can affect taste. 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 fluid requires less cooling energy (Lung et al. 2006). According to Sperber (2011), previous work has shown that pulsed electric field processing can process milk at a significantly lower temperature and preserve the integrity of milk fat and proteins, enzymatic activity and other desirable attributes.

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 dairy processing industry, the new rotary burner could be applied to boilers, 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 dairy 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.

LED lighting. Light Emitting Diode (LED) lights have been receiving a lot of attention as the next generation of energy efficient lighting. In typical florescent lighting, electrical arcs are used to excite mercury and phosphorous compounds, which then emit light. On the other hand, LED lights are semiconductor diodes that use far less energy to emit the same lumens of light. Several new LED light products are emerging on the market that are compatible with current light fixtures, such as T-8 light fixtures (Myer, Paget et al. 2009). LED lights might also prove particularly advantageous in refrigerated spaces, in which less heat generation by lighting will save refrigeration system energy.

UV pasteurization. UV pasteurization delivers a high intensity beam of ultraviolet light the flowing liquid in order to kill microorganisms. Because the killing is done by light, the energy intensive requirement of heating and cooling the fluid is eliminated. This has a potential added benefit of decreasing the flavor change associated with heat-dependent pasteurization methods. UV pasteurization has already been employed as an effective means of sterilizing water and other liquids. As of this writing, UV pasteurization has not been approved by the U.S Food and Drug Administration (F.D.A.) as an acceptable method of milk pasteurization. However, efforts are underway to demonstrate the effectiveness of UV pasteurization, and gain F.D.A. approval of its use in the dairy industry.

High hydrostatic pressure as a pasteurization method. An emerging pasteurization method for fluids is high hydrostatic pressure. The fluid, already packaged in a somewhat flexible container, is immersed in water and subjected to extremely high pressures. The high pressure, and subsequent high pressure drop, kills microorganism by bursting cell membranes and inactivating several essential enzymes. Although energy must be expended to create the high pressure, the energy intensive heating and cooling steps of traditional pasteurization are eliminated. There are still questions surrounding this technique, including throughput capacity and effect of the high pressure on proteins and other components in the milk.

Microfiltration as a pasteurization method. Microfiltration is a filtration technique, similar to ultrafiltration and reverse osmosis, all of which are already widely used in the dairy industry. The pore size in microfiltration is small enough that it effectively filters out bacteria. However, fat globules are also filtered out in microfiltration. Due to this, only skim milk can be pasteurized via microfiltration. For any other type of milk, the cream layer must be pasteurized separately, generally by normal heat pasteurization methods, and added in after (Walstra et al. 2006).

15 Basic Water Efficiency Measures

In many U.S. dairy processing facilities, water is a resource that can be just as critical and costly as energy in the production process. In the U.S. dairy industry, water is primarily used for CIP techniques to clean and sanitize processing equipment. It is also used for case washing and general plant cleaning. Specific water use in the dairy industry is estimated at upwards of 4,800 gallons of wastewater per ton of product (U.S. AEP 2002). In California alone, the water consumption of the dairy processing industry has been estimated at nearly 5.5 billion gallons per year (Pacific Institute 2003).

This chapter provides a brief overview of basic, proven water efficiency measures applicable to typical dairy processing plants. Because of the central role CIP plays in water use in the dairy processing industry, much of this chapter focuses on potential water efficiency improvements to CIP systems. In addition to reducing facility utility bills for water purchases, improved water efficiency can also lead to reduced energy consumption for water pumping and heating, reduced wastewater discharge volumes, and reduced wastewater treatment costs. In addition, several of these measures have additional benefits, such as waste heat recovery and reduced amount of cleaning chemicals required. Finally, 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.

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 lasting 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.

15.1 Clean In Place (CIP) Improvements

Federal law requires that dairy and other food processors adhere to certain standards of cleanliness and sanitation for their processing equipment. This is most commonly achieved by a CIP technique that allows the processor to clean and sanitize their processing equipment without having to disassemble and reassemble the equipment. Though the technique can vary from plant to plant, the following is a typical, generic CIP process:

1. Equipment is drained of all milk/product.
2. An initial rinse with water is used to remove much of the milk/product residue.
3. A hot alkaline detergent solution is circulated through the equipment, and then drained.
4. A water rinse is used to remove much of the residual alkaline solution.
5. An acid solution is circulated through the equipment, and then drained.
6. A water rinse is used to remove the residual acid solution.
7. A final sanitize solution prepared with potable water is used on the equipment.
8. Optional - Often, air is blown through the equipment to remove residual water or to push sanitizer through the system more efficiently.

The hot alkaline detergent solution is used to remove milk organics, such as carbohydrates, proteins and fats, as well as general soil that was not removed from the initial water rinse. The acid solution, in addition to neutralizing any leftover alkaline detergent, removes mineral deposits from the milk, such as calcium buildup. The sanitize solution is used as a final antimicrobial step prior to production (Chisti 1999; Ecolab 2011) .

Due to the multiple steps and washes associated with CIP, it is a significant source of water and energy use in a dairy plant. In fact, Ramirez et. al (2006) estimates that, in the Dutch dairy processing industry, CIP accounts for 9.5% of energy use in fluid milk processing, 26% of energy use in butter processing, and 19% of energy use in cheese production. The following are several measures that can be implemented into a CIP system to reduce the amount of water and energy used.

Using reuse or recovery distribution systems: Overall, there are a few types of CIP distribution systems that are widely used. Single use systems, which dispose of the rinse water and cleaning solution after one use, are the most versatile. However, these systems use copious quantities of water and energy in the cleaning process. More efficient systems are reuse systems and solution recovery systems. These systems can reclaim the alkaline detergent solution and reuse it for future cleaning. In addition, the relatively clean final rinse water can be captured and used for the next CIP cycle's initial rinse (Ecolab 2011).

Single phase cleaning: The use of a single cleaning solution that removes both organics and mineral deposits can eliminate the need for a two-step (i.e. separate alkaline wash and acid wash) cleaning process. This technique saves water associated with the interim rinse step and the second wash. This measure estimates a 25% water reduction and 10% energy use reduction compared to a typical five-step process (Ecolab 2011).

Over-ride procedure: This technique is generally used for equipment that requires a fast turnaround. Instead of separate acid wash and alkaline wash steps, the first step (acid step) is kept circulating while alkaline detergent is added to the required concentration. Although more detergent is used with this technique, since some must be added to neutralize the acid, approximately a 10% water reduction is possible (Ecolab 2011).

Optimization of phase separation with reuse CIP systems: In reuse systems, it is sometimes unclear when the return solution is too contaminated to be recycled. Measuring the conductivity and turbidity of the returning solution can be used to determine at what point the solution can be recycled and at what point the solution needs to be disposed of. This allows water to be recycled that normally would be disposed of. Water use can be reduced by up to 10% with this method (Ecolab 2011).

Pulse rinse on tanks: Often a constant stream of water is used in rinse steps. However, a pulsed rinse, where the water is stopped periodically throughout the step, can be more effective at rinsing while reducing water usage by approximately 10% (Ecolab 2011).

RO or evaporative water use in CIP: Water from evaporation process steps, as well as high quality RO reject water, can be diverted and used in the CIP system. Depending on how much evaporation processing is done at a facility, up to 50% of CIP water can be sourced from this method. In addition, since water reclaimed from evaporation processes is already hot, up to 10% of steam can be reduced from the CIP process (Ecolab 2011).

Air blows: This technique uses air to blow out residual detergent and/or sanitizer solutions so that less water is required in the subsequent rinse steps. While this measure can save up to 5% of water, this must be weighed against the cost of a compressor, the electricity used to operate the compressor, and air purification requirements (Ecolab 2011).

15.2 General Facility Water Conservation Techniques

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.
- Keeping spray nozzles free of dirt and scale.
- Installing water meters on equipment to better enable monitoring and reduction of water consumption.
- 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).

Wastewater treatment. Disposal of wastewater can be a costly expense, especially when the exact contents of the wastewater stream are unknown. Treating wastewater with microorganisms that digest dairy waste in wastewater gives certainty to the final wastewater composition. This allows a facility to more easily dispose the wastewater stream to the municipal sewage system at a lower cost.

Recycling of milk waste as fertilizer. Waste milk and dairy products can be used as fertilizers on farms. Often, a plant can form a partnership with a dairy farmer where, after delivering a tanker of milk, the farmer then loads the empty tanker with waste milk to use as fertilizer on their farm.

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.[10]

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).

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 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, which reduces the energy efficiency. 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.

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[10] 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.

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).

Low pressure foam cleaning. Traditionally, walls, floors, and some 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.

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).

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. 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 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).

16 Summary and Conclusions

The U.S. dairy processing industry spent nearly $1.5 billion on purchased fuels and electricity in 2008, 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 spikes 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. dairy 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.

Table 5.1 summarized the energy efficiency measures presented in this Energy Guide. While the expected savings associated with some of the individual measures may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Many of the measures 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. dairy 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 5.1.

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.

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Glossary

ASD	Adjustable-speed drive
bhp	Boiler horsepower
CHP	Combined heat and power
CIP	Clean In Place
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
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: 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).

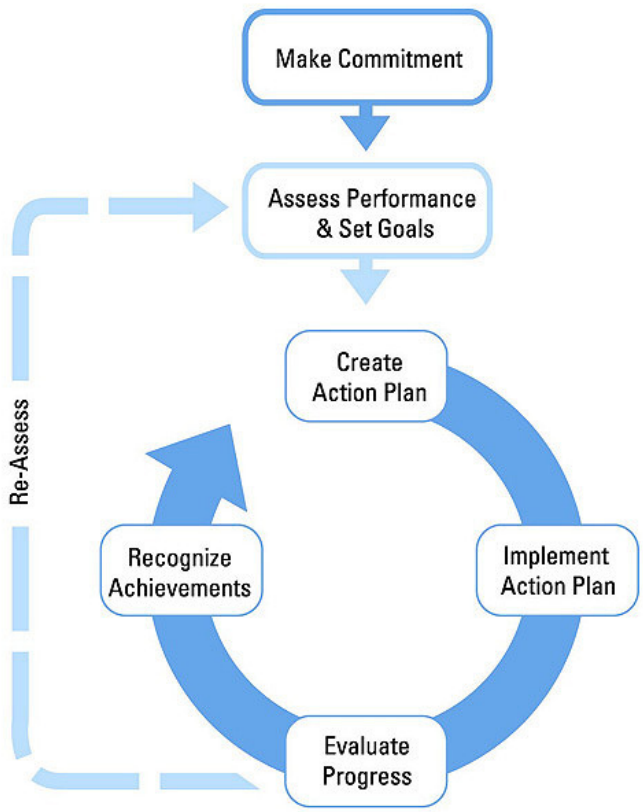
- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed 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 B: Guidelines for Energy Management 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	

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 C: 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 D: 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

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

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

The federal government, as well as 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. In addition, many utilities and energy providers have incentive programs to encourage efficiency improvements and renewable energy use. Contact your energy provider for incentives that can apply to your facility.
This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. Many states have similar programs, such as a property tax exemption for value-added solar and wind energy installations. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions. For a comprehensive list of federal and state incentives, please visit the Database of State Incentives for Renewables and Efficiency website: http://www.dsireusa.org/

DOE Energy Efficiency and Renewable Energy – Industrial Technologies Program

Description:	The Department of Energy's Office of Energy Efficiency and Renewable Energy has several financial opportunities as part of their Industrial Technologies program. In addition to funding for R+D projects, there is a searchable database for federal, state, and local financial opportunities.
Target Group:	Any industry
Format:	Solicitation/Database
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www1.eere.energy.gov/industry/financial/index.html

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/

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 – 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/

California – Local Green Building Programs

Description: Several local cities and counties have financial incentives for energy efficiency and alternative energy improvements to commercial and industrial buildings. Check your local city and county for updates or new programs.

Target Group: Commercial, Industrial, Residential
Format: Open year round
URL:
Los Angeles - https://www.ladwp.com/ladwp/cms/ladwp002224.jsp
San Bernardino - http://www.sbcounty.gov/greencountysb/
San Diego - http://www.sdcounty.ca.gov/dplu/greenbuildings.html
Santa Monica - http://www.solarsantamonica.com/index.html
Santa Clara - http://santaclaraca.gov/index.aspx?page=1046
San Francisco http://sfwater.org/mto_main.cfm/MC_ID/12/MSC_ID/139/MTO_ID/361

California – State Alternative Energy Programs

Description: California has several statewide financial incentives for alternative energy improvements. They include: Sales tax exemption for alternative energy manufacturing equipment, California Feed-in tariff for selling energy back into the grid, Property tax exclusion for solar energy systems, and rebates for photovoltaic, solar water heating systems, emerging renewables, and self-generation systems.

Target Group: Commercial, Industrial, Residential
Format: Open year round
URL:
Sales tax exemption - http://www.treasurer.ca.gov/caeatfa/sb71/index.asp
Feed-in tariff - http://www.cpuc.ca.gov/feedintariff
Property tax exemption - http://www.boe.ca.gov/
PV rebates - http://www.cpuc.ca.gov/PUC/energy/solar
Solar water heating rebate - https://www.csithermal.com/
Emerging renewables - http://www.consumerenergycenter.org/erprebate
Self Generation rebate - http://www.cpuc.ca.gov/PUC/energy/DistGen/sgip/index.htm

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. Offers several financial incentives for improved energy efficiency and alternative energy sources.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Administration
URL:	http://focusonenergy.com

Wisconsin – Solar and Wind Energy Tax Exemption

Description:	Wisconsin exempts any value-added wind or solar energy system from property taxes.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Revenue
URL:	http://www.revenue.wi.gov/forms/govexmpt/pr-303.pdf

Wisconsin – Solar and Wind Energy Tax Exemption

Description:	Wisconsin exempts any value-added wind or solar energy system from property taxes.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Revenue
URL:	http://www.revenue.wi.gov/forms/govexmpt/pr-303.pdf