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Opportunities for Automated Demand Response in California's Dairy Processing Industry

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ABSTRACT

During periods of peak electrical demand on the energy grid or when there is a shortage of supply, the stability of the grid may be compromised or the cost of supplying electricity may rise dramatically, respectively. Demand response programs are designed to mitigate the severity of these problems and improve reliability by reducing the demand on the grid during such critical times. In 2010, the Demand Response Research Center convened a group of industry experts to suggest potential industries that would be good demand response program candidates for further review. The dairy industry was suggested due to the perception that the industry had suitable flexibility and automatic controls in place. The purpose of this report is to provide an initial description of the industry with regard to demand response potential, specifically automated demand response.

This report qualitatively describes the potential for participation in demand response and automated demand response by dairy processing facilities in California, as well as barriers to widespread participation. The report first describes the magnitude, timing, location, purpose, and manner of energy use. Typical process equipment and controls are discussed, as well as common impediments to participation in demand response and automated demand response programs. Two case studies of demand response at dairy facilities in California and across the country are reviewed. Finally, recommendations are made for future research that can enhance the understanding of demand response potential in this industry.

Keywords: Dairy, Dairy Processing, Demand Response, Energy Efficiency, Auto-DR

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EXECUTIVE SUMMARY

The dairy processing industry is a large consumer of energy. In the United States, energy use by the dairy processing industry in 2010 was 30,500 GWh (104 trillion Btu), 9,671 GWh (33 trillion Btu) of which was electricity. Dairy processing involves a diverse group of products and processes and a particular plant may be involved in only one or in several different product types. Because of the variety of dairy processing plants, energy intensities can range from 0.11 kWh/L to 0.29 kWh/L of processed milk.

Available data indicates that dairy production and product energy intensities are relatively constant year-round. This suggests a flat annual load profile. However, actual daily load profiles for dairy processing facilities are still required to better quantify the demand response potential for the different program types.

This study identified process cooling, refrigeration, packaging, separation, machine drives (e.g., churning and pumping) and clean-in-place as the major electricity consuming processes. This study also found that barriers for adopting demand response in the dairy industry include: perishability of products, little excess production capacity, insufficient storage capacity relative to incoming shipments, the need to comply with a complex regulatory regime, and the need to recover and restart (cleaning) if processes are interrupted.

Some processes that could be delayed for the purposes of demand response without affecting product quality include the labeling of milk bottles or the cutting and packaging of cheese. Batch pasteurization could in some instances be shifted without harming the product. Despite limitations on major process equipment to participate in demand response, there is a large potential for plants to run on backup power, solar, or cogeneration. Also, dairy plants have energy uses that overlap with other sectors previously evaluated for demand response, including refrigerated warehouses and wastewater treatment. Lastly, dairy plants have generic energy uses common to many types of buildings, such as facility HVAC and lighting, which can be good candidates for demand response.

In existing case studies, load sheds of 3.3 MW and 1 MW were achieved at two different facilities by shutting down evaporators, separators, and dryers. These results suggest that despite all the limitations, significant demand response potential exists at the dairy processing facilities. Conducting further demand response case studies and facility submetering could shed more light on the full demand response potential of this sector.

Future research should focus on the following areas:

- Obtaining demand profiles for dairy processing plants in California.
- Further analyzing and quantifying the demand response potential.
- Identifying shed or shift strategies tailored specifically for the dairy processing industry.
- Quantifying the risks associated with the identified shed or shift strategies.
- Surveying the control capabilities in place.
- Addressing specific sub-sectors of the dairy processing industry, particularly cheese making and the ice cream and frozen dessert sector.

CHAPTER 1:

Introduction

The Demand Response Research Center (DRRC), led by Lawrence Berkeley National Laboratory (LBNL), is funded in part by the California Energy Commission's (CEC) Public Interest Energy Research Program (PIER). The Center exists to conduct and disseminate research that broadens the knowledge base about demand response (DR) strategies that reduce or increase utility customer demand side load during times of peak demand, critical market conditions, price signals, and over or under generation caused by intermittent renewable sources. These strategies are aimed at improving the reliability of the power grid, thus allowing utilities to supply power more efficiently and lowering the average energy cost to the consumer. To effect these changes, the DRRC focuses on policies and tariffs, the state of utility markets and technology, and customer technology and behavior.

DR strategies include direct and indirect control of loads by the utility and implementing dynamic pricing programs designed to reward end users for reducing load during peak hours and critical times (price response). The automated DR (Auto-DR) research project works to support increased penetration of DR in large facilities through automation of DR strategies. In 2006, the Industrial DR Team was formed within the DRRC to analyze DR capabilities of industrial sites. Through research and case studies of industrial sectors and entities, the team gathers knowledge on the feasibility of industrial DR strategies with an emphasis on Auto-DR and works to encourage implementation of these strategies.

In 2010, LBNL convened a panel of industrial control experts to elicit opinions regarding the DR potential for several industries and to help identify candidates for further research. This group suggested the dairy processing industry as such a candidate and judged that it had at least moderately good DR potential largely based on their expert opinion that there was a higher than average level of control systems in place.

The purpose of this report is to follow up on the feedback from that expert group and to create an initial description of the dairy processing industry with regard to DR through review of the existing literature and consultation with persons within the industry.

CHAPTER 2:

Characteristics of Dairy Processing Industry

2.1 Overview

Dairy processing in the United States is widely distributed, with dairy facilities located in all 50 states and in Puerto Rico (Dairy Farming Today, 2015). According to Dairy Plants USA (2015), there are 1,173 dairy processing plants in the U.S., which is identical to the finding of Brush et al. (2011) that was based on U.S. Census data, with about 16% (187) located in California.

The dairy industry can comprise as much as 20% of the value of agriculture (IDF, 2013). Brush et al. (2011) estimated the value of shipments in the U.S. dairy industry at just over \$90 billion in 2008, which was equivalent to 15% of the entire U.S. food industry (Brush, Masanet, & Worrell, 2011).

2.2 Design of Dairy Processing Plants

The major functional divisions of dairy processing plants are: the reception area, processing area (which contains the homogenizers, pasteurizers, centrifuges, and other processing equipment), electrical system, chilling system, boilers and steam system, packaging, and storage. Many plants also have a facility-wide compressed air system. Dairy processing plants are largely, but not fully, automated. The automation involves several automatic processes, each of which is actuated manually **Invalid source specified..**

Dairy processing involves a diverse group of products and processes, and a particular plant may be involved in only one or several different product types. As a result, it is difficult to make conclusions about energy use in processing plants based on industry-level data. Illustrative of this diversity, Natural Resources Canada (2001) reported on a sample of 17 fluid-milk processing plants¹, eight of which produced only fluid milk products (regular milk, flavored milk, creams, and micro filtered milk). The other nine were considered to be “complex” plants, which produced not only fluid milk, but also ice cream, yogurt, and/or ultra-high temperature cream. The total energy intensity of the 17 plants varied widely, ranging from 0.11 kWh/L to 0.29 kWh/L.

2.3 Constraints on Dairy Processing Plants

2.3.1 Regulations

Dairy products are subject to spoilage and, if improperly handled, can be subject to contamination. In addition, there are regulations in place to assure food safety from a security perspective. As a result, the dairy processing industry operates under higher levels of regulation than many other industries.

At the federal level, the most important of these regulations is the Pasteurized Milk Ordinance (PMO) (FDA, 2011). This ordinance stipulates plant design and factors that affect production.

¹ The 17 plants represent about half of the fluid milk processing in Canada.

The latter include: length of time to cool raw milk, temperatures allowed for processing and storage, timing and frequency for utensil cleaning, storage tank and other equipment characteristics, and the characteristics of finished products. The PMO also requires that plants establish a Hazard Analysis Critical Control Points (HACCP) plan.

Dairy processors that have products sold across state lines must further comply with the requirements of the Interstate Milk Shippers List (IMS) from the U.S. Food and Drug Administration (FDA, 2015). There are also applicable state-specific regulations.

As part of the larger regulatory compliance, plant operators may have to formalize, and obtain approval of, Standard Operating Procedures (SOPs) and Standard Sanitation Operating Procedures (SSOPs). Complying with these requirements, particularly the time requirements, limits the flexibility of dairy processing plants to participate in DR.

The requirements to clean processing equipment, coupled with the need to keep the processing equipment (e.g., pasteurization tunnel) full of fluid, presents processors with problems related to product quality (e.g., dilution, adulteration) and product loss (e.g., spillage).

2.3.2 Storage Capacity

Dairy processing plants, particularly large ones, are also constrained in their ability to stop or shift operations for demand response by the frequency of incoming shipments. Dairy farms often harvest milk twice daily and, increasingly, three times daily, which is then shipped to the processors. Silos in receiving areas do not have large enough capacity compared to the expected incoming product, which limits the ability of processors to delay processing. None of the sources that we reviewed that discussed plant layout or process flow (Walstra 1999, Brush et al. 2011, Focus on Energy 2006, Mane 2014) indicated that there would typically be any intermediate storage between the initial reception and the final product storage.

2.4 Dairy Products

The dairy processing industry is listed in the North American Industry Classification System (NAICS) as code 31151 and 31152. The industry includes five sub-codes, which are listed in Table 1.

Table 1: NAICS Codes for the Dairy Processing Industry

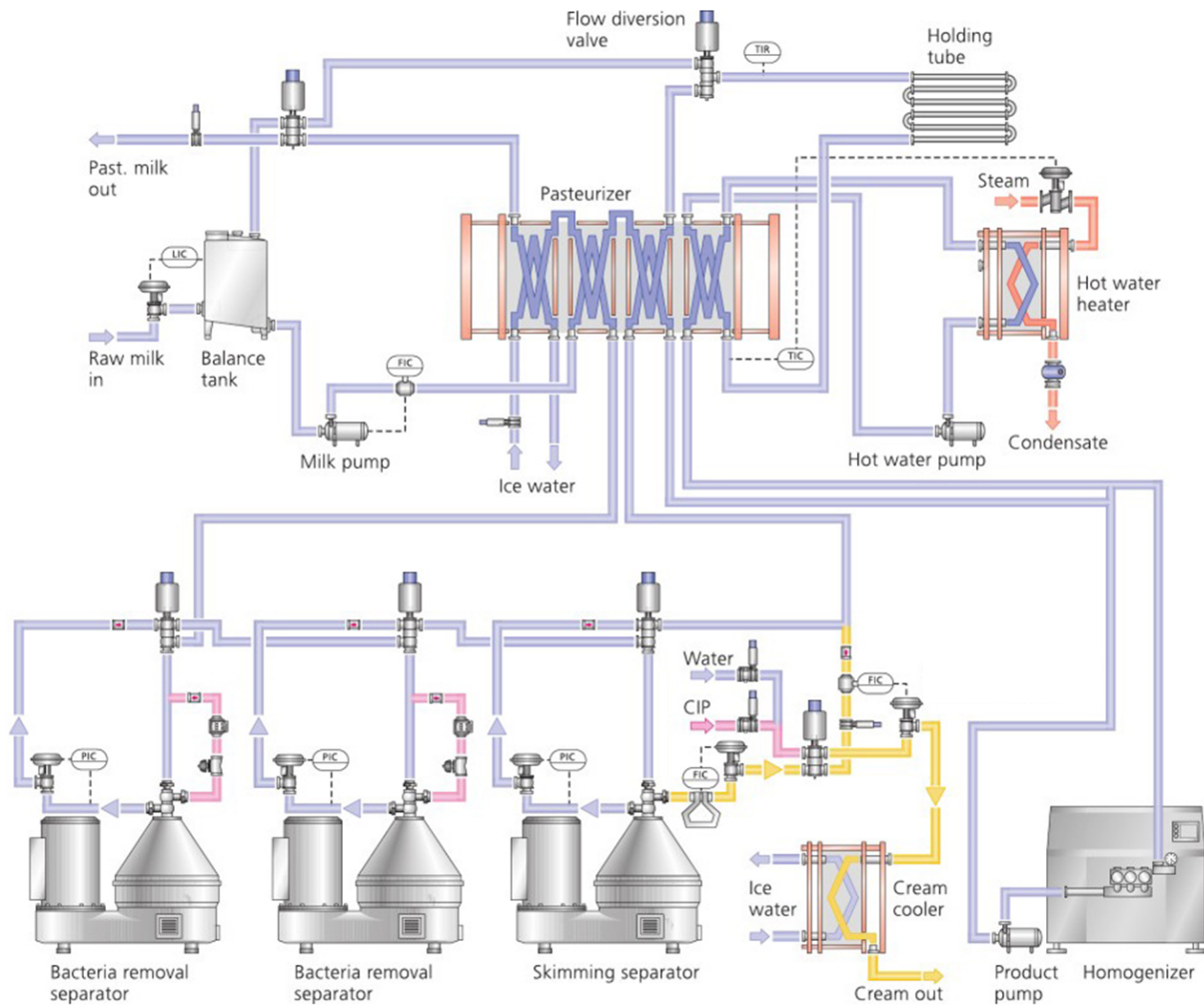
NAICS Codes	Description	Key Products
311511	Fluid milk manufacturing	Fluid milk, cream, sour cream, yogurt, cottage cheese, eggnog
311512	Creamery butter manufacturing	Butter
311513	Cheese manufacturing	Processed cheese, cheddar, mozzarella, provolone, romano, parmesan, swiss, ricotta
311514	Dry, condensed, and evaporated dairy manufacturing	Evaporated milk, sweetened condensed milk, dry milk powder
311520	Ice cream and frozen dessert manufacturing	Ice cream, sherbet, frozen yogurt

Source: U.S. Census, 2011

Walstra (1999, 2006), Brush et al. (2011), Xu and Flapper (2009, 2011) provide descriptions and process diagrams of the production processes for all five sub-sectors. Below, we describe the process for fluid milk and give only summaries for the other products. Those interested in the details of the processing activities for other sub-sectors are referred to those earlier works.

A representative diagram of the fluid milk production process is shown in Figure 1. Some plants do not carry out the operations in the same order as might be shown in a single diagram.²

Figure 1: Process diagram for fluid milk production



Source: GEA Westfalia, 2010

² Xu and Flapper (2011) note that these processes may not always be carried out in the same order as they are listed here. For instance, Wardrop Engineering (1997) and Mane (2014) describe homogenization as preceding pasteurization. Walstra (1999) indicates that when homogenization is preceded by pasteurization, the risk of recontamination is reduced. Brush et al. (2011) describe pasteurization as preceding homogenization.

2.4.1 Fluid Milk Processing (311511)

The major activities in fluid milk manufacturing include:

2.4.1.1 Reception

Raw milk shipments from dairy farms are transported in refrigerated vehicles. The incoming raw milk may be subject to clarification in which foreign material or particulates are removed by a centrifuge. The received milk is typically cooled further (39°F, 4°C) and placed in refrigerated silos prior to processing. Clean-In-Place (CIP), as described below, is typically needed after the raw milk is sent to the processing phase.

In dairy processing, equipment must be cleaned in place both with minimal frequency and after certain events. The main purposes are to prevent the spread or growth of microorganisms and to prevent fouling, which is the buildup of denatured proteins and insoluble salts in heat exchangers or pipes (Ramirez et al. 2006). Brush et al. (2011) note that fouling is a common occurrence and can significantly decrease plant efficiencies. For example, Ramirez et al. (2006), citing the previous work of Singh (1991), report that fouling in one dairy processing plant was responsible for an 8% increase in total energy consumption. Almost all of the dairy processes include one or more CIP events, typically after storage stages, and after heat treatments. The typical CIP process consists of high temperature (150 to 170°F, 65 to 75°C) rinses, with alternating alkaline and acidic cleaning solutions with water rinses before and after.

2.4.1.2 Separation/Standardization

The drawing off of cream, either entirely or to a desired level, is typically done by centrifuging, and optionally by adding fats, cream, or milk solids.

2.4.1.3 Homogenization

The purpose of homogenization is to break up fat globules and to prevent fat-soluble and water-soluble portions from separating. It most commonly uses a piston pump to create a large pressure drop across a small opening that the milk stream is forced through.

2.4.1.4 Pasteurization

Milk is heat treated to destroy pathogens in the milk with the main purposes of: 1) preventing spoilage and 2) increasing the shelf life of the processed milk. Pasteurization may be a batch process, or a continuous one.

The most common pasteurization process uses a gear pump or flow regulator to pass the milk stream through a heat exchanger, which heats the milk to the desired temperature. It is then pumped through a length of piping to hold it at this temperature for a specified period of time, before being re-cooled. The exact time and temperature used varies by method, but 145°F (63°C) over 30 minutes for a batch process, or 161°F (72°C) over 15 seconds for a continuous process, are typical (FDA, 2011). Some milk is sterilized by holding it at a high temperature for longer, which gives longer shelf life, but may affect flavor characteristics.

2.4.1.5 Chilling

Following pasteurization, the standardized treated milk is cooled to 39°F (4°C).

Most dairy processors use a process called regeneration to cut down on energy costs. Regeneration cools the outlet stream so that the recovered energy can be used to heat the incoming stream. Recovery rates are approximately 85% to 90%. 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 (Brush et al. 2011).

2.4.1.6 Packaging

In this step, the final product is packed in sterilized containers and kept in refrigerated storage until shipment. In some processes such as yogurt production, packaging occurs immediately after all of the ingredients are mixed together. In many other processes, packaging can be delayed as long as sufficient storage and refrigeration capacity are available. Because packaging uses motors and conveyor belts, delaying this part of the process could be viewed as a load shift strategy.

2.4.1.7 Refrigerated Storage

Refrigerated storage is the largest energy consumer at the dairy processing facilities. Previous work done by LBNL identified refrigerated warehouses as ideal candidates for DR (Lekov et al. 2009b). Previous studies also documented case studies where load sheds of approximately 35% (580kW) and 41% (330kW) of the facility's baseline demand were achieved (Goli et al. 2011). Available thermal mass at refrigerated facilities (especially freezers) might allow complete refrigeration system shutdown without significant temperature rise. The allowable duration of shutdown depends on factors such as warehouse type (cooler, freezer, etc.), refrigeration system design, outside air temperature, product mass and type. Refrigeration system shutdowns of up to 6 hours are common for freezer facilities.

2.4.2 Creamery Butter Manufacturing (311512)

In this process, cream from milk production is processed further to make butter. The steps include pasteurization, ripening, churning, washing, shaping, packaging, and refrigerated storage. In the ripening step, pasteurized cream is held at a high temperature to allow milk fat to crystallize, thus making churning easier and reducing the amount of fat lost in buttermilk.

2.4.3 Cheese Manufacturing (311513)

Raw milk undergoes the following processes to make cheese: standardization, filtration, pasteurization, cooling and aging (with additional ingredients), draining of liquid whey, processing, cutting, packaging, and storage/aging. Processed cheese products have additional stages of cooking, mixing, homogenization, and cooling between the cutting and packaging stages.

A side product of cheese manufacturing is liquid whey, which is removed from the cheese making process after the cooking and aging steps. Whey is difficult to dispose of in liquid form, but it can be used as a nutritional supplement because of its protein content. The most basic process takes liquid whey from cheese making, filters it (usually), and concentrates it using reverse osmosis, micro-filtration, or ultra-filtration. Next, it is processed further by pasteurization, evaporation, and drying. The latter step usually involves spray drying. Alternatives to the production process include removing water prior to spray drying through

lactose crystallization, or using a fluidized bed drying step afterward, which allows powder leaving the spray drying to retain more moisture content.

2.4.4 Dry, Condensed, and Evaporated Dairy Product Manufacturing (311514)

Dry milk powder production starts with standardized milk, which is heat treated and optionally put through an evaporation stage. These steps are followed by homogenization, after which point the concentrated milk is dried using a spray roller or by vacuum drying. The dried powder is sifted and then packaged.

Evaporated milk takes raw milk as input, which is then clarified, cooled, and standardized, similar to fluid milk. The standardized milk is then pre-heated, and subjected to evaporation, sterilized, packaged, and cooled. Sterilization may precede packaging or be done in-package.

The production of sweetened condensed milk is similar to evaporated milk, but differs in that sugar is added after the evaporation stage. That stage is followed by a cooling process that leads to the formation of lactose crystals. The larger crystals are removed by centrifuging, followed by packaging.

None of these three products require cold storage.

2.4.5 Ice Cream and Frozen Dessert Manufacturing (311520)

This process starts with cream either from milk processing or as directly received. The cream is then standardized and combined with flavoring and sweetening ingredients, as well as with stabilizing or emulsifying ingredients. This mix is then pasteurized, homogenized, and cooled. The cooled mixture is aged by holding it in a cold tank, which allows the fat to crystalize and the stabilizers to hydrate. The aged mix is then partially frozen, mixed with air for texture, and final flavoring ingredients (i.e., fruits and/or nuts) are added as desired. The partially frozen mix is packaged and then “hardened”, which completes the freezing process. The product is then sent to frozen storage.

CHAPTER 3: Energy Use

3.1 Magnitude of Energy Consumption

To assess the potential for DR in the dairy industry, it is important to understand the magnitude of energy use and demand, the daily and seasonal load patterns, and the role of energy-intensive equipment and process (Lekov et al. 2009a).

3.1.1 National Energy Use

The U.S. Department of Energy (DOE) produces a quadrennial survey of energy use in manufacturing called the Manufacturing Energy Consumption Survey (MECS), which is the primary source for national estimates. In the last two surveys, the MECS included data for the dairy processing industry (NAICS 31151) as a separate category.

Energy use in the dairy processing industry includes both electricity and fossil fuels; the latter is primarily natural gas. In 2010, the estimated total energy consumed by the dairy processing industry in the United States was 104 TBtu (110 PJ) (EIA MECS, 2010). Of this amount, electricity use was 9,700 GWh (33 TBtu, 35 PJ) and natural gas use was 66 TBtu (70 PJ). Table 2 disaggregates the national 2010 estimates by energy type and end uses.

Table 2: 2010 U.S. Energy Consumption by End-Use in the Dairy Processing Sector

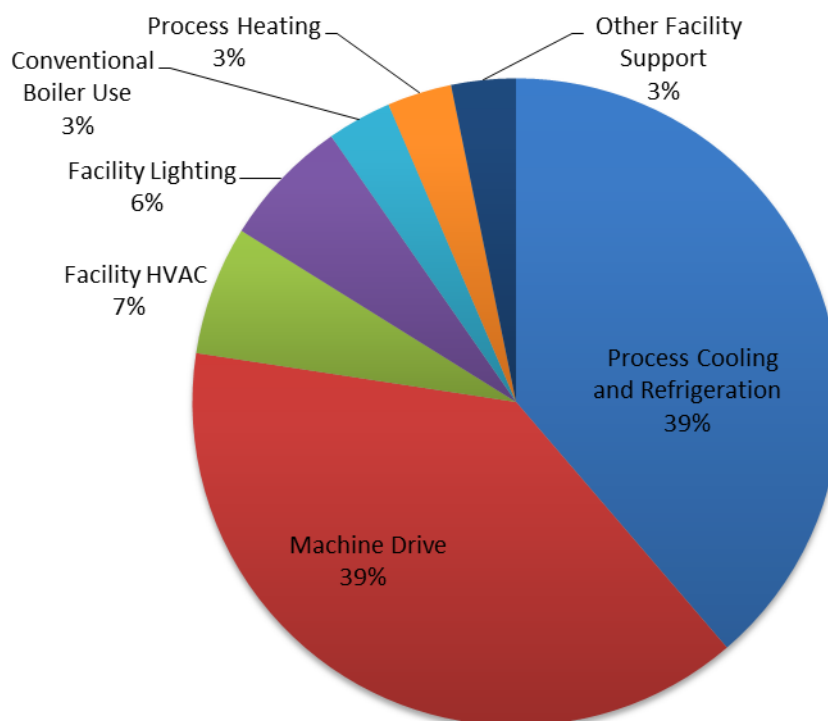
	Electricity (TBtu)	Natural Gas (TBtu)
TOTAL CONSUMPTION³	33	66
Indirect Uses-Boiler Fuel	1	41
Conventional Boiler Use	1	17
CHP and/or Cogeneration Process	--	24
Direct Uses-Total Process	25	19
Process Heating	1	16
Process Cooling and Refrigeration	12	*
Machine Drive	12	1
Electro-Chemical Processes	*	--
Other Process Use	*	1
Direct Uses-Total Non-Process	6	5
Facility HVAC	2	3
Facility Lighting	2	--
Other Facility Support	1	1
Onsite Transportation	*	*
Conventional Electricity Generation	--	*
Other Non-Process Use	*	*
End Use Not Reported	1	2

Source: MECS Table 5.4 (EIA MECS, 2010)

³ The consumption estimates in this table are directly from MECS and in some instances the subgroups do not sum to the total. This is due to rounding and unquantified values where the numbers are classified by MECS as “too small to report”. These instances are indicated by asterisks.

The electricity end-use estimates from MECS are presented graphically in Figure 2.

Figure 2: 2010 Percent Electricity Use in the Dairy Industry, by Activity



Source: (EIA MECS, 2010)

3.1.2 Energy Use in California

California has led the United States in dairy production since 1993 (CMAB, 2008), being the largest producer of total milk, butter, ice cream, nonfat dry milk, and whey protein concentrate. California accounts for more than 20% of the United States' milk production. In 2013, California produced 41.2 billion pounds of milk (CMAB, 2008). California is second in cheese production following Wisconsin. The MECS does not report state level energy use estimates, but Xu et al. (2012) estimated total energy use at 4,600 GWh (16.6 PJ, 15.7 TBtu) of which 1,166 GWh (4.2 PJ, 3.6 TBtu) was electricity. This estimate of California's dairy processing energy consumption is equal to 15% of overall U.S. dairy energy consumption (30,500 GWh, 104 TBtu), which is in rough agreement with California's 20% share of U.S. dairy production.

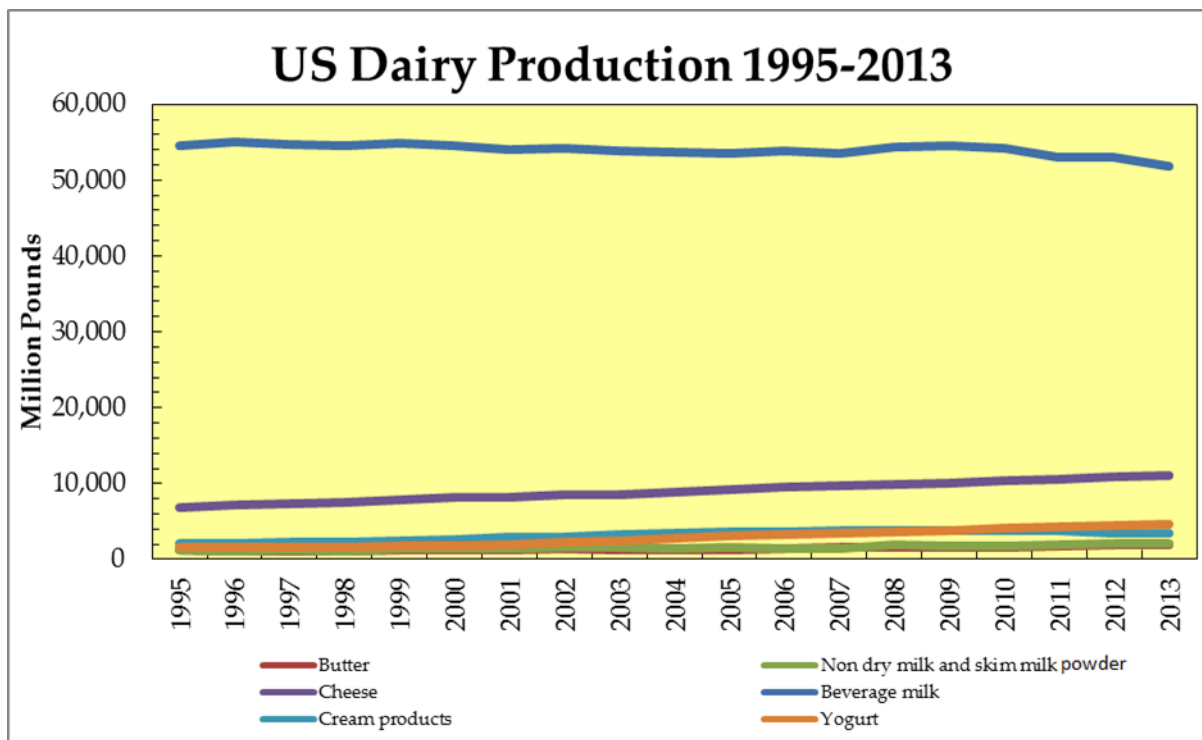
3.1.3 Dairy Industry Growth Projections

Xu and Flapper (2009) found a positive growing trend for overall milk production in the United States and California over the period 1995-2005, exhibiting average annual growth rates of 1.3% (U.S.) and 4% (California) by mass. Data from the U.S. Census Bureau's Annual Survey of Manufacturers (ASM) (U.S. Census, 2011) reveal consistent growth in raw milk production over the period 1980-2012. Average year-to-year growth was 1.4%.

We examined more recent production since the year 2006 and found that these trends have not uniformly continued. In particular, the growth in U.S. raw milk production has not resulted in an equivalent increase in the production of fluid milk, production of which has been flat or

slightly declining (USDA 2014a, 2014b). Instead, the increase has gone into yogurt, cheese, and cream products. The peak production year for fluid milk was 2009 and production in each subsequent year has declined. These declines are not large: ranging from -0.1% to -2.0%. Production of cream products (e.g., heavy cream, half-and-half), which had been increasing through about 2007, subsequently plateaued and declined in recent years. Production of butter and dried products has shown modest growth. Only cheese making and yogurt production have had substantial increases in production volume. These data are displayed in Figure 3.

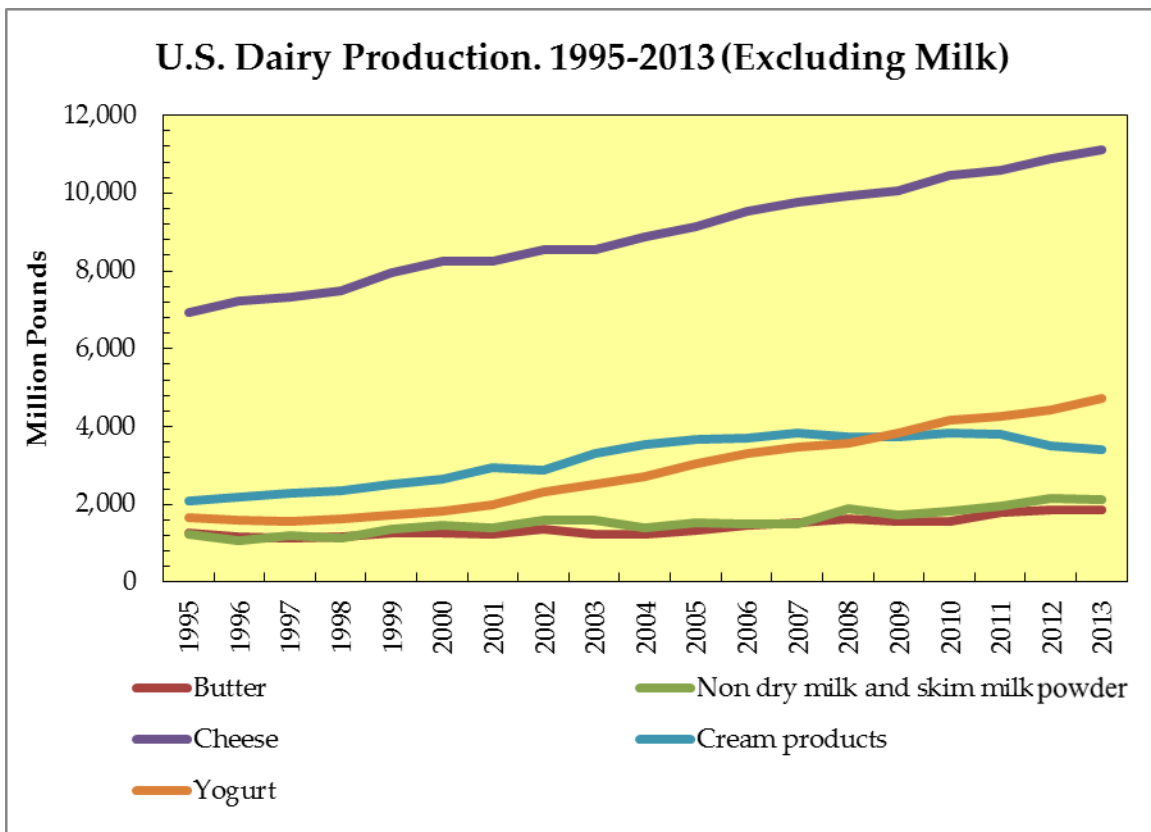
Figure 3: U.S. Dairy Production 1995-2013, by Product Type



Source: (USDA 2014a, 2014b)

Because the production number for fluid milk is so much greater than the other sub-sectors, Figure 4 shows the same data, but with fluid milk excluded.

Figure 4: U.S. Dairy Production, 1995-2013, by Product Type, excluding Beverage Milk



Source: (USDA 2014a, 2014b)

3.1.4 Energy Consuming Processes

Along with the increases in production that Xu and Flapper (2009) found, the energy use associated with milk production, increased at the rate of 5.7% per year during the period 1995 through 2005. However, the 2010 MECS estimates show a large decrease in natural gas use and a smaller reduction in electricity use compared to the 2006 survey. In the earlier survey, total energy was 120 TBtu, electricity was 10,257 GWh (35 TBtu), and natural gas was 83 TBtu. By far the largest change between these two surveys is the change in natural gas estimate for combined heat and power (CHP) and cogeneration, which has increased to 24 TBtu from the previous estimate of 1 TBtu. Accompanying this increase are decreases in process heating and conventional boiler use. The primary focus of this paper is electrical DR, so these changes in natural gas usage are less relevant, but they suggest that the industry is pursuing efficiency measures. Table 3 displays the MECS electrical energy consumption estimates for 2006 and 2010 by usage type.

Table 3: 2006-2010 Electrical Consumption in the Dairy Processing Industry, by End Use in TBtu

Year	2006	2010
TOTAL ENERGY CONSUMPTION	35	33
Indirect Uses-Boiler Fuel	1	1
Conventional Boiler Use	1	1
CHP and/or Cogeneration Process	0	--
Direct Uses-Total Process	27	25
Process Heating	2	1
Process Cooling and Refrigeration	11	12
Machine Drive	14	12
Electro-Chemical Processes	*	*
Other Process Use	1	*
Direct Uses-Total Non-process	7	6
Facility HVAC (g)	3	2
Facility Lighting	3	2
Other Facility Support	1	1
Onsite Transportation	*	*
Conventional Electricity Generation	--	--
Other Non-process Use	*	*
End Use Not Reported	*	1

Source: U.S. Department of Energy (EIA MECS, 2006 and 2010)

In addition to the MECS data, the U.S. Census Bureau's ASM (U.S. Census, 2011) disaggregates energy consumption by sub-sector. The annual estimates of purchased electricity from the ASM are presented in

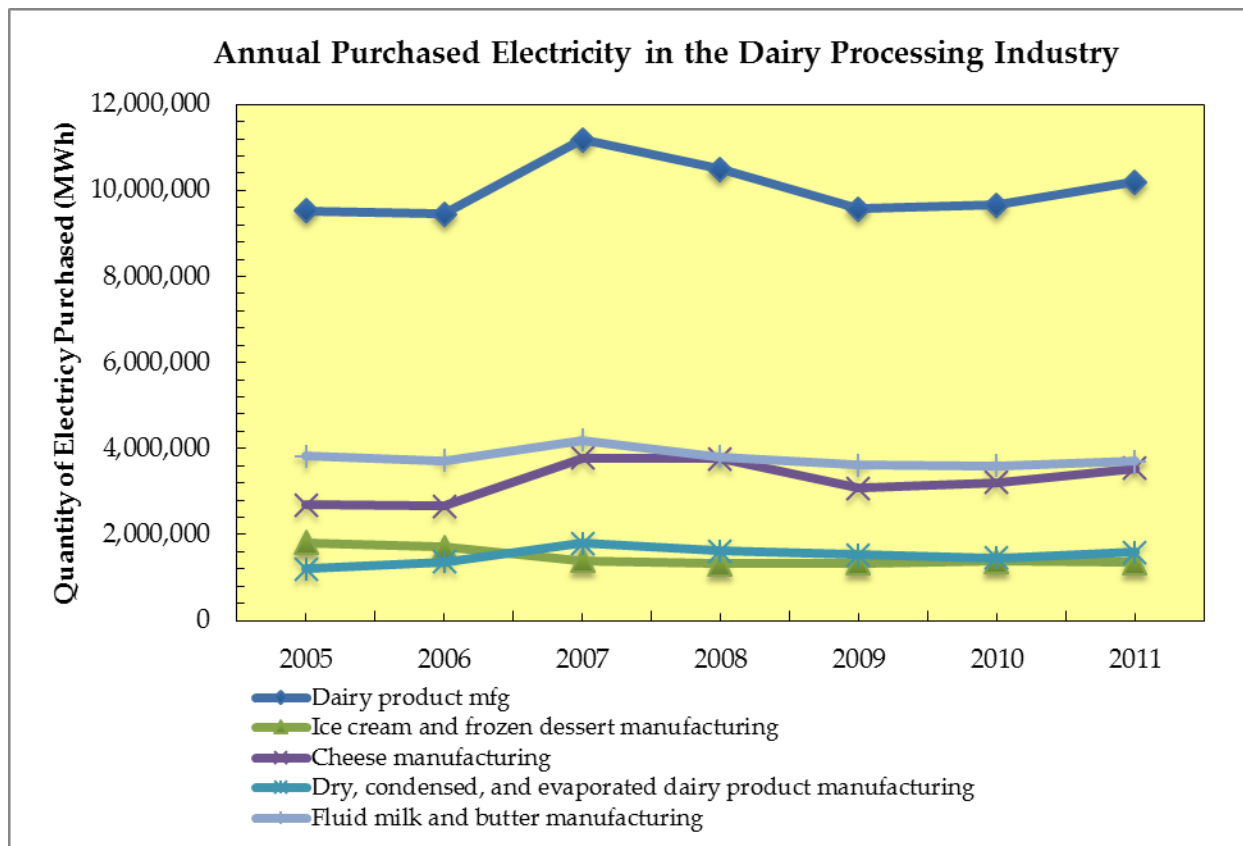
Figure 5. While there is certainly some year-to-year variation, there is no clear trend.

Xu et al. (2012) commented on the recent trends and in production and energy consumption. They concluded that even though there was an increased market share for specialty products (e.g., cheese, yogurt), which are more energy intensive than drinking milk, the fluid-milk sector overall has apparently prevented the sector average energy from increasing. This stability suggests improved energy efficiency in the sector:

“...it is clear that development and implementation of energy-saving strategies and programs in fluid-milk sector has contributed to reversing the trend of increasing energy demand per equivalent fluid-milk products” (Xu et al. 2012).

Energy efficiency measures have been well described in the existing literature (Brush et. al. 2011, Focus on Energy 2006) and interested persons are referred there.

Figure 5: Annual Purchased Electricity in the Dairy Processing Industry



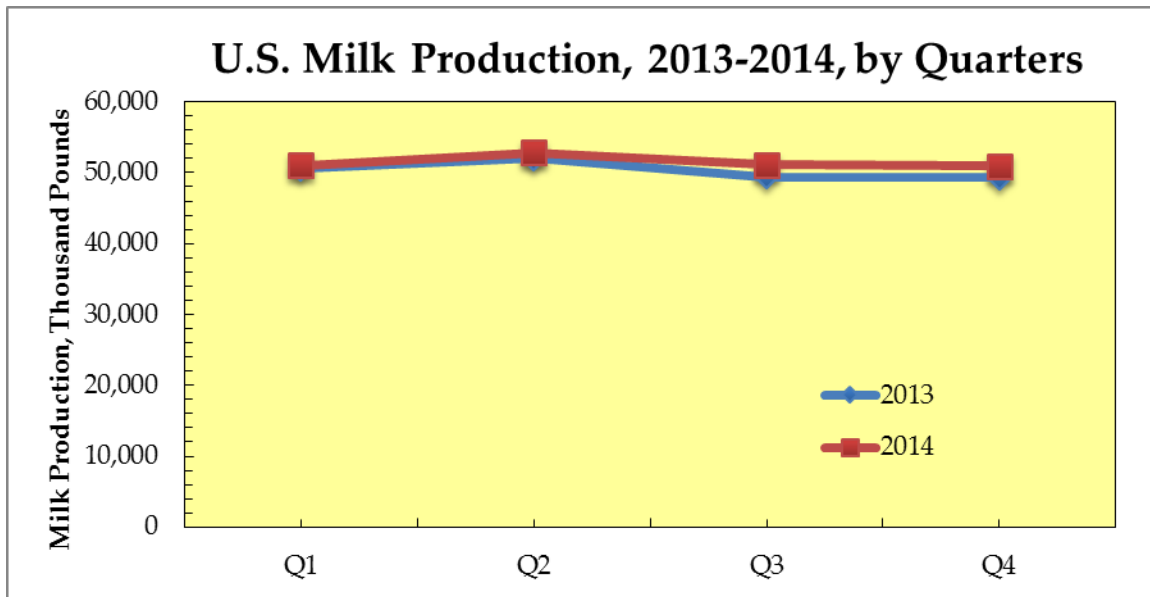
Source: ASM (U.S. Census, 2011)

3.2 Timing of Energy Consumption

Although there is natural seasonal variation in milk production in the U.S. due to cow lactation cycles, it is not highly seasonal. In particular, the European Union Milk Market Observatory (MMO, 2015) reviewed monthly raw milk production data for the U.S. They found that the seasonal variation in the United States was small. In all cases, peak production was in the late spring (May). In 2014 and adjusting for unequal length months, MMO found that the seasonal difference in U.S. peak raw milk production to be about 8% greater than the lowest month. The relatively small seasonal variation in milk production is likely due, at least in part, to the U.S. artificial insemination which causes cows to lactate year round (McCarty, 2015). U.S. Department of Agriculture (USDA, 2015) milk production estimates for 2013 and 2014 show that milk production is largely constant⁴. Figure 6 shows the USDA production estimates by quarter. Note that, to the extent that there is a production peak, it is not during the peak electrical use season. This can limit dairy industry's ability to participate in DR during peak summer months.

⁴ MMO's estimates for the U.S. were based on USDA data.

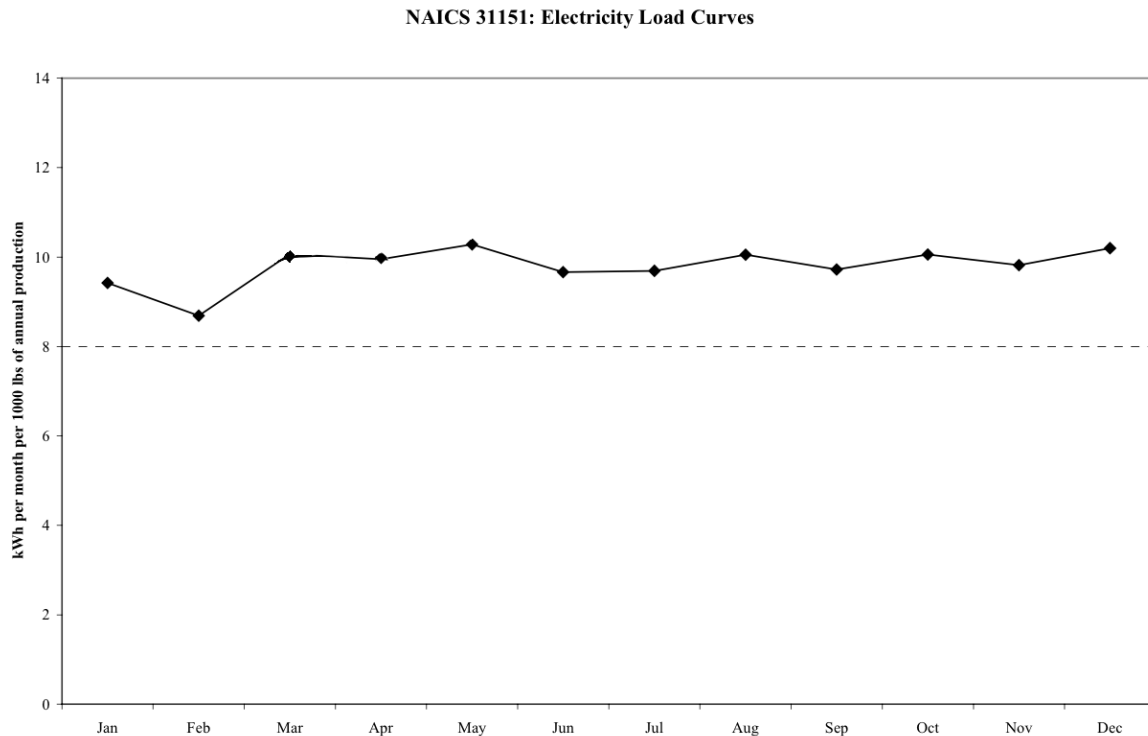
Figure 6: U.S. Milk Production, 2013-2014, by Calendar Quarters



Source: (USDA, 2015)

Because raw milk is processed shortly after harvesting and with the milk production curve being relatively flat, it is expected that the energy use would likewise show little seasonal variation. Unfortunately, the great majority of energy reports that were reviewed were energy total consumption or intensity, and there was little description of load or load shapes on a monthly basis. However, Sikirica et al. (2003) did estimate electricity load curves for the dairy processing activities in several U.S. states. Excluding “house loads,” such as HVAC and lighting, those curves are roughly flat. For California, the range appears to be about 8.25 to 10.1 kWh per month per 1000 lb. of annual production. As with the national milk production curve, to the extent that there is a peak in the load curve, it is somewhat non-coincident with the peak electrical season. The electricity load curve for California is reproduced in Figure 7.

Figure 7: Estimated Electrical Load for Dairy Processing Activities in California.



Source: Reproduced from (Sikirica et al. 2003); used with permission.

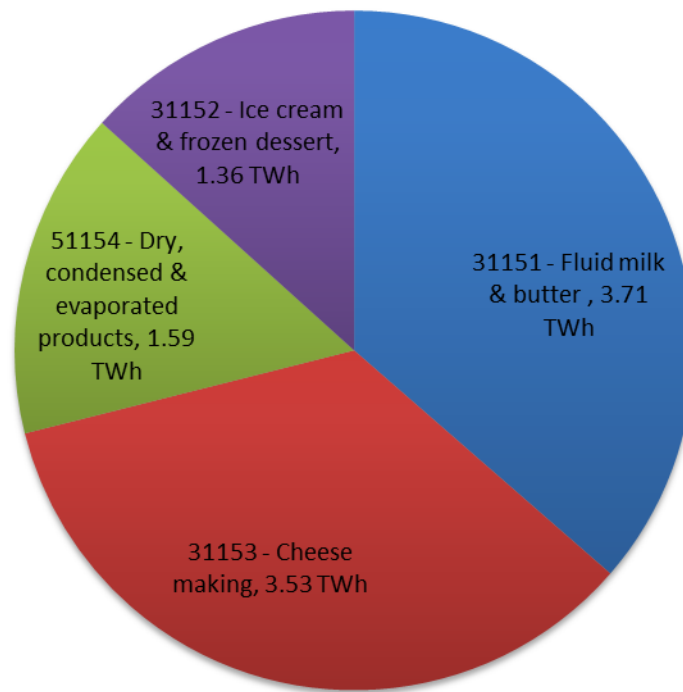
We were not able to find any quantitative information on daily load variation in the literature. Anecdotal evidence and consultation with industry experts indicate that most dairy processing plants run at or close to capacity on a continuous basis.

Taking Figures 6 and 7 into consideration, we can conclude that dairy production and product energy intensity are flat year-round. This will result in a flat annual load profile. However, daily load profiles for dairy processing facilities are still needed to help us understand the DR potential.

3.3 Significant Energy Using Processes and Equipment

The ASM (U.S. Census, 2011) reports energy use by product type (NAICS), unlike the MECS, which disaggregates total use by energy and equipment types. The most recent ASM (U.S. Census, 2010) estimates for electricity use in the dairy processing industry and its sub-sectors are presented in Figure 8. The total sector electricity estimate (10,190 GWh) is approximately the same as the 2010 MECS estimate (9,671 GWh). These values are generally consistent with those in Brush et al. (2011, Table 1.1), who had used 2008 ASM data.

Figure 8: Site Electricity Use (10.19 TWh Total) by NAICS Group, 2011



Source: (U.S. Census, 2010)

The largest electricity use is fluid milk plus butter, closely followed by cheese making, with dry/evaporative products and ice cream accounting for much smaller shares. Note that these values are only for electrical uses. When fuel consumption is included, the pattern is quite different. In particular, the energy use for dry production is a much larger share of the total.

Per the MECS, the largest share of electrical use in dairies is for two main uses: “machine drives” and “process cooling and refrigeration”. Machine drives are largely pumps, homogenizers, and centrifuges, but also include churns, presses, and conveyors. Process cooling occurs at several points in dairy processing, notably as part of the initial receiving, after pasteurization, drying and/or centrifuging, and for some value-added products including cheese and ice cream. For the purposes of assessing DR opportunities, combining process cooling and refrigeration into a single category causes difficulties, because the two are not equally amenable to interruption, reduction, or scheduling.

Sikirica et al. (2003) carried out a detailed process by product analysis. Their estimates are based on total production figures from ASM 2000 (55,496 million lbs.⁵ for the entire U.S., 6,436 million

⁵ Sikirica et al. (2003) do not include the “Ice Cream and Frozen Dessert” sub-sector, so this production estimate most likely does not include that sub-sector.

lbs. for California) and thus are not directly comparable to values from the current year⁶. In particular, the differential growth in sub-sectors already described requires careful consideration of these figures. Their electricity consumption estimates for the U.S. and for California by product are presented in Table 4.

Consistent with the current MECS and ASM values, fluid milk is estimated to have the largest electricity consumption, followed closely by cheese making. The fraction of electricity used for refrigeration varies widely by sector, but for most sectors is relatively small. Fluid milk is the only sector in which the energy used for refrigeration comes close to the sum of electricity consumed elsewhere. Overall, Sikirica et al.'s estimate is that 24% of the sector electricity is used for refrigeration. In the fluid milk sector, that proportion rises to 42%. Note that Sikirica et al. (2003) did not include the ice cream and frozen dessert sector, and it would be expected that refrigeration energy would be quite high in that sector. The overall fraction of electricity use estimated by Sikirica et al. is, however, largely consistent with the later estimate by Lung et al. (2006) of 25%.

Table 5 provides a further disaggregation of electricity use by sector, product, and process based on Sikirica et al.'s analysis. The following discusses electricity use in each sector.

3.3.1. Fluid Milk (311511)

The major electricity using activities in this sector, listed in order of decreasing energy use magnitude are: packaging, process cooling, and separation. Together, these account for 73% of sector electricity use. The large sector consumption is due in part to the greater product volume. Sikirica et al. (2003) attributed electrical intensities⁷ of 16 Wh/lb (55 Btu/lb), and 25 Wh/lb (84 Btu/lb) to packaging and process cooling, respectively.

⁶ We did not attempt to scale the consumption estimates to current production levels, because updating them would entail a review of the efficiency assumptions, which is beyond the scope of this report.

⁷ Sikirica et al. refer to these values as "energy requirements". They do not account for the coefficient of performance (COP) of refrigeration equipment as is done for their consumption values.

Table 4: U.S. and California Electricity use in the Dairy Sector by Product Type

Electricity Consumption (million Btu)		U.S.			California		
Sector	Product	Refrigeration	Other	Total	Refrigeration	Other	Total
NAICS 311511: Fluid Milk	Fluid Milk	3,783,339	5,116,269	8,899,607	438,763	593,346	1,032,108
	Cottage Cheese, Yogurt, Other	115,680	312,714	428,395	16,103	43,530	59,633
	Total	3,899,019	5,428,983	9,328,002	454,865	636,876	1,091,741
	% Refrigeration	41.80%	58.20%				
NAICS 311512: Butter	Butter	26,096	114,367	140,463	7,376	32,328	39,704
	Total	26,096	114,367	140,463	7,376	32,328	39,704
	% Refrigeration	18.58%	81.42%				
NAICS 311513: Cheese	Cheese	840,471	5,346,124	6,186,595	152,389	969,328	1,121,718
	Dry Whey	120,955	769,381	890,337	13,642	86,774	100,416
	Total	961,426	6,115,506	7,076,932	166,031	1,056,102	1,222,133
	% Refrigeration	13.59%	86.41%				
NAICS 311514: Evaporated and Condensed Milk	Evaporated and Condensed	0	391,717	391,717	0	121,226	121,226
	Dry Skim Powder	0	3,607,015	3,607,015	0	1,538,151	1,538,151
	Total	0	3,998,732	3,998,732	0	1,659,377	1,659,377
	% Refrigeration	0.00%	100.00%				
Total NAICS 31151: Dairy (except frozen)	Total	4,886,541	15,657,588	20,544,129	628,273	3,384,683	4,012,956
	% Refrigeration	23.79%	76.21%				

Source: Sikirica, et al., 2003

Table 5: U.S. and California Energy Electricity Use (Million Btu) by Product and Process

		U.S.		California	
	Energy Consumption (million Btu)	Refrigeration	Other	Refrigeration	Other

NAICS 311511: Fluid Milk					
	Final Storage	517,902	-	60,062	-
	Packaging	-	3,025,672	-	350,894
	Pre-Packaging Storage	260,712	-	30,235	-
	Deodorization	-	-	-	-
	Cooling	2,476,767	-	287,236	-
	Homogenization	-	575,681	-	66,763
	Pasteurization	-	-	-	-
	Separation	-	1,030,416	-	119,500
	Clarification/Standardization	-	484,500	-	56,189
	Receiving and Storage	527,958	-	61,228	-
	Total	3,783,338	5,116,269	438,763	593,346
Cottage cheese and Yogurt					
	Storage	9,143	-	1,273	-
	Packaging	-	2,482	-	345
	Creaming	-	5,273	-	734
	Drier	-	-	-	-
	Drawing, Washing, Cooling	-	6,549	-	912
	Cooker	-	-	-	-
	Settling	-	-	-	-
	Pasteurization, Cooling	2,540	-	354	-
	Separation	-	202,973	-	28,254
	Clarification/Standardization	-	95,438	-	13,285
	Receiving and Storage	103,998	-	14,477	-
	Total Cottage Cheese and Yogurt	115,680	312,714	16,103	43,530
	Total 311511	3,899,019	5,428,983	454,865	636,876
311512 Creamery Butter		0			
	Storage	11,885	-	3,359	-
	Packaging	-	20,123	-	5,688
	Churn	-	94,244	-	26,640
	Chilling	14,211	-	4,017	-
	Deodorizing	-	-	-	-
	Pasteurization	-	-	-	-
	Separation	-	-	-	-
	Total 311512	26,096	114,367	7,376	32,328
311513 Natural and Processed Cheese		0			
	Cooking, Pasteurizing	-	-	-	-
	Finishing vat	-	-	-	-
	Make Vat	-	-	-	-
	Starter Media	-	-	-	-
	Pasteurization	-	-	-	-
	Motors, Pumps	840,471	5,346,124	152,389	969,328
	Total	840,471	5,346,124	152,389	969,328
Dry Whey					
	Spray Drier	-	-	-	-
	Whey Evaporators	-	-	-	-
	Motors, Pumps	120,955	769,381	13,642	86,774
		U.S.		California	
	Energy Consumption (million Btu)	Refrigeration	Other	Refrigeration	Other
	Total Dry Whey	120,955	769,381	13,642	86,774
	Total 311513	961,426	6,115,505	166,031	1,056,102

311514 Canned Evaporative Milk					
	Sterilization	-	-	-	-
	Canning	-	104,807	-	32,435
	Homogenizing Pumps	-	26,202	-	8,109
	Concentration	-	52,404	-	16,218
	Pasteurization or Stabilization	-	-	-	-
	Clarification	-	208,304	-	64,465
	Total	-	391,717	-	121,226
Powdered Dry Milk					
	Evaporative Cooling	-	1,109,851	-	473,277
	Spray Drying	-	-	-	-
	Homogenizing Pumps	-	554,925	-	236,639
	Concentration	-	1,109,851	-	473,277
	Pasteurization or Stabilization	-	-	-	-
	Clarification	-	832,388	-	354,958
	Total Powdered Dry Milk	-	3,607,015	-	1,538,151
	Total 311514	0	3,998,732	-	1,659,377

Source: Sikirica, et al., 2003

3.3.2 Butter Making (311512)

Sikirica et al. (2003) estimated that about 67% of the electricity in this sector was used for churning, which had an electrical intensity of 74⁸ Btu/lb (22 Wh/lb). The next largest consuming processes were packaging (14%) and chilling (10%). Refrigerated storage accounted for about 8% of the sector electricity.

3.3.3 Cheese Making (311513)

The sector proportion of electricity dedicated to process motors and pumps was 75%; the remainder was pumps and motors for refrigeration, compressors, and air handlers. Both cheese making and dried whey were attributed identical energy per unit production: 193 Btu/lb (57 Wh/lb) for motor and pumps for refrigeration, and 647 Btu/lb (190 Wh/lb) for pumps and motors for non-refrigeration purposes.

3.3.4 Dried and Evaporative Products (311514)

As described by Sikirica et al. (2003), the major electricity using activities in this sector are, in order of size, evaporative cooling, concentration, and clarification for dried milk. In aggregate, these three activities account for 76% of the sector's estimated electricity use. These are all process activities, and there was no refrigeration consumption in the Sikirica et al. analysis. Production energy intensities of 31 Btu/lb (9 Wh/lb) were ascribed to cooling and concentration; clarification was 23 Btu/lb (7 Wh/lb). Although Sikirica et al. ascribes a large load to evaporative cooling for dried evaporative milk and Ramirez et al. (2006) includes such a step in his process description, there is no mention of this stage in other sources (Brush et al. 2011, Xu et al. 2012). We were not able to resolve the apparent divergence within the scope of this project.

⁸ Brush et al. (2011) report, based on Sikirica et al., that refrigeration for butter making has an electrical intensity of 175 Btu/lb. We are unable to verify how that value was derived from Sikirica et al.

There are two major limitations on the usefulness of the estimates derived from Sikirica et al. First, they do not include the “Ice Cream and Frozen Dessert” sub-sector in their analysis, even though this sector would be expected to have high cooling loads. Second, they do not explicitly breakout energy for Clean-in-Place. The latter is discussed in the following section.

3.3.5 Clean-in-Place

Clean-in-Place (CIP) is a potentially large user of energy in dairy processing, but it is largely not reported in a way that disaggregates it from processing energy. Ramirez et al. (2006) made estimates for CIP energy fractions in the fluid milk, butter, and cheese making sub-sectors of the European dairy industry. Those estimates are presented in Table 6.

Table 6: Energy Consumption Percentage for Clean-in-Place.

Product Type	Energy Consumption %
Fluid Milk	9.5%
Butter Making	26%
Cheese Making	19%

Source: Ramirez et. al. 2006

Based on Natural Resources Canada’s (2001) sample of 17 fluid-milk processing plants, 16 of the plants had a CIP energy intensity of 0.0001 kWh/L to 0.093 kWh/L. One plant did not disaggregate energy use to this level. The average CIP energy intensity was about 0.041 kWh/L, which is about 20% of the average total energy intensity (0.20 kWh/L). Because of the way the data are presented in that report⁹, however, it is not possible to discern what fraction of total energy use is related to CIP for each plant.

In addition to associated energy, CIP uses a considerable volume of water. Brush et al. (2011) reviewed previous research into water use in the dairy industry. They reported that the water use intensity for the dairy processing industry is about 2,400 to 4,800 gallons of wastewater per ton of product, and water consumption in California is about 5.5 billion gallons per year.

⁹ In the report’s charts, plants are simply numbered from 1 to 17 in order of the lowest to highest value for the metric presented (e.g., energy intensity, energy cost). Thus, there is no continuity in plant numbering between charts.

CHAPTER 4:

Energy Efficiency and Demand Response Opportunities

Although the energy use of the dairy processing industry is large overall, and there is considerable literature on the energy use and general energy efficiency within the dairy processing industry, DR opportunities in dairy processing have not been widely discussed in the literature. In particular, Wardrop Engineering (1994) prepared a guide on energy conservation and cost savings opportunities in the dairy processing industry for the National Dairy Council of Canada (Natural Resources Canada, 2001). Focus on Energy (2006), a Wisconsin-based Non-Governmental Organization (NGO), has produced a substantial list of industry energy efficiency “best practice” recommendations. Brush et al. (2011) wrote a guide for the ENERGY STAR program focused on energy and/or plant managers, which described the following general areas for improved energy efficiency: steam systems, motor and pump systems, refrigeration systems, compressed air systems, building facilities, self-generation, pasteurization processes, evaporation processes, and drying processes. They estimated that these categories collectively account for over 90% of the energy used in the dairy processing industry. In aggregate, these documents recommended roughly 100 energy efficiency measures.

None of these documents emphasized DR, load shifting, or scheduled load shedding as likely measures in the dairy industry. Brush et al. discussed one implementation of DR in a more general discussion of monitoring and control systems (pg. 42), but despite the stated focus of the paper on the dairy industry, the example given is a juice processing plant. Focus on Energy made two specific recommendations regarding load shedding, but neither is specific to dairy processing activities.

CEATI International (2010), in conjunction with Manitoba Hydro and the Ontario Power Authority, produced a 122 page user’s guide to DR. They addressed dairies as agricultural facilities (i.e., dairy farms) and food processing plants (but not dairy processing specifically). However, the guide’s format is more of an industry white paper rather than a peer-reviewed publication with citations. When we requested citations, they responded that no sources were available.

Because of the relative paucity of information found in the published literature regarding DR potential, we consulted several people who are involved in dairy processing at several levels to solicit their feedback: (1) the manager of a farm with integrated processing plant, (2) a former plant manager and trainer for industry members, (3) the managers of an implementation company, and (4) an academic specializing in the dairy industry. All were uniformly pessimistic about the potential for load shifting or shedding in those processes characteristic of the dairy processing industry.

The most important reasons they provided include:

- Perishability of milk is a major concern.

- Plants tend to run continuously and tend to have little excess capacity.
- Plants do not have large storage capacity relative to incoming shipments, so reducing flow rates is problematic.
- There are relatively few points at which existing plants have intermediate storage capacity (i.e., between processing steps).
- The need to comply with a complex regulatory regime.
- If processes are interrupted, there is a need to clean, which poses a risk of dilution or loss of product and may introduce additional energy use,
- There is a need to maintain presence of fluid in equipment (e.g., pasteurizer), if production is halted, which may also introduce extra energy use, and risks of dilution or product loss.

Similarly, in reporting on a successful implementation of an automatic control program, Southern California Edison noted: “Given that the dairy industry operates 24/7, Wyant [California Dairies, Inc.] said it’s a challenge to shed load during high-peak periods through DR programs, which makes energy efficiency even more important” (SCE, 2010).

Dried products such as powdered milk or dry whey have very high total energy use and were described as the easiest to interrupt (Patel, 2015). However, because most drying is fueled by natural gas, these are also the processes that use the least electricity.

Aside from the specific processing activities, dairy processing plants also have energy-using functions that are more generic and resemble other types of buildings. Many of these have higher coincident peak usage than the processing functions and may be amenable to DR strategies familiar from other kinds of facilities. These include:

- Facility Lighting
- Facility HVAC
- Refrigerated storage
- Wastewater management

4.1 Load Shedding

Load shedding is a strategy that typically involves turning off non-essential electrical equipment, running essential equipment at lower rates, or powering essential equipment via onsite distributed generation. The following describes specific opportunities related to load shedding.

4.1.1 Pumps

Pumps are used in many dairy-processing activities to move the fluid milk or cream through the processing system. Facilities may be able to use Variable Frequency Drives (VFD) to operate pumps at lower capacity, which in turn will better match operational requirements and reduce demand within regulatory limits. VFDs are typically controlled through a Programmable Logic

Controller (PLC) which offers the ability to integrate DR strategies into the overall controller algorithm.

4.1.2 Facility Lighting

Lighting systems can be operated to reduce facility energy use and overall energy demand by lowering lighting levels or turning off lighting systems that are not critical to plant operations. There are regulatory limits regarding facility illumination in the processing areas of dairy facilities that would limit the flexibility of dairy processing plants in this regard. Lekov et al. (2009a) reported that warehouse spaces could reduce lighting loads between 50% and 100% and that the office spaces connected with warehouse facilities could achieve 20% reductions. These estimates are likely generally applicable to the non-processing sections of dairy plants.

4.1.3 Facility HVAC

Heating, ventilating and air conditioning system loads can be reduced during DR events by turning systems off and allowing indoor air temperatures to fluctuate, or by raising temperature set points (e.g., in office spaces).

4.1.4 On-site generation

4.1.4.1 *Backup Power*

Many, if not most, dairy processing facilities have on-site backup generation capability, which allows the building's load to be shifted off the local grid (CEATI International, 2010). One of our industry consultants (McCarty, 2015) stated that all large processing plants would have backup power and that in his view "it's a poor dairyman" who lacks this capability. The ability to run on backup power can make dairy plants appear as good candidates for DR programs.

Switching to backup generation can usually be done quickly without interruptions to service, and where it is possible, taking entire plants off line could result in substantial peak load reductions. However, there are several limitations to the potential of this approach. Where backup generation consists of diesel-fueled generators, as is typical, local air-quality regulations and Environmental Protection Agency (EPA) rules may limit this strategy. Another potential limitation is purchasing agreements with utilities that might limit which facilities could go entirely onto backup power. Lastly, while running on backup power could be helpful for system peak load management, it is unlikely to save energy overall; at the margin, the grid already will be running fairly efficient natural gas generators.

4.1.4.2 *Solar Power*

Anderson and Duke (2007) examined the potential for solar power use in the dairy processing industry in New Zealand. They concluded that the potential was high, in that the best solar systems were able to meet a significant fraction of a facility's water heating and cooling loads, and can even meet the entire heating load during cool months. They do note that their opinion is that New Zealand is an ideal location for using solar energy. California has a tremendous supply of renewable resources including solar. California's dairy processing industry can greatly benefit from a combination of on-site solar photovoltaic and solar thermal technologies for the purposes of generating electricity and heat. More investigation is needed.

4.1.4.3 Cogeneration

Brush et al. (2011) noted that use of on-site electricity generation appeared to be 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, 2009), accounting for only 1% of natural gas consumed (EIA MECS, 2006). Similarly, Sun et al. (2011) reported that 94% of dairy processing energy is purchased, leaving a small remainder to be met through co-generation. The most recent instances of the ASM (U.S. Census, 2010) indicate that the value was too small to report. However, MECS (EIA MECS, 2010) estimated "CHP and cogeneration" at 24 TBtu, which is a major increase from the 1 TBtu reported in their previous survey. This information suggests that cogeneration units at dairy processing facilities are being operated below their rated capacity; therefore, a temporary increase in generation, and lowering the plant's demand from the grid can increase the facility's DR potential. This, along with the presumably associated reductions in boiler fuel and process heating, is the largest change in the current MECS energy estimates for the dairy processing industry. Together with other changes in energy use patterns, these changes suggest that the dairy industry is working to implement energy efficiency measures. How much impact this can have on peak load is not known at present.

CADDET (1996) reported on a cogeneration system retrofit at one of the largest milk processing plants in New York: Honeywell Farms Dairy. The most important measures were implementing: (1) waste energy recovery using absorption refrigeration for sub-cooling and (2) exhaust heat recovery for steam generation. Overall, the plant COP improved 6% at all loads and electrical demand was reduced more than 50%. Note that the brief report for CADDET does not indicate that the savings were specifically on-peak or otherwise.

4.2 Load Shifting

Load shifting strategies involve rescheduling energy-intensive processes to off-peak times in place of shedding the load. In particular, when advance notice of a DR event is available, it may be possible that some processing operations could be scheduled before the event or delayed until after the peak. As already noted, however, the main activities in the dairy product processes are reported to be relatively constrained and not ideal candidates for load shifting. Examples in dairy processing that could be delayed without affecting product quality (CEATI International, 2010) include the labeling of milk bottles or the cutting and packaging of cheese. Batch pasteurization could in some instances be shifted without harming the product. Not all plants will have such flexibility.

In addition, most dairy processing plants include refrigerated storage spaces that would be expected to act much as a refrigerated warehouse. Lekov et al. (2009a) identified cold storage pre-cooling, shifting battery charger loads, and disabling electric defrost as likely DR strategies for these kinds of spaces. Also, dairy processing produces considerable wastewater, mostly from CIP activity. Some facilities pre-treat their wastewater onsite before discharging it. Wastewater is an area previously researched by the DRRC. Lastly, dairy processing plants include generic building functions such as lighting and HVAC, which can be amenable to DR strategies. The following describes these opportunities in further detail.

4.2.1 Pre-Cooling

Dairy processing facilities that include cold storage space can shift load and reduce peak demands by pre-cooling these areas to a lower temperature prior to a DR event, and then allowing the temperature to rise naturally (CEATI International, 2010). Because the temperature will rise during the event, these spaces will need to be monitored to ensure that product quality does not suffer. Another possible way to reduce demand on the refrigeration system is for a facility to keep cold products on ice during a DR event.

4.2.2 Shutting Off Refrigeration and Freezers

Cold-storage areas used for cheeses, ice cream, and other value-added products may be particularly good candidates for DR. Even when the refrigeration to these areas is shut off, the insulation of the space and the thermal mass of the product itself reduces thawing or temperature creep. Monitoring equipment is required to ensure that temperatures remain within regulatory requirements, and food processors must be prepared to end curtailment if product temperatures rise too rapidly.

CEATI International (2010) reported that a dairy participating in an auto DR program achieved an 80 percent load reduction in their cheese production line for 2-hour events. The main DR measure was turning off compressors and allowing temperatures to “float” in the cold storage section of the operation without affecting product quality. A demand curtailment of 160 kWh was reported (average of 80 kW over the 2 hour period).

4.2.3 Thermal Storage

Thermal storage, cold water, or ice slurry systems, while not common in the dairy industry, have the potential to shift electric load to off-peak hours, reduce peak loads on the power system, and lower energy charges during the cooling period. These systems could be options for either new construction or when plants are retrofitted. Thermal storage is a method of storing energy for cooling to be used at a later time. This can be done by chilling water or creating ice and storing it in an insulated container. There are several approaches to using thermal storage. The refrigeration system can be run at a steady rate with the storage system used to store cooling energy at times when demand is lower than production. This allows the refrigeration system to run closer to its optimum efficiency. Another method is to run the refrigeration system primarily (or only) during the low energy cost off-peak hours and use the stored energy during peak load times. Grozdek (2009) presented modeled and experimental data for a mixed dairy and cheese processing plant. He concluded that the thermal storage system achieved a 20% energy cost reduction compared to a non-storage system. Gadis (1997) reported on the use of this method in a cheese making plant to reduce production costs. In both cases, the reported cost savings were attributed to lower off peak pricing. We did not find any discussion of thermal storage applied to process cooling, but it could be helpful for process cooling (i.e., cooling liquid milk after pasteurization).

4.2.4 Improve Defrost Control Strategy

Defrosting can be scheduled for off-peak times, so that facilities that employ electrical defrost can shut that equipment down during peak events. In general, defrosting should be done as

needed rather than simply by schedule. This strategy may involve working within an energy management plan to gather data on the time required for ice to build up. It can have wider efficiency implications, because defrosting before ice forms on the coils can impair the energy efficiency of the system. Other defrost control improvements could include reviewing whether using a hot gas defrost method is necessary, reducing the hot gas defrost pressure so that it is as low as possible, and if the temperature of the refrigerated base is above 38°F to 40°F, allowing ice to melt using ambient air (Focus on Energy, 2006).

4.2.5 Battery Charging

Battery charging for forklifts and pallet lifts is an energy intensive process and can contribute to peak power usage when the charging is done during the peak time. Therefore, whenever possible, charging should be done during off-peak periods (Focus on Energy, 2006). Also, because of the energy intensity of this process, it could add significant heating loads to a refrigeration system if the charging is done in that facility and should be kept separate from refrigerated or conditioned spaces.

4.2.6 Control Systems

Control systems have been used in the dairy processing industry for years (US-AEP, 2002). Industry members that we consulted generally agreed. However, with rapid technological progress, there is variation on how up to date organizations or specific plants might be. Even where savings are not strongly related to peak demand, Auto-DR and control system automation can lead to significant energy savings. For example, California Dairies installed an Auto-DR system in their Visalia and Artesia facilities in partnership with SCE and EPS Corp. As reported, the system did not primarily function to automatically reduce peak demand. Instead, using information from the control system, a number of efficiency measures were developed, including: (1) staggered boiler startup, which resulted in 2.5% reduction in natural gas use; and more efficient operation of: (2) boilers (3% reduction in natural gas, 58% in electricity); (3) compressed air (55% reduction in electrical use); and (4) refrigeration (25% reduction in electricity). The associated load shed was 3.3 MW. Annual *electrical* energy savings for the project were estimated at 2.8 GWh, or an average of 320 kW **Invalid source specified..** The plant also was projected to save nearly 23 GWh of *total* energy and to reduce carbon dioxide emissions by 10,400 metric tons *over a three year period* (SCE, 2010).

4.2.6 Wastewater:

There are two major sources of wastewater in dairy processing plants. The larger of these originates in the start-up and shut-down operations of the high-temperature, short-time (HTST) pasteurization process. This waste is a mixture of milk mixed with water. The other source of wastewater comes from CIP related to equipment and tank cleaning, which is comprised of milk along with cleaning solutions or detergents. Over time, milk waste degrades to form corrosive lactic and formic acids. DR strategies for wastewater processing are described in previous LBNL reports and may be applicable to these wastewater streams (Lekov et al. 2009a).

More specifically, the primary options available to dairy processors for wastewater management are discharge to a sewer, if they are in an urban area, or reusing the wastewater

for irrigation onsite (Kennedy, Jenks Consultants, 2010). In both cases, wastewater needs to be pumped, pre-treated, and then discharged or reused. Wastewater pumping and treatment are energy intensive processes and therefore could be a good candidate for DR.

Wastewater treatment in the dairy processing industry, similar to municipal wastewater treatment, uses processes such as effluent solids removal, anaerobic digestion, and pH and toxins control. Previous LBNL studies (as listed below) have identified load shed and shift strategies for wastewater treatment. In particular, loads can be shed or shifted through: 1) lowering the throughput of aerator blowers, pumps, and other equipment (e.g., centrifuges); 2) temporarily transitioning to onsite power generators when it is available; 3) over-oxygenation of wastewater in anticipation of aeration blower shutdown; and 4) storing wastewater for processing during off-peak periods. The largest load reductions can be achieved by targeting effluent pumps and centrifuges.¹⁰

4.2.7 Integration with other sectors:

Dairy processing plants receive inputs from agricultural sites and ship finished products to market or secondary processors (e.g., fluid or concentrated milk shipped to a cultured products plant). The details of these connections can have noticeable impacts on energy and resource usage. As an example, McCarty Family Farms described achieving savings in water usage by changing their transportation carrier. The new carrier used lighter trailers, allowing a greater payload (given limits on total weight of the vehicle). Moreover, the new carrier achieved more rapid turnaround allowing one CIP cycle to be eliminated. Water use savings were estimated to be 1.5 acre feet per year (and of course associated energy). Sun et al. (2011) reported on farm-to-cheese-processing energy use, comparing standard practice (cold transport of milk from farm to processing with plant HTST) to several scenarios involving on-farm concentration or pasteurization, and concluded that significant energy savings were possible. In particular, the scenario with on farm pasteurization plus concentration with aseptic milk transportation at 88°F was estimated to save 33% of total energy costs. In many instances, however, measures of this sort will involve multiple businesses and implementation may be difficult.

4.2.8 Emerging Technologies:

There are several emerging technologies that have been researched and have the potential to impact energy use in the dairy processing industry. The most important are alternatives to heat pasteurization. One is UV pasteurization, which is under review for FDA approval. Others include pulsed electrical field pasteurization (Brush et al. 2011) and high hydrostatic pressure pasteurization (San Martin et al. 2002). None of these technologies are presently approved for use in dairy processing, although some are being used in other food producing areas, most

¹⁰ For further information regarding wastewater Auto-DR potential, please refer to the following six LBNL reports: 1) Aghajanzadeh et. al. 2015, 2).Thompson et al. 2008, 3) Lekov et al. 2009a 4) Thompson et al. 2010, 5) Goli et al. 2011, 6) Olsen et al. 2012.

often as an adjunct. These alternatives may be less energy intensive overall, because they depend less on heating, which will directly reduce fuel energy, but may also indirectly reduce the need for cooling energy. They are purported to have other benefits, such as less sensory impact than with heat treatments.

CHAPTER 5:

Case Studies

Our literature and web search resulted in a limited number of DR case studies in the dairy processing industry. This section discusses successful DR and Auto-DR implementation at two dairy processing facilities. Both of these case studies highlight the feasibility and the large load shed potential at dairy processing facilities. More case studies and information are required to evaluate the impact of DR events on normal operations and the final product quality.

5.1 California Dairies Inc.

California Dairies, Inc. (CDI) produces 18 billion pounds of milk products annually for commercial and consumer use. As one of the nation's largest suppliers of butter, CDI supplies all sectors of the butter market including consumer retail, food service, private label, and food manufacturing. CDI also produces dry milk powders and other items including cheese, condensed products, fluid milk, and specialty dairy products. CDI's products are available in all 50 United States and in more than 50 foreign countries (CDI, 2015).

Because the plants at cities of Visalia and Tipton are located at the end of a long electricity distribution line, CDI often experiences voltage sag and production losses **Invalid source specified..** This problem has resulted in a series of distributed generation, energy efficiency, and Auto-DR projects at both facilities.

Successful Auto-DR implementation at the Visalia plant resulted in a load shed of 3.3 MW. CDI installed the system under SCE's Auto-DR program, which at the time provided incentives of up to \$300 per kW saved. The initiative focused on CDI's powdered milk and butter production lines, including evaporators, separators, and dryers. It also covered supporting systems, including compressed air, refrigeration, and wastewater treatment. The Auto-DR system allowed CDI to control key production systems, reduce electrical use when possible, and better manage energy consumption during regular production (CDI, 2011).

5.2 Cabot Creamery

Cabot Creamery Cooperative has operated continuously in Vermont since 1919 and makes a full line of cheese, yogurt, sour cream, cottage cheese, and butter. Cabot Creamery deployed EnerNOC's DemandSMART comprehensive DR application to reduce energy usage during times of peak demand.

During an emergency DR event in August 2007, Cabot Creamery shut down large refrigeration, ice-making machinery, and key manufacturing areas such as batch pasteurization for 2.5 hours. Through this DR event, Cabot Creamery shed 1 MW of electricity, which exceeded estimates of 750 kW. Cabot Creamery receives estimated annual payments of \$20,000 from EnerNOC for their participation in the DR program (EnerNOC, Inc., 2008).

CHAPTER 6:

Conclusions and Future Research

Although the aggregate energy consumption for the dairy processing industry is considerable, based on the present state of knowledge and barriers identified, it appears that the prospects for effectively implementing DR measures in this sector are somewhat limited. Not only does the limited information regarding load suggest that the industry does not contribute greatly to peak system load, the large fraction of the energy used occurs in processes that are relatively constrained and not amenable to DR strategies. As a result, the industry as a whole may be one that is more suited to continue to adopt the standard “set and forget” energy efficiency measures than the more challenging offerings for DR programs that require more sophisticated technology. More work with this industry is needed by DR providers to enhance the understanding and training needed to promote demand response.

Many or most dairy processing facilities have backup power and can run off-grid, so facility-level load shed and shifting could be highly available on short notice for reliability. This strategy could be beneficial under cases of heavy grid congestion. In particular, it would remove the entire load of any participating plants and has the potential for large peak savings. However, it is currently not considered a recommended strategy for DR and may not be approved under local and federal rules, and also has the potential to increase air pollution, and is unlikely to save energy overall.

Beyond that, dairy processing plants include considerable refrigeration use and cold storage. These aspects present opportunities for load shifting, and the generic strategies that apply to most buildings such as curtailing HVAC and lighting also apply. There is opportunity here for some short term DR strategies as highlighted in one of the case studies.

A limitation of this study is that we attempted to address the entire dairy processing sector, but for future work, it may be more illuminating to look at the sub-sectors individually. In particular, the cheese-making sub-sector is recommended, because of its relatively large energy use, and the high proportion of refrigeration energy use. The ice cream and frozen dessert sub-sector was omitted from some previous studies and also may be a good area for further investigation.

Another goal for future work should be to obtain more granular data, particularly load data. The standard data sets (e.g., MECS) describe energy use primarily by sector, and occasionally by end uses. Energy by product is disaggregated by process. For example, the magnitude of energy used for refrigeration in the cheese making sub-sector is not commonly known and is scattered over several reports. The energy use specific to particular equipment types within processes is even less available. Xu and Flapper (2009) put it this way:

“... gathering energy information and establishing a performance baseline about the fluid-milk processes and their supporting systems is the foundation to quantitatively compare performance across plants, processes, and to track a plant’s own performance overtime.

There is a need to obtain actual energy and production data on the level of individual process steps as well as on the plant level ...”

In this regard, Xu et al. (2012) anticipated that the users of the BEST-Dairy tool would contribute data, which could improve the understanding of energy and water usage in individual dairy plants, and help to develop benchmarks. However, consultation with program staff indicated that, although the BEST tool is being downloaded and used in the industry, the hope that it would lead to publicly-available benchmarking of energy consumption, load, or water usage largely has not been realized (Ke, 2015).

Other possible topics for further research include:

- Detailed study on the population of dairy processing plants in California, their energy consumption, energy demand, and timing of energy demand, including site surveys.
- What is the level of process automation in existing plants?
- Explore the level of sensors and control systems in place, and the feasibility, if low, of improving them.
- What is the current market penetration of continuous versus batch pasteurization?
- How many dairy processing facilities actually have storage capability sufficient to allow process shifting while meeting PMO (plus state and local) regulations?
- Are there any feasible cost-effective measures that would increase the ability of dairy processing plants to temporarily reduce flow for DR?
- What are the barriers to thermal storage systems and in what aspects of dairy processing might it be profitably implemented?
- Study to understand the prevalence of cogeneration and its relationship to DR potential. Would cogeneration/CHP increase DR potential or limit flexibility by linking processes?
- What is the actual ability of plants to schedulable self-generation, with regard to air quality regulation and utility contracts?

REFERENCES

- Aghajanzadeh, A., Wray, C., & McKane, A. (2015). *Opportunities for Automated Demand Response in California Wastewater Treatment Facilities* (Draft Report). Berkeley: Lawrence Berkeley National Laboratory.
- Anderson, T. N., & Duke, M. (2007). *Solar Energy Use for Energy Savings in Dairy Processing Plants*. IPENZ engineering treNz 2008-001.
- Brush, A., Masanet, E., & Worrell, E. (2011). *Energy Efficiency Improvement and Cost Saving for the Dairy Processing Industry*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL 6261E.
- CADDET. (1996). *Retrofit Cogeneration System at Milk Processing Plant, Result 257*. Sittard, The Netherlands: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies.
- CDI. (2011, January 26). *Dairy Cuts 3.3 MW with Free Demand Response*. <http://www.environmentalleader.com/2011/01/26/dairy-cuts-3-3-mw-with-free-demand-response/> Accessed 4/5/2015
- CDI. (2015). *California Dairies Inc*. <http://www.californiadairies.com/about> Accessed 3/8/2015
- CEATI International. (2010). *DR for Small to Midsize Business Customers*. http://www.ceati.com/freepublications/7047_Guide_Web.pdf Accessed 1/13/2015
- CMAB. (2008). *Real California Cheese Facts*. Retrieved from California Milk Advisory Board: http://www.californiadairyroom.com/Press_Kit/Dairy_Industry_Facts
- Dairy Farming Today. (2015). *The U.S. Dairy Industry Fact Sheet*. <http://www.dairyfarmingtoday.org/SiteCollectionDocuments/economicfactsheet.pdf> Accessed 1/13/2015
- Dairy Plants USA. (2015). <http://directoryupdate.bnpmedia.com/ibg/index.cfm?pid=491&lid=656&prodcode=00110> Accessed 3/6/2015
- EIA. (2006). United States Department of Energy. Retrieved from Manufacturing Consumption of Energy, 2006 Data Tables: <http://www.eia.gov/consumption/manufacturing/data/2006/> Accessed 2/10/2015
- EIA. (2010a). 2005 Energy Consumption by Manufacturers – *Data Tables in Manufacturing Energy Consumption Survey*. Retrieved from Washington, DC: Energy Information Agency: <http://www.eia.doe.gov/emeu/mecs>
- EIA. (2010b). United States Department of Energy. Retrieved from Manufacturing Consumption of Energy, 2010 Data Tables: <http://www.eia.gov/consumption/manufacturing/data/2010/> Accessed 2/10/2015

EIA MECS. (2006). Manufacturing Energy Consumption Survey (MECS). Retrieved from Washington, DC: Energy Information Agency: <http://www.eia.gov/consumption/manufacturing/> Accessed 2/10/2015

EIA MECS. (2010). Manufacturing Energy Consumption Survey. Retrieved from Washington, DC: Energy Information Agency: <http://www.eia.gov/consumption/manufacturing/> Accessed 2/10/2015

EnerNOC, Inc. (2008). Cabot Creamery makes DemandSMART a critical part of its environmental stewardship. https://www.portlandgeneral.com/business/medium_large/products_services/docs/agriculture.pdf Accessed 4/6/2015

EPS Corp. (2011, January 25). *EPS Corp Helps California Dairies, Inc. Shed 3.3 MW of Energy Use*. <http://www.epsway.com/news/press-releases/eps-corp-helps-california-dairies-inc-shed-3-3-mw-of-energy-use/> Accessed 4/1/2015

FDA. (2011). *Grade "A" Pasteurized Milk Ordinance, 2011 Revision*. Retrieved from United States Food and Drug Administration: <http://www.fda.gov/downloads/Food/GuidanceRegulation/UCM291757.pdf> Accessed 1/13/2015

FDA. (2015). *Interstate Milk Shippers List*. Retrieved from United States Food and Drug Administration: <http://www.fda.gov/Food/GuidanceRegulation/FederalStateFoodPrograms/ucm2007965.htm>

Flapper, J. (2009). *Environmental Impact Analysis and Benchmarking in the Dairy Processing Industry*. EES 2009-81M. IVEM. The Netherlands: University of Groningen, Groningen.

Focus on Energy. (2006). *Dairy Processing Industry Energy Best Guidebook*. Wisconsin.

GEA Westfalia. (2010). <http://www.westfalia-separator.com.sg/v2/uploads/pics/westfalia-separator-prolong.jpg> Accessed 4/2/2015

Gladis, S. (1997). *Ice Slurry Thermal Energy Storage For Cheese Process Cooling*. ASHRAE Transactions, Volume 103, Part 2.

Goli, S., McKane, A., Olsen, D. (2011). *Demand Response Opportunities in Industrial Refrigerated Warehouses in California*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-4873E.

Goli, S., Olsen, D., McKane, A., & Piette, M. A. (2011). *2008-2010 Research Summary: Analysis of Demand Response Opportunities in California Industry*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-5680.

Grozdek, M. (2009). Load Shifting and Storage of Cooling Energy through Ice Bank or Ice Slurry Systems: Modeling and Experimental Analysis. Doctoral Thesis, Division of Applied Thermodynamics and Refrigeration. Stockholm, Sweden: Department of Energy Technology, Royal Institute of Technology <http://www.diva-ortal.org/smash/get/diva2:236431/FULLTEXT02>.

- IDF. (2013, February). *The Economic Importance of Dairying, IDF Factsheet*. Retrieved from International Dairy Federation: http://www.idf-germany.com/fileadmin/user_upload/idf-germany/download/14-IDF-Factsheet-The-economic-importance-of-dairying.pdf.
- Ke, J. (2015). Personal Communication. Lawrence Berkeley National Laboratory.
- Kennedy, Jenks Consultants. (2010). *Energy Use in Wastewater Treatment in the Food and Beverage Industry*. San Francisco: Pacific Gas & Electric Company.
- Lekov, A., Thompson, L., McKane, A., Song, K., & Piette, M. A. (2009a). *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase I Report*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-2572E.
- Lekov, A., Thompson, L., McKane, A., Rockoff, A., & Piette, M. A. (2009b). *Opportunities for Energy Efficiency and Automated Demand Responses in Industrial Refrigerated Warehouses in California*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-1991E.
- Lung, R., Masanet, E., & McKane, A. (2006). *The Role of Emerging Technologies in Improving Energy Efficiency: Examples from the Food Processing Industry*. Industrial Energy Technology Conference. New Orleans, LA: ESL-IE-06-05-28.
- Mane, S. R. (2013). *Energy Management in a Dairy Industry*. IRAJ International Conference, 10th ISBN 978-93-82702-25-2. Pune, India: MTech, Energy Science & Engineering, ITBombay, Mumbai.
- McCarty, K. (2015). Personal Communication. McCarty Family Farms.
- Metz, C. (2015). Personal Communication. EnSave.
- MMO. (2015, January 16). *Raw Milk Productions of New Zealand, Australia and USA*. Retrieved from Milk Market Observatory: http://ec.europa.eu/agriculture/milk-market-observatory/pdf/world-raw-milk-production-us-nz-au_en.pdf. Accessed 1/13/2015
- Natural Resources Canada. (2001). *Energy Performance Indicator Report: Fluid Milk Plants*. National Dairy Council of Canada.
- Olsen, D., Goli, S., Faulkner, D., & McKane, A. (2012). *Opportunities for Automated Demand Response in Wastewater Treatment Facilities in California - Southeast Water Pollution Control Plant Case Study*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-6056E.
- Aghajanzadeh, A., Schetrit, O., Olsen, D., & Lanzisera, S. (2014). *Low-Cost, Scalable, Fast Demand Response for Municipal Wastewater and Recycling Facilities (Draft Report)*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-Draft
- Patel, H. (2015). Personal Communication. South Dakota State University.
- Ramirez, C. A., Patel, M., & Blok, K. (2006). *From Fluid Milk to Milk Powder: Energy Use and Energy Efficiency in the European Dairy Industry*. Energy 31(12), 1984-2004.

- San Martin, M. F., Barbosa-Canovas, G. V., & Swanson, B. G. (2002). *Food Processing by High Hydrostatic Pressure*. *Critical Reviews in Food Science and Nutrition*, 42(6): 627-645.
- Sandu, C., & Singh, R. K. (1991). *Energy increase in operation and cleaning due to heat exchanger fouling in milk pasteurization*. *Food Technology*, 45:84-91.
- SCE. (2010). *Power Bulletin*, March, Vol. 10, No. 3.
- Sikirica, S. J., Chen, J., Bluestein, J., Elson, A., McGervey, J., & Caughey, D. (2003). *Topical Report: Research Collaboration Program Food Processing Technology Project, Phase 1*. Des Plaines, Illinois: Gas Technology Institute GRI-03/0075.
- Solar Turbines Inc. (2008). <https://mysolar.cat.com/cda/files/914026/7/dscp-cd.pdf> Accessed 2015
- Sun, A., Reindl, D., & Reinemann, D. (2011). *Energy Use in Wisconsin's Dairy Industry and Options for Improved Energy Efficiency*. <http://fyi.uwex.edu/greencheese/files/2011/06/Energy-Use-in-WI-Dairy-Industry-Sun-et-al.pdf>
- Thompson, L., Lekov, A., McKane, A., & Piette, M. A. (2010). *Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-3889E.
- Thompson, L., Song, K., Lekov, A., & McKane, A. (2008). *Automated Demand Response Opportunities in Wastewater Treatment Facilities*. Berkeley: Lawrence Berkeley National Laboratory. LBNL-1444E.
- U.S. Census. (2009). *Annual Survey of Manufacturers*. <http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t> Accessed 1/14/2015
- U.S. Census. (2010). *Annual Survey of Manufacturers*. <http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t> Accessed 1/14/2015
- U.S. Census. (2011). *Annual Survey of Manufacturers, Statistics for Industry Groups and Industries*. <http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t> Accessed 1/14/2015
- U.S. Census. (2012). *North American Industry Classification System*. Retrieved from Washington, DC: United States Census Bureau: <http://www.census.gov/cgi-bin/sssd/naics/naicsrch>
- U.S. Department of Energy and Hydraulic Institute. (2006, May). *Improving Pumping System Performance*.
- US-AEP. (2002). *Clean Technologies in U.S. Industries: Focus on Food Processing*. Retrieved from United States-Asia Environmental Partnership, Bangkok, Thailand: <http://infohouse.p2ric.org/ref/09/08853.htm>

USDA. (2013). *Fluid Milk Production and factors affecting supply*. Retrieved 1/14/2015, from milkprod factors_1_.xls: <http://www.ers.usda.gov/data-production/dairy-data.aspx> Accessed 1/14/2015

USDA. (2013). *Milk production and factors affecting supply, 1980-2012*. milkprod factors_1_.xls. Retrieved from Washington, DC: United States Department of Agriculture: <http://www.ers.usda.gov/data-products/dairy-data.aspx> Accessed 1/14/2015

USDA. (2014a). *Fluid Milk Sales by Product 1975-2013* Fluidsales_1_.xls. Retrieved 1/14/2015 from Washington, DC: United States Department of Agriculture: <http://www.ers.usda.gov/data-products/dairy-data.aspx> Accessed 1/14/2015

USDA. (2014b). *Commercial Disappearance, Dairy Product Categories* CmDsProds_.xls. Retrieved from Washington, DC: United States Department of Agriculture: <http://www.ers.usda.gov/data-products/dairy-data.aspx> Accessed 1/14/2015

USDA. (2015). *Milk Production*. Retrieved from Washington, DC: United States Department of Agriculture, National Agriculture Statistics Service: <http://usda.mannlib.cornell.edu/usda/nass/MilkProd//2010s/2015/MilkProd-01-22-2015.pdf> Accessed 2/1/2015

Walstra, P., Geurts, T. J., Noomen, A., Jellema, A., & Van Boekel, M. (1999). *Dairy Technology, Principles of Milk Properties, and Processes*. New York: Marcel Dekker Inc.

Walstra, P., Jan, T., Woulters, J., & Geurts, T. J. (2006). *Dairy Science and Technology 2nd Edition*. Boca Raton: CRC/Taylor & Francis.

Wardrop Engineering. (1994). *Guide to Energy Efficiency Opportunities in the Dairy Processing Industry*. Mississauga, Ontario.

Westervelt, R. (2015). Personal Communication. <http://www.powerinlearning.com/about-us.html>

Xu, T., & Flapper, J. (2011). *Reduce Energy Use and Greenhouse Gas Emissions from Global Dairy Processing Facilities*. Energy Policy 39, 234-2471.

Xu, T., Flapper, J., & Kramer, K. J. (2009a). *Characterization of Energy Use and Performance of Global Cheese Processing*. Energy Policy 34, 1993-2000.

Xu, T., & Flapper, J. (2009b). *Energy Use and Implications for Efficiency Strategies in Global Fluid-Milk Processing Industry*. Energy Policy 37, 5334-5341.

Xu, T., Flapper, J., Ke, J., Kramer, K., & Sathaye, J. (2012). *Development of a Computer-based Benchmarking and Analytical Tool: Benchmarking and Energy & Water Savings Tool in Dairy Plants (BEST-Dairy)*. Berkeley, CA: Lawrence Berkeley National Laboratory, LBNL-5679E.

APPENDIX A:

Glossary

ASHRAE	Formerly called American Society of Heating, Refrigerating, and Air-Conditioning Engineers; rebranded in 2012 as simply ASHRAE
ASM	Annual Survey of Manufacturers
Auto-DR	Automated Demand Response
BEST	Benchmarking and Energy/Water-Saving Tool
Btu	British thermal unit
CADDET	Centre for the Analysis and Dissemination of Demonstrated Energy Technologies
CEC	California Energy Commission
CHP	Combined Heat and Power
CIP	Clean In Place
CMAB	California Milk Advisory Board
COP	Coefficient of Performance
DOE	United States Department of Energy
DR	Demand Response
DRRC	Demand Response Research Center
EPA	United States Environmental Protection Agency
FDA	United States Food and Drug Administration
GRI	Gas Research Institute
GWh	Gigawatt Hour (Watthour $\times 10^9$)
HACCP	Hazard Analysis Critical Control Points
HTST	High-Temperature, Short-Time
HVAC	Heating, Ventilating, and Air-Conditioning
IAC	Industrial Assessment Center
IDF	International Dairy Federation
IMS	Interstate Milk Shippers
IRAJ	Institute of Research and Journals
kW	Kilowatt (Watt $\times 10^3$)
kWh	Kilowatt hour (Watthour $\times 10^3$)

L	Liter
lb	Pound (weight)
LBNL	Lawrence Berkeley National Laboratory
MECS	Manufacturing Energy Consumption Survey
MMO	Milk Market Observatory
MW	Megawatt (Watt $\times 10^6$)
NAICS	North American Industry Classification System
PIER	Public Interest Energy Research Program
PJ	Petajoule (Joule $\times 10^{15}$)
PMO	Pasteurized Milk Ordinance
SCE	Southern California Edison
SOP	Standard Operating Procedure
SSOP	Standard Sanitation Operating Procedure
TBtu	Trillion British thermal units (Btu $\times 10^{12}$)
TWh	Terawatt hour (Watt hour $\times 10^{12}$)
USDA	United States Department of Agriculture
US-AEP	United States - Asia Environmental Partnership
Wh	Watt hour