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Development of a Computer-based Benchmarking and Analytical Tool:

Benchmarking and Energy & Water Savings Tool in Dairy Plants (BEST-Dairy)

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PREFACE

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Renewable Energy Technologies
- Transportation

Development of a computer-based Benchmarking and Analytical Tool: Benchmarking and Energy & Water Savings Tool in Dairy Plants (BEST-Dairy) is the formal final report for the Industrial/Agricultural/Water End - Use Energy Efficiency project conducted by Lawrence Berkeley National Laboratory (contract number 500-06-058). The information from this project contributes to PIER's Industrial/Agricultural/Water End - Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916 - 654 - 4878.

ABSTRACT

The overall goal of the project is to develop a computer-based benchmarking and energy and water savings tool (BEST-Dairy) for use in the California dairy industry – including four dairy processes – cheese, fluid milk, butter, and milk powder.

BEST-Dairy tool developed in this project provides three options for the user to benchmark each of the dairy product included in the tool, with each option differentiated based on specific detail level of process or plant, i.e., 1) plant level; 2) process-group level, and 3) process-step level. For each detail level, the tool accounts for differences in production and other variables affecting energy use in dairy processes. The dairy products include cheese, fluid milk, butter, milk powder, etc. The BEST-Dairy tool can be applied to a wide range of dairy facilities to provide energy and water savings estimates, which are based upon the comparisons with the best available reference cases that were established through reviewing information from international and national samples. We have performed and completed alpha- and beta-testing (field testing) of the BEST-Dairy tool, through which feedback from voluntary users in the U.S. dairy industry was gathered to validate and improve the tool's functionality. BEST-Dairy v1.2 was formally published in May 2011, and has been made available for free downloads from the internet (i.e., http://best-dairy.lbl.gov). A user's manual has been developed and published as the companion documentation for use with the BEST-Dairy tool. In addition, we also carried out technology transfer activities by engaging the dairy industry in the process of tool development and testing, including field testing, technical presentations, and technical assistance throughout the project. To date, users from more than ten countries in addition to those in the U.S. have downloaded the BEST-Dairy from the LBNL website.

It is expected that the use of BEST-Dairy tool will advance understanding of energy and water usage in individual dairy plants, augment benchmarking activities in the market places, and facilitate implementation of efficiency measures and strategies to save energy and water usage in the dairy industry. Industrial adoption of this emerging tool and technology in the market is expected to benefit dairy plants, which are important customers of California utilities. Further demonstration of this benchmarking tool is recommended, for facilitating its commercialization and expansion in functions of the tool. Wider use of this BEST-Dairy tool and its continuous expansion (in functionality) will help to reduce the actual consumption of energy and water in the dairy industry sector. The outcomes comply very well with the goals set by the AB 1250 for PIER program.

This document may be revised as the Energy Commission deems necessary. Please check for the latest version at:

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Keywords: California, dairy process, dairy product, cheese, fluid milk, milk powder, butter, concentrated milk, benchmarking, energy efficiency, energy use, water use, energy intensity index, water intensity index, best available reference, international benchmarking, greenhouse gas (GHG) emission.

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GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

Term	**Definition**
BEST	Benchmarking and Energy& Water Savings Tool
BEST-Dairy	Benchmarking and Energy & Water Savings Tool for Dairy
CO_2	Carbon Dioxide
DOE	Department of Energy
SEC or EUI	Specific Energy Consumption, or Energy Use Intensity (EUI)
GHG	Greenhouse Gas
GWh	Gigawatt Hours
LBNL	Lawrence Berkeley National Laboratory
PAC	Project Advisory Committee
PIER	Public Interest Energy Research
TBtu	Terra British Thermal Units (Btu)
MMBtu	Million Btu
MJ	Mega Joules
GJ	Giga Joules
ERM	Energy-use per Raw Milk
EII	Energy Intensity Index or Indicator (EII)
WII	Water Intensity Index or Indicator (WII)

EXECUTIVE SUMMARY

The overall goal of the project is to develop a computer-based benchmarking and energy and water savings tool (BEST-Dairy) for use in the California dairy industry. The new BEST-Dairy tool is expected to allow a facility to be compared to best available reference dairy plant or process that will be identified and analyzed in this project. The use of the BEST-Dairy tool will also enable the provision of information on quantified savings potential and energy efficiency options when available for the facility. For this project, the BEST-Dairy tool was developed to cover four dairy processes – cheese, fluid milk, butter, and milk powder, although we have performed additional analysis and assessment for additional dairy products. BEST-Dairy allows users to identify or evaluate efficiency improvement opportunities for individual process or process-group measures that will save money, energy or water, or some combinations of these savings; and allows the dairy to develop an implementation priorities plan for potential efficiency improvements.

In this project, we first performed extensive literature reviews and data compilation, and conducted process analysis and modeling for various dairy products that included cheese, fluid milk, milk powder, butter and concentrated milk. Then we assessed energy and water efficiency opportunities in dairies, and developed an integrated benchmarking tool. We have performed and completed alpha- and beta-testing (i.e., field testing) of the BEST-Dairy tool, through which feedback from voluntary users from dairy industry was gathered to validate and improve tool functionality. BEST-Dairy v1.2 was formally published in May 2011, and has been made available for free downloads from the internet (http://best-dairy.lbl.gov).

The BEST-Dairy tool is an easy-to-use, computer-based tool (with a companion handbook) that can be used by facility engineers, energy managers, project developers, research institutions, industrial associations, and government agencies to benchmark and evaluate the energy and water efficiency and GHG mitigation potential of individual dairy facilities or processes. The tool can be used to assist decision makers in planning facility improvement projects related to achieving energy efficiency and GHG mitigation goals or targets in California and other part of the world. BEST-Dairy tool developed in this project is designed to provide three options for the user to benchmark various dairy products in terms of detail level of process or plant: 1) based on plant level; 2) based on process group level, and 3) based on a process step approach, all accounting for differences in production and other variables affecting energy use. It can be applied to a wide range of dairy facilities to provide savings estimates compared to best available reference case established by reviewing information from international and national samples.

A user's manual has been developed and published with documentation for use as the companion with the BEST-Dairy tool. In addition, we also carried out technology transfer activities by engaging the dairy industry in the process of tool development, including field testing, technical presentations, and technical assistance throughout the project.

It is expected that the use of BEST-Dairy tool will advance understanding of energy and water usage in individual dairy plants, augment benchmarking activities in the market places, and facilitate implementation of efficiency measures and strategies to save energy and water usage in the dairy industry. Industrial adoption of this emerging tool and technology in the market is expected to benefit dairy plants, which are important customers of California utilities. Wider use of this BEST-Dairy tool will help to reduce the actual consumption of energy and water in

the dairy industry sector. The outcomes comply very well with the goals set by the AB 1250 for PIER program.

Despite of the benefits from benchmarking and the tool made available to the industry, how to promulgate its wider adoption in the market remains a challenge against maximizing the values from benchmarking. It is therefore recommended that demonstration and deployment activities to be carried out in the future to facilitate commercialization of this benchmarking tool. Wider use of BEST-Dairy and its continuous expansion (in functionality) will allow users to identify or evaluate efficiency improvement opportunities for individual process or process-group measures leading to saving money, energy or water, or some combinations of these savings; and allowing the dairy to develop an implementation priorities plan for potential efficiency improvement.

1 CHAPTER 1: Project Introduction

1.1 Background

California's dairy processing industry is primarily comprised of four segments: fluid milk, butter, cheese, and milk powder products. According to the California Department of Food and Agriculture (CDFA 2006; 2009) and the California Milk Advisory Board (CMAD 2008), California has been the nation's largest milk producer since 1993, followed by Wisconsin, New York, Pennsylvania, and Idaho. With the increasing economic and environmental pressures and consequences of increased energy and water usage in California, making energy and water efficiency improvement will be an essential part of the business for dairy processing sectors.

There is considerable potential for energy efficiency improvement and reduction of greenhouse gas (GHG) emissions in the California dairy industry through implementing cross-cutting energy efficiency measures and process-specific measures. Benchmarking energy and water usages in dairy plants is an effective way to understand savings potential and to identify areas of efficiency improvement. However, not all dairies have the staff or the opportunity to perform the detailed facility audits necessary to identify potential for reducing energy use and GHG emissions. The lack of knowledge of such potential is an important barrier to improving facility efficiency in energy and water usage. For other industry sectors, benchmarking programs in the United States and abroad have been shown to improve knowledge of the energy performance of industrial facilities and buildings.

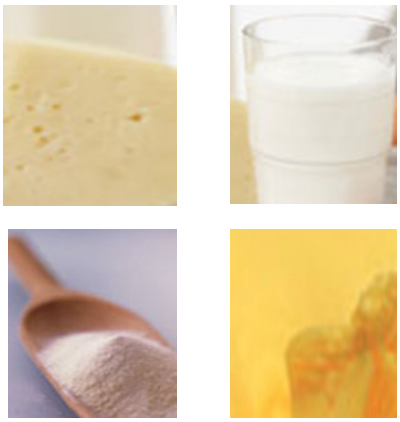
Benchmarking compares the performance of a facility to its industry peers or to industry best practice that can be identified and can measure how well a facility is performing with regard to its energy use, efficiency, and GHG emissions. In a well-designed benchmarking program, differences between facilities within an industry are addressed by normalizing for activities or factors that influence energy use. Such factors might include local climate and weather, plant capacity utilization, product mix, and materials use. Normalizing the quantities of energy usage and emissions by a specific factor or factors may allow control of these factors and a better understanding of the reasons for observed differences in energy efficiency. In addition, benchmarking can also spurs energy management practices, stimulating both energy-efficiency investments and the adoption of innovative energy management approaches that have led to reductions in industrial energy use and GHG emissions. Prior to this project, benchmarking tools have not been developed for the California dairy processing industry, and this project aims to fill the technology gap as well as knowledge gap.

1.2 Project Goal

The overall goal of the project is to develop a computer-based benchmarking and energy and water savings tool (BEST-Dairy) for use in the California dairy industry. The new BEST-Dairy

tool is expected to allow a facility to be compared to best available reference dairy plant or process that will be identified and analyzed in this project. The use of the BEST-Dairy tool will also enable the provision of information on quantified savings potential and energy efficiency options when available for the facility.

1.3 Project Scope



A computer-based BEST-Dairy tool will be developed, which will include benchmarking energy and water usage, identification and quantification of energy and water efficiency improvement potential in four dairy processes – cheese, fluid milk, butter, and milk powder. Specifically, the BEST-Dairy can be used to benchmark a facility's current energy and water use and compared with current global and national best practice for dairy facilities. The use of the tool can provide a baseline for the facility's existing operations against best-achievable performance for the following four dairy products: cheese, fluid milk, butter, and milk powder. BEST-Dairy allows users to identify or evaluate efficiency improvement opportunities for individual process or process-group measures that will save money, energy or water, or some combination of these savings and allows the dairy to develop an implementation priorities plan for potential efficiency improvements.

During the course of this BEST-Dairy project, we have come across relevant information on additional dairy products along with the four pre-determined products. For the added benefit of this project, we have, therefore, included additional dairy products in the analysis and tool development.

1.4 Method and Tasks

In this project, we conducted extensive literature research for each of the dairy product on the regional (e.g., California), national, and/or global levels, so that the BEST-Dairy tool may benefit from database that were made available publicly.

Key energy and water performance metrics were developed throughout the project that can be used to benchmark and compare energy/water performance in the dairy plants and processes. A Computer-based benchmarking tool using MS Excel and VBA was then developed to integrate information and modeling developed for the project. The BEST-Dairy tool first went through Alfa-test in LBNL (BEST-Dairy V1.1). Extensive cross-checking were performed before the refined version was delivered to industrial volunteers for Beta-tests. Feedback was gathered from the beta-testers within the U.S. to improve the tool. The final version of the BEST-Dairy (V1.2) was released in May 2011, which is available for free download from the internet.

For each of the four dairy products, we developed process-based benchmarking methodologies that account for the characteristics of each process step to calculate an overall performance indicator—the energy intensity index (EII) or the water intensity index (WII). The EII and WII allow comparisons of energy and water usage for process/plant over time, and comparisons between dairies and specific facilities. The process-based benchmark provides information on

the relative performance of each process and the information needed to target key processes for energy and water management activities. We also performed analysis and modeling of processes for various dairy products, and assessments and discussion of relevant energy-efficiency and water-efficiency technologies applicable to dairy processing industry. By integrating the analysis and modeling of processes and efficiency measures with the benchmarking tool, the BEST-Dairy was developed, enabling estimation of the potential amount of energy or water that can be saved in the process or plant. It will thereby show the extent to which the overall efficiency can be improved in the dairy process.

The tool will be developed in an MS-Excel spreadsheet environment to allow easy use by as many dairies as possible.

1.5 Outcomes and Report Structure

In this project, we first performed extensive literature reviews and data compilation, and conducted process analysis and modeling for various dairy products that included cheese, fluid milk, milk powder, butter and concentrated milk. Then we assessed energy and water efficiency opportunities in dairies, and developed an integrated benchmarking tool. We have performed and completed alpha- and beta-testing (field testing) of the BEST-Dairy tool, through which feedback from users from dairy industry was gathered to improve tool functionality. BEST-Dairy v1.2 was published in May 2011, and has been made available for free download from the internet (http://best-dairy.lbl.gov). A user's manual was developed for use with the BEST-Dairy tool. In addition, we also carried out technology transfer activities by engaging the dairy industry in the process of tool development, including field testing, technical presentations, and technical assistance throughout the project.

Following the first chapter on introduction, this final report includes three separate, sequential chapters – each including detailed analyses and modeling of one or more dairy processing: chapter two focuses on cheese benchmarking, chapter three on fluid-milk benchmarking, and chapter four on butter, milk powder, and others. Each of the three chapters addresses own objectives, methods used, and outcomes relevant to the BEST-Dairy tool.

Finally, Chapter five describes the development of BEST-Dairy tool in this project, including programming structure of the tool, and introduction of the User's Manual as the companion documentation to the tool. It also enlists technology transfer activities in this project. Finally, this chapter highlights the key outcomes of the project.

2 CHAPTER 2: Benchmarking Cheese Processes

2.1 Introduction

According to Food and Agriculture Organization (FAO 2009), the world production of raw milk and cheese reached 645 million metric tons (MMT) and 18.7 MMT, respectively, in 2005; with an average annual growth rate of respectively 1.8% and 2.5% over the last decade. In the European Union more than 95% of the total raw milk was processed to produce dairy products such as cheese, whey, liquid or powder milk, butter and cream (EC 2006). It was estimated that the annual emissions of carbon dioxide (CO_2), a major greenhouse gas from dairy processing plants are between 50 and 100 grams CO_2 per kg milk based upon a study on European Union's dairy processing (Sevenster 2008). This would easily translate into total annual CO_2 emissions in the tens of millions of metric tons from dairy processing plants in the whole world.

The global cheese-making industry processes approximately one quarter of the total raw milk production in the world to create a variety of consumer cheeses, and cheese processing can be very energy-intensive. Furthermore, the cheese industry is growing rapidly all over the world as is shown in the compiled information in Table 1. In many parts of the world, energy consumption in industrial sectors is intensive and remains as a major concern to power availability and reliability as well as to environmental impact induced by the increasing energy use. Within dairy processing industry, there are various processes associated with different products (e.g., liquid milk, butter, cream, and powder milk) that require energy for operating plant facility systems and processing equipment. Within California's dairy processing industry, for example, cheese-making is the most significant sector in that it uses a majority of raw milk and significant energy compared to its dairy product counterparts within the state. The significant energy use in cheese plants and a lack of programs or activities in improving efficiency could offer opportunities for energy savings through implementing cross-cutting and process-specific measures. With societal modernization and economic development that is particularly experienced in highly populated emerging markets and developing world, the demand for consumption of dairy products such as cheese and specialty dairy products is increasing rapidly. For example, consumption of dairy products in China has almost doubled between 2000 and 2003 (FAO 2007). Across the world, coupled with the production increase is the increasing energy demand for the dairy processing; yet there is limited availability of tools and programs to address the energy concerns associated with dairy processing.

Currently, information on energy efficiency for the cheese-making sector is limited and at best fragmented. In addition, there is essentially no published research on developing strategies or tools to improve the energy efficiency in the cheese-making sector. Adding to the problem, not all dairies have the staff, resources, guides, or tools to perform the detailed assessment that is necessary to identify opportunities for reducing energy use and greenhouse gas emissions. The lack of knowledge and understanding of such opportunities or information available is an important barrier to improving energy efficiency in cheese-making plants. Therefore, it is

necessary and important to develop relevant information and to fill the existing knowledge gap to improve the understanding of the state-of-the-art energy performance in the cheese-making sector. The outcomes could become the basis for developing benchmarking tools and strategies aiming at improving the efficiency while reducing operation costs in this important industrial sector.

2.2 Chapter Objectives

This chapter aims to develop integrated energy information and address knowledge gap in the cheese-making industries, through performing literature reviews, conducting data collection and analysis of energy information to characterize the production and energy usage associated with this industrial sector. Details of the outcomes have been documented and published as a journal paper (Xu et al. 2009). In particular, this chapter will include the following tasks:

1) Perform process analysis and modeling for cheese-making
2) Analyze and characterize energy usage in existing cheese markets and cheese-making plants
3) Assess and quantify the magnitudes of specific energy consumption (SEC) across countries, regions, individual plants, and processes to compare energy performance of cheese-making processes
4) Summarize the information developed for integrated benchmarking framework for cheese-making.

2.3 Chapter Method

In this chapter, we first gathered and compiled dairy production and energy data through performing extensive literature research on dairy processing industries, with a focus on the global cheese-making industries. Then we performed reviews and analysis of available production and energy data to characterize energy use in the sector, including process analysis and modeling. The characterization will then provide a basis for performance comparison, which can suggest possible efficiency improvement opportunities. Finally, in order to illustrate how to benefit from characterization results, the chapter short-lists technologies that have been identified to improve energy efficiency in cheese-making plants.

2.3.1 Specific energy consumption, or energy use intensity

Specific energy consumption (SEC), sometimes also referred to as energy use intensity, has been adopted to benchmark energy intensity and to assess energy performance of the plants in a variety of industries (Ramirez et al 2006, Hu and Chuah 2003, Worrel et al. 2003, Hu et al. 2009). In addition to analyzing energy data associated with cheese-making markets in the selected countries (regions) from which the data are available in open literatures, we used specific energy consumption as a metric to characterize energy usage in cheese-making plants and processes in this study.

Specific energy consumption is defined as the energy use, in the form of either primary energy or final energy (i.e., end-use), divided by the production of cheese products. In this chapter, a SEC value can be applied to any specific process step within a cheese plant (Equation 1), and can be used to quantify the overall energy intensity of a cheese plant (Equation 2). When focusing on the energy end-use, we quantify the magnitudes of SEC using final energy

whenever feasible to compare the levels of efficiency of different equipment or processes using the same energy source; when focusing on understanding total efficiency and environmental impact associated with energy use in cheese-making, we resort more to magnitudes of SEC based on primary energy when feasible to compare the intensity of required source energy consumption. . Either form of SEC (final or primary) characterizes the magnitudes of energy use intensity for existing cheese production in a plant normalized by the associated final cheese production.

$$SEC_i = \frac{E_i}{P_i} \qquad \text{Eq. (1)}$$

$$SEC = \frac{\sum_{i=1}^{n} E_i}{P} \qquad \text{Eq. (2)}$$

Where:

E_i = actual energy usage of process step i

P_i = production quantity for process step i

n = number of process steps to be aggregated

P = total actual cheese production

In general, a plant or process with a lower SEC value corresponds to a higher level of energy efficiency when comparing with a similar plant or similar process. By comparing to a benchmark SEC, the information developed can be used to assess the relative energy-efficiency potential of a plant. The SEC values can also be used for evaluating and tracking a plant's progress in energy efficiency improvements over time, by eliminating the effects of a change in product mix.

2.3.2 Dairy processes analysis and modeling

In order to develop meaningful SEC values for cheese-making processes and plants, a good understanding of the cheese-making process is needed. Cheese is one of the various dairy products that have one thing in common - they are all made out of raw milk. Raw milk consists of water and a variety of milk solids that include fat, casein protein (an important element for cheese), whey protein, lactose, organic acids, mineral substances, and a small part of miscellaneous solids. Different dairy products contain different concentrations of solids, so essentially manufacturing dairy products is mostly about concentrating and separating solids (Feitz et al. 2007). Furthermore, hygiene issues are very important as milk contains bacteria and can be very perishable (Walstra et al. 2006). To concentrate or separate solids, different techniques can be used based on controls of weight, molecular structure, boiling/freezing point, and other parameters. Sometimes microorganisms are used to enable separation and to give the product its own characteristics. The cheese-making process typically consists of various stages, some of which require substantial amounts of energy input. Figure 1 illustrates major processes for typical cheese making.

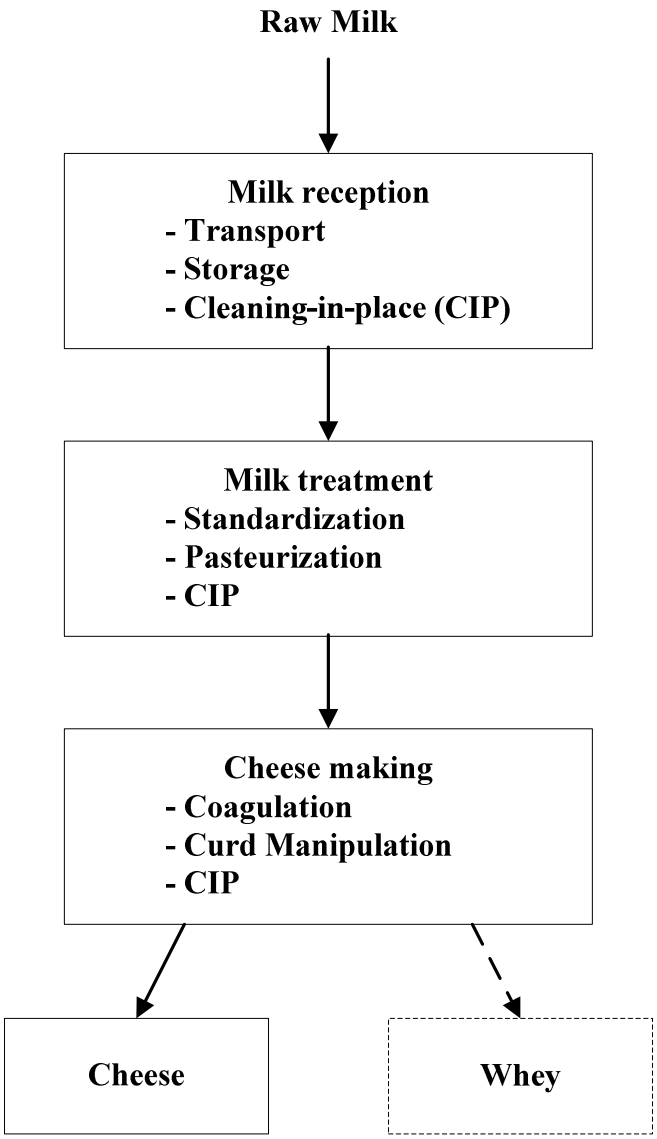


Figure 1 Analysis and modeling of major process steps in typical cheese-making

Specifically, the first step in cheese-making process is milk reception that requires transporting, storing and maintaining the raw milk at a low temperature (4-7 °C) to prevent it from perishing. The second step is milk treatment that require standardization of solids content (mainly fat and protein), which will involve separation and additional follow-up processes. In addition, pasteurization of the standardized milk is required prior to cheese-making to meet hygiene requirements. Moreover, according to Kelly et al. (2008), there has been consistent interest in more novel strategies for pre-treatment of cheese-milk to increase yield or control microbiology. In the third step of cheese making, the process is continued by adding a starter with specific temperature control and pH regulation - leading to coagulation and eventually formation of curd (mainly casein protein, fat and water). For each of these steps, daily cleaning-in-place (CIP) of the process and storage equipment is also required for hygiene reasons. The remainder, whey, is drained off from the curd. After salt is added to the curd to inhibit the bacterial activity, the curd is shaped into a cheese product. Cheese storage and ripening can alter the taste and appearance further until the desired cheese is produced.

In general, energy use in dairy processing are associated with processes of concentration (e.g., heating), separation (e.g., dynamic power), biological conversion (e.g., temperature control, storage), and hygiene requirements (e.g., CIP). The cheese manufacturing sector typically uses thermal energy (mainly natural gas) and electricity. Thermal energy (e.g., natural gas) is used in processes like pasteurization, evaporation, and cleaning, while electricity is used for transportation (e.g., pumps), storage (e.g., refrigeration), separation (e.g., centrifugation and ultra-filtration), and cleaning.

In this chapter, we analyzed energy data by fuel type for each process step to the extent possible, and assessed SEC levels for processes and plants for a selection of regions or countries from which the data is available in open literatures. The analysis will illustrate energy-efficiency potential or energy-saving opportunities for cheese-making plants, and will help to identify "state-of-the-art" cheese-making plants or processes that exhibit higher benchmarked energy performance.

2.4 Energy Benchmark and Opportunity Assessment

2.4.1 Characterization of energy usage in existing markets and cheese-making plants

The compiled information presented in Table 1 shows that Northern America and Europe are by far the largest cheese producers in the world, while the majority of the other continents have experienced increasing annual raw milk and cheese production. In particular, positive annual growth in cheese production is experienced in every continent.

This chapter will further focus on a more detailed analysis of cheese production and energy use in the United States (including California) and a few European countries because of their large share in global cheese production and data availability.

Table 2 shows production and energy consumption data for the dairy processing sector by country or region. Annual milk production in the United States including California has maintained a positive growing trend, exhibiting an average annual growth rate of 1.3% (USA) and 4% (California) during 1995 and 2005; while the European countries in this study (i.e., Great Britain, Netherland, Denmark, and Norway) showed slight declines within the same period.

Associated with the milk production, the total electricity use for processing milk in the USA increased at the rate of 5.7% while the majority of the European countries in this study experience negative growth trend in energy use (except for Denmark).

It is also evident that variation of total energy intensity (end-use SEC) per country is relatively large – ranging from 0.8 up to 1.9 MJ per kg raw milk, while shares of energy sources (fuel versus electricity) also varied across the countries. Great Britain exhibited relatively low values of total energy intensity, which may be partially attributed to the product mixes with a relatively lower share of energy intensive products (USDOA 2009, CBS 2009, EC 2008). In the case of The Netherlands, a significant share (i.e., 11/13=85%) of energy used in dairy processing came from fuel (e.g., natural gas) because there are a lot of plants that use combined heat and power (CHP) to generate onsite electricity (Ramirez et al. 2006).

Table 1 Global raw milk and cheese production in 2005 (Data source: FAO 2009)

	Unit	Africa	America (Northern)[a)]	America (Latin)[a)]	Asia	Europe	Pacific	World Total
Raw milk production	10^9 kg	32.3	88.1	66.9	217.9	215.4	24.8	645.3
Annual growth[b)]	%	3.3%	1.2%	2.9%	4.3%	-0.5%	3.4%	1.8%
Produced cheese	10^9 kg	0.9	4.9	0.9	1.4	9.9	0.7	18.7
Annual growth[b)]	%	4.1%	2.5%	1.3%	3%	2.3%	4.7%	2.5%

Notes:

a) Latin America includes Mexico

b) Annual growth rate is calculated for the period of 1995-2005

Table 2. Production and final energy use for the dairy processing sector by country or region (in 2005, unless stated otherwise)

Dairy sector	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from:
Raw milk production	10^9 kg	80.3	17.1	14.5	10.8	4.6	1.6	FAO2009,USDOA 2009, CBS 2009
(growth rate)[a)]	(%/year)	(1.3)	(4.0)	(-0.3)	(-0.3)	(-0.3)	(-0.4)	
Raw milk processed[b)]	10^9 kg	77.8	17.3	14.0	10.5	4.5	1.5	EC 2008
Revenue[c)]	10^9 $	$76.9	$9.8	$12	$6.3	$3.9	$1.7	US Census 2006,DEFRA 2007, XE 2009
Final energy (end use)								
Total	PJ	107-142[d)]	16.6[e)]	11.3	13.1	7.1	2.4	CBS, US Census 2006, 2009, CEC 2004a & b, Statistics Denmark 2009a, Statistics Norway 2009, DECC 2009
(growth rate)	(%/year)	(5.7)[f)]	(N/A)	(-2.4)	(-0.7)	(1.2)	(-0.1)	
Electricity	PJ	32.0	3.8[e)]	4.2	2.0	1.6	1.6	
Fuel	PJ	75-110[d)]	12.8[e)]	7.1	11.0	5.5	0.7	
Total energy intensity	MJ / kg raw milk	1.4-1.9[g)]	1.0	0.8	1.2	1.4	1.5	
GHG emissions	10^9 kg CO_2	10.2[g)]	1.2[h)]	1.1[g)]	0.90[g)]	0.55[i)]	0.11[g)]	EIA 2007, Marnay et al. 2002, EIA 2009, Statistics Denmark 2009b

Notes:

a) Annual growth rate derived from growth between 1995 - 2005

b) Milk processed for USA and Norway estimated based on similar ratios of GBR, NLD & DNK. Milk processed for California is slightly higher than its own milk production due to additional import from other states (CDFA 2009)

c) US$, using currency conversion rates of July 1st, 2005 (XE 2009)

d) Final fuel energy range for USA for 2002-2006 was estimated based on total fuel expenditure divided by yearly gas price, and using electricity/fuel ratio in food industry in 2002 (EIA 2007)

e) Energy use for Californian dairy sector based on 2004 with high uncertainties, no data for 2005 was found available in this study

f) USA energy growth rate only based on electricity consumption because of insufficient total energy data

g) USA energy intensity for the dairy sector based on range for 2002-2006 due to uncertainty in fuel use

g) Estimation based on average countrywide GHG emissions for primary energy

h) Estimation with high uncertainties based on average GHG emissions for electricity in California (Marnay et al. 2002) and fuel emission factors (EIA 2009)

i) Estimation based on average countrywide GHG emissions for primary energy and values calculated by(Statistics Denmark 2009b).

Table 3 shows comparable information on cheese production and energy consumption for the cheese-making sector by country or region, including end-use energy intensity (final SEC) for cheese-making on the state or national level (e.g., California).

Table 3. Production and final energy use for the cheese-making sector by country or region

Cheese sector	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from
Raw milk processed	10^9 kg	35.5[c)]	8.0[b)]	3.5	6.0[d)]	2.8[c)]	0.6[c)]	EIA 2009, CMAB 2008, DEFRA 2008
Cheese production[a)]	10^9 kg (%/ year)	4.51 (2.6)	1.02 (8.4)	0.39 (1.0)	0.67 (-0.3)	0.36 (1.3)	0.08 (-0.4)	FAO 2009,USDOA 2009, EC 2008
Revenue[e)]	10^9 $	$17.6[f)]	$2.17[g)]	N/A	$2.6	N/A	$0.56	CBS 2009, US Census 2006, XE 2009, US Census 2004a.
Energy end use								
Total[h)]	TJ	35000-40000[i)]	7439[j)]	N/A	3386[k)]	N/A	N/A	US Census 2006, CEC 2004a
Intensity[h)] or SEC	MJ / kg cheese	8.4-9.6[l)]	8.0[j)]	N/A	4.9[k)]	N/A	N/A	Oldenhof 2004

Notes

a) Annual growth rate derived from growth between 1995 - 2005

b) Milk processed for cheese in California is 47% of total milk production according to CMAB 2008

c) The ratio of raw milk to cheese in California is also used for USA, Denmark and Norway as these countries all produce a significant share of fresh cheese which has a higher yield (Walstra et al. 2006)

d) For NLD the ratio of milk to cheese is estimated based on the same ratio as GBR, as both countries produce a relatively low amount of fresh cheese.

e) $ currency conversion rates of July 1st, 2005 have been used (XE 2009).

f) Revenue for Cheese in the USA is derived by multiplying the revenue including processed cheese (i.e. blended, grinded, sliced, etc.) by the same ratio between revenues of cheese and processed cheese in 2002

g) Revenue for cheese in California is for 2002 and therefore probably lower due to the industry growth and inflation

h) Energy use and intensity includes processing of liquid whey, but not the production of whey powder

i) Final electricity use is 9673 TJ, while final fuel energy use range is estimated for USA. This estimation is based on both the same electricity to fuel ratio for 2005 as in 2002 calculated by using the same fuel price as for the entire food industry ((US Census 2004a, US Census 2006), and on the total fuel expenditure, $189 million, divided by a fuel price that increased from 2002 to 2005 in the same way done for natural gas (EIA). The total energy use was then compensated for processed cheese using same energy ratio between cheese and processed cheese in NLD 2004.

j) Californian cheese energy use excludes cottage cheese and includes processed cheese, but the production of processed cheese in California is very small, below 4% of revenue in 2002 (US Census 2004a). The total final energy use is based on Californian Energy Balance numbers, which were 1796 TJ electricity and 4325 TJ natural gas and an estimation for other fuel use. The estimation was based on the same ratio between natural gas and other fuels in the food industry in the West Census Region (US Census 2004a). The intensity does not include cottage cheese

and has been corrected for processed cheese using the same energy ratio between cheese and processed cheese in NLD (Oldenhof 2004).

k) Energy use for cheese in NLD is derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in (Oldenhof 2004).

l) USA cheese energy intensity excludes cottage cheese and was, therefore, calculated by dividing total final energy use by the total quantity of cheese produced minus the amount of cottage cheese produced.

Compared to the entire dairy sector by country and state, cheese production exhibited sustained annual growth rates (e.g., USA at 2.6%, California at 8.4% from 1995 to 2005). Coupled with the increased cheese production was the increased energy use in cheese sector in USA. For example, the final electricity consumption was 8.5 PJ in 2002 and 9.6 PJ in 2006, exhibiting a total growth rate at 12.8% during the period and at 3.1% annually. The annual growth rate of electricity use was slightly higher than the annual growth rate of cheese production during 2002 and 2006 in USA (i.e., 2.7%), indicating increasing electricity intensity over the years (US Census 2006). In some European countries, i.e., Great Britain and Demark, average annual cheese production was actually growing despite the fact that their annual raw milk production was declining. Corresponding to the increasing annual cheese production was the increasing share of raw milk used for cheese production.

Table 3 shows large differences in average SEC values for cheese production among USA (8.4-9.6 MJ per kg cheese) and the Netherlands (4.9 MJ per kg cheese). Contrasting to its lower overall energy intensity of the Californian dairy sector (1.0 MJ per kg of raw milk processed) than that of the Netherlands (1.2 MJ per kg of raw milked processed) was the higher cheese energy intensity (i.e., SEC value) in California (8.0 MJ per kg cheese) than in The Netherlands (i.e., 4.9 per kg cheese). The disparity of the magnitudes indicates that potential in energy savings could be very large in California's cheese processing sector as well as in the cheese-making sector in entire United States.

2.4.2 Specific energy consumption of cheese plants and processes

One caveat in evaluating an overall industrial plant is that there is a rarely a completely homogenous and identical production (output) to use as the basis for calculating energy use intensity. In electricity generation, it is common to think of energy intensity in terms of energy use per kilowatt-hour of electricity generated. There is basically one output commodity in electricity generation, so this metric makes sense. For industrial manufacturing, such as cheese making, output is generally much more heterogeneous. Producing different cheese varieties also have different energy requirements, resulting from variations in process conditions, like temperature, cooking time etc. Other factors that influence the energy use of plants are among others production location (climate), plant size and age (FAO 1990, Bosia 2008). While the cheese-making processes can be different from one another depending on various final cheese types, we consider specific energy consumption as a starting point to characterize energy use through normalizing via cheese production in mass.

Table 4 shows various ranges of specific energy consumption among individual cheese plants grouped by country or region (indicated in row) based upon available literatures that were reviewed in this study. The ranges of SEC values were significant within the same country as well as across different continents. For example, the lowest total SEC (2.3 MJ/kg cheese) in the USA is less than one-third of its average total SEC (ranging 8.4-9.6 MJ/kg cheese, Table 3) while the highest total SEC (16.8 MJ/kg cheese) is about twice the average SEC. In Europe the SEC

values ranged from 2.1 to 68.2 MJ/kg cheese, exhibiting difference of more than thirty times. The relative shares of fuel vs. electricity also changed from region to region. Apparently, the magnitude of the difference in SEC values for cheese-making sector likely indicates significant opportunities or potentials for energy savings. Based on the SEC ranges, the lower end of the ranges noted could be used as a starting target for best practice and energy efficiency improvement in cheese plants. Table 5 shows the average energy distribution of 34 Dutch cheese plants in the late 1990s. On average the energy intensity of cheese in these plants in The Netherlands in 1998 was about 4.3 MJ/kg cheese. The breakdown is based on a report from Arcadis (2000). Some values are directly taken from the report; others are estimated by using the intensities for similar processes in production of other products and additional reports (ETSU 1998, NRCAN 2001). If the cheese is stored longer than 14 days (post-cheese making), on average 32% extra energy is used for that additional step for cheese storage/ripening.

Table 4 Ranges of final SEC values for the individual cheese plants reviewed

SEC Range MJ/kg cheese[a]	# plants	Total[b]		Electricity[b]		Fuel[b]		Sources
		Low	High	Low	High	Low	High	
USA	12	2.3	16.8	0.5	2.3	0.4	14.7	IACD 2008,Morgan 2006
Australia	5 or more	1.8	6.8	0.8	0.8	1.0	4.3[c]	Feitz 2007,Joyce & Burgi 1993, Prasad et al. 2004
Europe	n/a	2.1[e]	68.2[e]	0.7	26.4[d]	1.4	41.8[d]	IPPC 2006
Scandinavia	12	3.9	26.8	N/A		N/A		Korsstrom & Lampi 2002.
Netherlands	34	2.4[a,f]	10.8[a,f]	N/A		N/A		Arcadis 2000

Notes:

a) Values include liquid whey processing, except for Dutch data

b) Ranges in electricity and fuel consumption do not always add up to the ranges in total consumption because plants have varying distributions in electricity and fuel use. Total consumption is calculated by using consumption levels of electricity and fuel from the same plant except for Europe (see comment e).

c) Average use of plants that participated in a survey in 1982 in Australia.

d) Includes whey powder production

e) Calculated by summing up electricity and fuel consumption, respectively. The source literature does not indicate the plants from which corresponding numbers are derived. Therefore, the lowest and highest SEC are not necessarily for the same plant. Consequently, the SEC values shown here are meant to indicate a wide range observed from a combination of different plants, rather than to indicate the SEC ranges strictly corresponding to those individual plants. In another word, both ends of the SEC numbers shown in the table can be regarded as "conservative."

f) Derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.385 for electricity and 1.0 for natural gas as used in (Arcadis 2000).

Table 5 Average primary energy breakdown for cheese plants in 1998 in the Netherlands (Arcadis 2000)

		Percentage of cheese-making primary SEC value		
Ranges in share of total primary energy use		Low	Ave	High
Milk reception	Reception/thermization	8%	9%	10%
Milk treatment	Standardization*	1%	n/a	4%
	Pasteurization*	17%	n/a	26%
Cheese making	Cheese processing	7%	n/a	14%
Cheese storage	Cheese treatment/storage	12%	n/a	32%
Supporting processes	Pressurized air	2%	2%	3%
	CIP	8%	9%	10%
	Cooling/refrigeration	8%	9%	10%
	Other*	6%	n/a	22%
Total cheese-making	**Primary SEC_{prim} 4.3 MJ/kg in 1998**	**-**	**100%**	**-**
	Primary SEC_{prim} 3.9 MJ/kg in 2002	**-**	**100%**	**-**
Post-cheese making, i.e., additional to cheese-making SEC	Cheese ripening/storage[a)]	9%	32%	65%
	Whey processing 1998	n/a	55%	n/a
	Whey processing 2002	n/a	43%	n/a

* Notes - – not applicable n/a – not available

a) Range is based on data from 14 Dutch cheese plants that store cheese for longer than 14 days[Arcadis 2000]

Furthermore, additional use of primary energy required for liquid whey processing on-site, was equivalent to 43% of the total cheese-making primary SEC (i.e., 3.9 MJ/kg cheese) in 2002 (Oldenhof 2004), and 55% of the total cheese-making SEC (i.e., 4.3 MJ/kg cheese) in 1998 (Arcadis 2000) of the energy use on top of Dutch cheese production. However, energy intensity for this additional step greatly depends on the level of actual whey solid concentration as this can vary greatly-ranging from raw-whey's 5% solid content to 15%-60% solids content (Arcadis 2000). In addition, we calculated that the actual energy intensity of the additional process for whey-making was 0.20 MJ per kg raw whey in 1998 and 0.16 MJ / kg raw whey in 2002 (EC 2008).

Table 6 shows the distribution of energy use in California cheese-making processes based upon the study report (CIFAR 2006). The distribution is presented as the percentage of energy use for four grouped-functions compared to the total final energy use in the cheese plants. Each of the grouped-functions included a mixed of process equipment and facility equipment; therefore, it is different from actual cheese-making process steps. For example, pumps, motors, fans, conveyors and lighting in the first group are supporting equipment for the process and mainly use electricity that counts for 35% of the total energy use in cheese-making. The second group includes major processing equipment that mainly uses thermal energy, representing largest portion (i.e., 40%) of total energy use in cheese-making. Additional cooling utilities mainly use

electric energy, accounting for about 20% of the total energy use. The last group includes equipment for hygiene processes that uses both thermal energy and electricity.

Table 6. Distribution of final energy use (%) for cheese-processing sector in California (CIFAR 2006)

Pumps	Pasteurization	Cooling	Sanitation	Total	Total SEC
Motors Fans Conveyors Lighting	Heating Systems Evaporators Dryers Sterilization	Freezing Refrigeration	Clean in Place		MJ / kg cheese
35%	40%	20%	5%	100%	8.0

In summary, the function-based energy distribution may indicate the relative energy demand for groups of equipment or facility that provide specific functions, but it does not provide direct information on energy use for specific process or facility systems.

For characterizing energy use in processes, it would be advantageous to quantify SEC values based upon process-step whenever possible. For example, when following the process-step approach, processes with higher energy demand (high SEC values) can be readily identified. In addition, process step SEC values can be used to compare a number of different facilities, even if their production methods and outputs may vary.

Our extensive literature research has resulted in a limited set of data that is available for quantifying process-step SEC values in cheese-making processes. Table 7 shows some average SEC values for different cheese-making processes in the Netherlands in the late 1990s based upon the study by Arcadis 2000 . The same study also found that in the Netherlands there was a clear correlation between plant size and SEC values, i.e., large plants tend to be associated with lower SEC values than smaller plants. This indicated that larger plants tended to be more energy efficient when using SEC to compare energy performance.

Table 7. Average primary SEC of processes for cheese-making in The Netherlands, late 1990s (Arcadis 2000)

Process	Fuel (final) (MJ/kg)	Electricity (final) (MJ/kg)	Primary MJ_{Prim}/kg
Process stage:			
Milk reception	n/a	n/a	0.4
Milk treatment	n/a	n/a	n/a
Cheese making	n/a	n/a	0.3-0.6
Cheese treatment / storage	n/a	n/a	0.5-1.4
Utilities:			
Refrigeration	-	0.15	0.4
Pressurized air	-	0.04	0.1
CIP	0.28	0.03	0.4
Specific process:			Per kg milk input
Separation (centrifugation)	-	0.004-0.008	0.01-0.02[a)]

[*] Notes - – not applicable n/a – not available

a) Derived from final electricity use by dividing it by a conversion factor from primary to final electricity of 0.385 as used in Arcadis 2000.

3. Energy saving measures and strategies

Using the SEC information, inefficient processes within an individual plant can be identified by comparing process-specific SEC values for each process with certain energy-efficiency targets that could be identified through benchmarking. Best practices can be recommended based upon SEC characterization and benchmarking. Once the inefficient processes are identified, energy-efficiency technologies and measures could be identified, recommended, and implemented to improve the energy efficiency of the processes. For example, in The Netherlands many dairy companies signed agreements to dedicate themselves to increase energy efficiency. These long-term agreements, starting in 2001, have required participating companies to formulate an energy reduction plan every four years and to implement "proven" reduction measures with a payback period of less than five years. The overall efficiency of the industry has been monitored and efficiency measures were developed for energy reductions (SenterNovem 2008). The measures include cross-cutting measures that are common used in a variety of food processing or some other manufacturing industries (e.g., variable frequency control, leak repair in steam systems, and refrigeration systems), and potential process-specific measures that can be applicable to specific dairy processes (e.g., changes in production process and pasteurization). As a result from these measures and programs, we have found a significant energy reduction in terms of specific energy consumption for the cheese-making sector in the Netherlands, i.e., the

total cheese-making primary SEC was reduced to 3.9 MJ/kg cheese in 2002 (Oldenhof 2004) from 4.3 MJ/kg cheese in 1998 (Arcadis 2000) as shown in Table 5.

Coupled with the increased cheese production was the increased energy use in cheese sector in USA. For example, the final electricity consumption was 8.5 PJ in 2002 and 9.6 PJ in 2006, exhibiting a total growth rate at 12.8% during the period and an annual growth rate at 3.1%. The annual growth rate of electricity use was slightly higher than the growth rate of cheese production during 2002 and 2006 in USA (i.e., 2.7%)(FAO 2009, US Census 2006). The SEC values for the cheese plants in USA have increased over the years. To our knowledge, there was no known systematic energy program that promotes implementation of energy efficiency measurements or implementation.

The analysis indicates that there is positive association between implementation of energy-monitoring program (including implementing efficiency measures) and the decreasing trends of specific energy consumption over time, and suggests that developing and promulgating an energy-benchmarking framework including process-step approach and efficiency measures should be recommended for evaluating energy performance and improving energy efficiency in cheese-making industry.

2.4.3 Discussion

Overall, the information presented in the Table 4 through Table 7 has provided meaningful characterization of energy use in cheese-making industry by quantifying the magnitudes of various energy intensity (SEC based on primary or final energy consumption) of cheese-making plants, and in some cases, SEC values for specific process steps. The availability of such benchmarks based on reviews and analyses of the energy data gathered from cheese plants around the world in this study is useful for assessing the relative efficiency of cheese-making process across regions, plants, or individual process steps. As a starting point, the quantitative data such as SEC values presented can be used to establish the performance target for best practices in cheese-making sector. However, it is also clear that the data from available open literature for fully quantifying SEC values for process-step is still limited and often fragmented for the regions and countries identified in this study.

There is a need to obtain actual energy and production data on the level of individual process step as well as on the plant level through future energy benchmarking, including future international and regional collaboration in sharing the new data. Once more SEC values are determined through further benchmarking work, quantitative assessment of the energy efficiency for individual process steps and equipment can be made, after which the achievable energy-efficiency potential can be estimated. Developing an energy benchmarking tool that provides comparing process-step energy use and energy-efficiency measures can facilitate gathering of energy data and may spur energy-efficiency investments.

2.5 Chapter Summary

This chapter has presented process modeling analysis and opportunity assessment, including characterization results of energy use in cheese-making processing based upon an extensive literature reviews and data compilation for cheese production and energy use across continents, countries, or regions. Major conclusions are:

- In the dairy processing industries across several countries, the magnitudes of average end-use energy intensity exhibited large variations, with energy intensity ranging from 0.8 to 1.9 MJ per kg of raw milk processed.
- In the cheese processing industries across regions, the magnitudes of average end-use energy intensity also exhibited significant variations, with the SEC values ranging from 4.9 to 8.9 MJ per kg cheese across a small number of regions and countries.
- In the cheese processing industries, the magnitudes of final energy intensity of individual plants exhibited even more significant variations, with the SEC values found ranging from 2.3 to 16.8 MJ per kg cheese in the USA, and from 1.8 (Feitz 2007) to 68.2 MJ per kg cheese in the entire world.
- Coupled with the growth in cheese production was the increasing electricity use for the cheese-making sector in the USA, contrasting to the decreasing trend of specific energy consumption for cheese-making in Netherlands where strategic programs and policies on promoting energy efficiency have been in effect.

Because magnitudes of energy use are affected collectively by products (such as types and quantity), processes, equipment, facility, plant size and location, and additional factors, variations in energy efficiency and normalized energy intensity are expected. We have found that the growth trends in cheese-making industries and the large variations exhibited in specific energy use (final or primary) in the cheese sector worldwide have indicated likely significant opportunities in energy savings in the cheese-processing sector. Process-specific SEC values appear to be useful for assessing and identifying opportunities for energy savings in actual cheese plants. The outcomes are used in the integrated energy-benchmarking as part of the BEST-dairy development. Available information on efficiency measures was rather limited even though extensive literature reviews were conducted in the project.

3 CHAPTER 3: Benchmarking Fluid Milk Processes

3.1 Introduction

In this chapter, fluid milk products are referred to as common fresh milk products, which are processed from raw milk for liquid or fluid consumption such as drinking milk; fermented dairy products; and cream. Among these fresh fluid products, processing drinking milk requires the least change from raw milk during milk treatment process (e.g., pasteurization or sterilization) while meeting requirements for food safety, shelf life, flavor, and fat content. Often treatment processes would affect both shelf life and flavor. Because of lactic acid bacteria, fermented milk products (e.g., cultured buttermilk, sour cream, fermented milks and yogurt) from additional fermentation during fluid-milk processing are sourer than most other milk products. In addition, separated cream from the milk treatment process can be further treated and processed to produce cream products.

According to a recent study on the statistics from Food and Agriculture Organization (FAO 2009, Xu et al. 2009), the average annual growth rate of world production of total raw milk was 1.8% from 1995 to 2005, as summarized in Table 8. It was also estimated that the annual Carbon Dioxide (CO_2) greenhouse gas emissions from dairy processing plants are between 50 and 100 grams CO_2 per kg milk based upon a study on European Union's dairy processing (Sevenster et al. 2008). This would translate into total annual CO_2 emissions of up to 60 million metric tons associated with energy used in dairy processing plants in the world. The fluid-milk processing industry uses approximately 58-67% of the total raw milk production in the world to create a variety of fluid milk products. Considering the energy required to process dairy products per raw milk input, the amount of CO_2 emissions of associated with energy used in processing fresh fluid-milk products can be very significant.

Table 8 Global raw milk and fluid-milk production in 2005 (Data source: FAO 2009)

	Unit	Africa	America (Northern)[a)]	America (Latin)[a)]	Asia	Europe	Pacific	World Total
Raw milk production	**10^9 kg**	32.3	88.1	66.9	217.9	215.4	24.8	645.3
Annual growth[b)]	%	3.3%	1.2%	2.9%	4.3%	-0.5%	3.4%	1.8%
Processed fluid milk	**10^9 kg**							58-67%[c)]

Notes:

a) Latin America includes Mexico

b) Annual growth rate is calculated for the period of 1995-2005

c) Source: Flapper 2009. Estimated by subtracting the raw milk needed for processing milk powder, cheese and concentrated milk from total of world raw milk production .

Global energy consumption in industrial sectors account for the most significant share of total energy use. For example industrial energy use accounts for one-third in the USA (US DOE 2009), and approximately 70% in China (NBS and NDRC 2007). The high energy demand from global industries remains as a major concern to power availability and reliability as well as to environmental impact associated emissions of greenhouse gas and pollutants associate with the processes and their energy use. Within dairy processing industry, there are various processes associated with different products (e.g., fluid milk, butter, cream, and powder milk) that require energy for operating plant facility systems and processing equipment. Through implementing cross-cutting and process-specific measures in fluid-milk processing plants, the savings potential in energy use associated with the processing could be realized. With societal modernization and global economic development that is particularly experienced in highly populated emerging markets and developing world, the demand for consumption of dairy products such as specialty dairy products is increasing rapidly. Across the world, coupled with the production increase is the increasing energy demand for dairy processing; yet there is limited availability of tools and programs to address the energy concerns associated with dairy processing.

Currently, information on energy efficiency for the fluid-milk processing is limited and at best fragmented. In addition, published research on developing strategies or tools to improve the energy efficiency in the fluid-milk processing sector is rather limited. Adding to the problem, not all dairies have the staff, resources, guides, or tools to perform the detailed assessment that is necessary to identify opportunities for reducing energy use and greenhouse gas emissions. The lack of knowledge and understanding of such opportunities or information available is an important barrier to improving energy efficiency in fluid-milk processing plants. Therefore, it is necessary and important to review and develop relevant information and to fill the existing knowledge gap to improve the understanding of the state-of-the-art energy performance in the fluid-milk processing sector.

The outcomes of the data and process analyses will become the basis for developing benchmarking framework, strategies, and policy options aiming at improving the efficiency while reducing operation costs in this important sector.

3.2 Chapter Objective

This chapter aims to address the energy information and knowledge gap in the fluid-milk processing industries, through performing literature reviews, conducting data collection and analysis of energy information to characterize the process, production and energy usage associated with fluid-milk processing. Major findings have been documented and published as a recent journal paper (Xu and Flapper 2009). In particular, this chapter will include the following tasks:

1) Analyze and characterize energy usage in existing fluid-milk markets and processing plants, including process analysis and modeling
2) Assess and quantify the magnitudes of specific energy consumption (SEC) across countries, regions, individual plants, and processes to compare energy performance of fluid-milk processes
3) Summarize the information developed for integrated benchmarking framework for fluid-milk making.

3.3 Chapter Method

This chapter reviews and characterizes energy use in fluid-milk processing, and discusses energy-savings opportunities and impact and implications of implementing energy programs on the fluid-milk processing industry in different countries and regions.

Specifically, we first gathered and compiled dairy production and energy data through performing extensive literature research on dairy processing industries, with a focus on the regional or national fluid-milk processing industries. Then we performed reviews and analysis of available production and energy data to characterize energy use in the sector. The characterization can provide a basis for performance comparison, which can suggest possible efficiency improvement opportunities.

3.3.1 Specific energy consumption, or energy use intensity

Similar to the energy metrics defined and used for cheese, we used specific energy consumption as a metric to characterize energy usage in fluid-milk processing plants and processes in this study. Specific energy consumption is defined as the energy use, primary energy or final energy (end use), divided by the production of fluid-milk products. SEC can be applied to any specific process step within a fluid-milk processing plant (Equation 3), and can be used to calculate the overall SEC of a fluid-milk processing plant (Equation 4). Overall SEC is a measurement of the total production energy use of a plant normalized by final fluid-milk production.

$$SEC_i = \frac{E_i}{P_i} \qquad \text{Eq. (3)}$$

$$SEC = \frac{\sum_{i=1}^{n} E_i}{P} \qquad \text{Eq. (4)}$$

Where:

E_i = actual energy usage of process step i

P_i = production quantity for process step i

n = number of process steps to be aggregated

P = total actual fluid-milk production

A plant or process with a lower SEC value corresponds to a similar plant or similar process that is more energy efficient. By comparing to a benchmark SEC, the information developed can be used to assess the energy-efficiency potential of a plant. The SEC can also be used for evaluating and tracking a plant's progress in energy efficiency improvements, by eliminating the effects of a change in product mix.

In order to develop meaningful SEC values for fluid-milk processes and plants, a good understanding of the fluid-milk processing is needed.

3.3.2 Dairy processes analysis and modeling

Raw milk consists of water and a variety of milk solids that include fat, casein, whey protein, lactose, organic acids, mineral substances, and a small part of miscellaneous solids. Different dairy products contain different concentrations of solids, so essentially manufacturing dairy products is mostly about concentrating and separating solids (Feitz et al. 2007). Furthermore, hygiene issues are very important as milk contains bacteria and can be very perishable (Walstra et al. 2006). To concentrate or separate solids, different techniques can be used based on controls of weight, molecular structure, boiling/freezing point, and other parameters. Sometimes microorganisms are used to enable separation and to give the product its own characteristics.

As shown in Figure 2, the fluid-milk processes typically consist of various stages: reception (transport and storage), treatment (standardization, separation, homogenization, pasteurization, sterilization, etc.), some of which require substantial amounts of energy input.

Different types of fresh milk products require different processes in dairy treatments and steps; however, some steps are similar especially at the earlier stage of the fluid-milk processing. Specifically, the first step in fluid-milk processing process is milk reception that requires transporting, storing and maintaining the raw milk at a low temperature (4-7 °C) to prevent it from perishing. The second step is typically fluid-milk treatments that require standardization of solids content (mainly fat and protein), which will involve separation and additional follow-up processes pending the products. In addition, homogenization and pasteurization of the standardized milk is required prior to making of drinking-milk and fermentation process needed for fermented products. In some cases, additional sterilization or ultra-heat treatment (UHT) would be needed to meet specific hygiene and shelf-life requirements.

During fermentation process, inoculation, incubation and stirring is required to complete the steps toward making fermented milk products such as cultured buttermilk, sour cream, fermented milks and yogurt. Yogurt is probably the most popular fermented dairy product and is produced in a variety of compositions solid and fat content, e.g., set yogurt and stirred yogurt. Set yogurt is the traditional yogurt product and is generally made of concentrated milk, but it can also be produced from non-concentrated milk. Stirred yogurt is another common yogurt type and is generally produced out of non-concentrated milk. The manufacturing process of yogurt starts with producing standardized milk. This standardized milk is homogenized and intensively pasteurized after which it is cooled to still fairly warm conditions (30-45°C). Next, the milk is inoculated with a starter. After sufficient fermentation, the product is cooled to refrigeration temperatures.

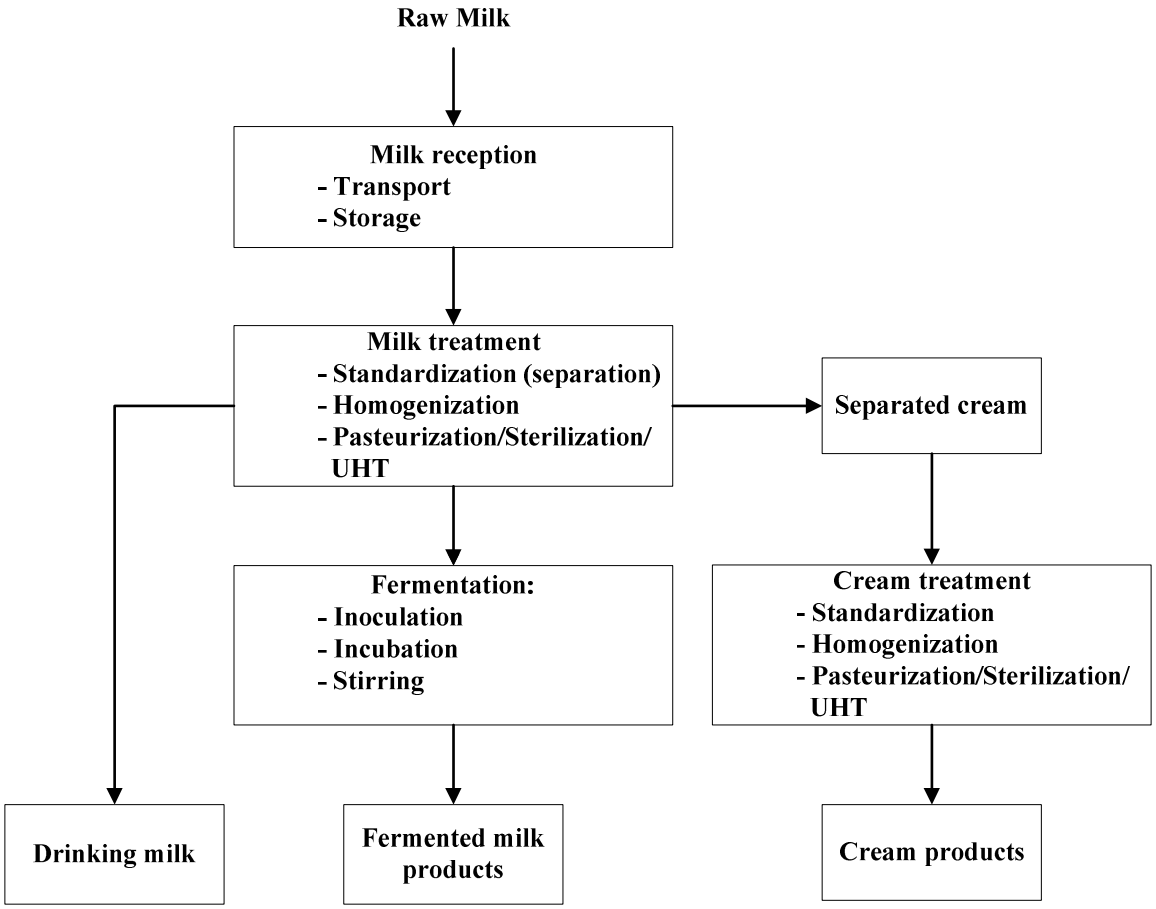


Figure 2 Analysis and modeling of major process steps in typical fluid-milk processing (CIP not shown)

For cream making, after cream is separated from milk treatment process, it needs homogenization to prevent formation of cream layer during storage unless a thickening agent is added (which is generally the case with whipping cream). It also needs to be treated to reduce microorganisms through pasteurization, sterilization or UHT. In case UHT is used, homogenization needs to be done after heat treatment; otherwise UHT will cause coagulation. After thermal treatment, cream products need to be cooled down and packed except for sterilized cream as this needs to be packed before it enters the sterilization process.

For each of these steps daily cleaning-in-place (CIP) of the process and storage equipment is also required for hygiene reasons. In general, energy use in dairy processing are associated with processes of pasteurization (e.g., heating), separation (e.g., dynamic power), biological conversion (e.g., temperature control), and hygiene requirements (e.g., refrigeration, CIP). The fluid-milk processing typically uses thermal energy (mainly natural gas) and electricity. Thermal energy (e.g., natural gas) is used in processes like pasteurization and cleaning, while electricity is used for transportation (e.g., pumps), storage (e.g., refrigeration), separation (e.g., centrifugation), and cleaning.

In this chapter, we analyzed energy data by fuel type for each process step to the extent possible, and assessed SEC levels for processes and plants for a selection of regions or countries. The analysis will illustrate energy-efficiency potential or energy-saving opportunities in fluid-milk processing plants.

3.4 Energy Benchmark and Opportunity Assessment

3.4.1 Characterization of energy usage in existing markets and fluid-milk plants

Based upon a recent study on production and energy consumption data for the dairy processing industry by country or region by Xu et al. 2009, annual milk production in the USA has maintained a positive growing trend, exhibiting an average annual growth rate of 1.3% during 1995 and 2005. Associated with the increased milk production, the total electricity use for processing milk in the USA increased at the rate of 5.7% while milk production in some European countries in the study experienced a slightly declining trend in production or the associated energy use.

Because data for California dairies is limited, this chapter will focus on a more detailed analysis of fluid-milk processing sector and its energy use in the USA (including California) and a few European countries for potential referencing, largely because of their large share in global fluid-milk production and data availability to characterize the energy use.

Table 9 summarizes our analysis of comparable information on fresh fluid-milk production as a whole (with drinking-milk production as an important subset) and associated energy consumption for the fluid-milk sector by country and region from which the data is available. The analysis includes calculating and estimating specific energy consumption (final energy end-use) for fresh fluid-milk processing on the state or national level.

Table 9 shows the total amount of raw milk processed for fluid-milk production, the total fluid-milk production, drinking milk production, and the associated final energy end use for various countries. The fluid milk production is significant compared to total amount of raw milk processed in the world's dairy processing industries as shown in Table 1. In addition, the scales of production output of fluid-milk products were dominated by drink milk production, which was close to the raw milk used in this sector. The national average of SEC values for fluid-milk production in the USA ranged from 1.0 to 1.5 MJ per kg fluid-milk, higher than that of the Netherlands (approximately 0.8 MJ per kg fluid-milk), which was equivalent to primary energy SEC value of approximately 1.05 MJ per kg fluid-milk in 2002.

Table 9. Production and final energy use for the fresh fluid-milk production sector by country and region (in 2005 unless otherwise specified)

Fresh fluid milk production	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from
Total raw milk processed for fluid-milk production [a)]	10^9 kg	30-35.0	3.3	8.6	2.2	0.7-0.8	0.8	CDFA 2006; Flapper 2009; Xu et al. 2009
Total fluid milk production	10^9 kg (%/ year)[b)]	30-35.0[c)] (n/a)	3.4 **(n/a)**	7.4 (-0.2%)	1.5 (-1.3%)	0.8 (0.1%)	0.6[d)] (-1.5%)	US Census 2004b; CDFA 2009; EC 2008; Statistics Norway 2009
Total revenue[e)]	10^9 $	$20.9[f)]	$4.0[f)]	n/a	n/a	n/a	$0.8 [d)]	US Census 2004b; Statistics Norway 2009; XE 2008
Drinking milk production*	10^9 kg (%/ year)[b)]	25-30·**0** [c)] **(n/a)**	2.9 (n/a)	6.8 (-0.3%)	0.8 (-0.9%)	0.5 (-1.3%)	0.5[d)] (-2.3%)	US Census 2004b; CDFA 2006; EC 2008; Statistics Statbank 2009
Final energy (end use)								
Total	PJ	35-45.0[g)]	-	n/a	1.2 [i)]	n/a	n/a	Census 2006; Oldenhof 2004
Overall energy intensity (SEC)	MJ / kg fluid-milk product	1.0-1.5[h)]	-	n/a	0.8[i)]	n/a	n/a	

Notes

* Drinking milk category is often the largest within fresh fluid milk products.

a) Raw milk processed is calculated by subtracting milk processed for cheese, milk powder and concentrated milk from total amount of raw milk processed, except for California. Butter is assumed to be a side product since this is produced from cream and not directly from raw milk. California raw milk processed for fresh milk products is obtained from CDFA 2006. For USA and Denmark a range is presented because of data availability.

b) Annual growth rate derived from growth between 1995 – 2005

c) The range of estimation is based on 1997 from US Census (2004b).

d) 2004 data from Norway Statistics 2009

e) $ currency conversion rates of July 1st, 2005 have been used (XE 2008)

f) Revenues for fresh products in USA and California are from 2002 and therefore probably too low for 2005 due to inflation.

g) Final energy use for both fluid milk manufacturing and butter. Final fuel energy range estimation for U.S. based on both total fuel expenditure divided by yearly gas price and maintaining electricity/fuel ratio in food industry from 2002 MECS (EIA 2007)

h) Intensity for USA has been calculated by dividing it by total amount of fresh products plus butter. A range has been presented because the production quantities are also presented in a range. The energy intensity of butter does not influence the total intensity greatly.

i) Energy use for fresh products in NLD is for the year 2002 and is derived from primary energy use (1.05 MJ per kg fluid-milk) and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in Oldenhof 2004.

3.4.2 Specific energy consumption of fluid-milk plants and processes

In power generation industry, it is very straightforward to compare energy efficiency using specific energy (energy intensity) in terms of energy use per kilowatt-hour of electricity generated because the output is rather homogeneous. In evaluating an overall dairy plant, there is a rarely a completely homogenous and identical production (output) to use as the basis for calculating energy use intensity. Producing different fluid-milk varieties also have different energy requirements, resulting from variations in process conditions and requirements, e.g., temperature, cleaning, cooking time, etc. Additional factors that influence the energy use of plants include production location (climate), plant size (capacity and layout) and age, plant utilization rate, integrated or non-integrated operation and automation, energy prices, thermal energy and electricity balances, extent of energy conservation measures adopted and usual practices in the plants. While the fluid-milk processes can be different from one another depending on various final product types, we consider specific energy consumption as a starting point to characterize energy use through normalizing by fluid-milk production mass. Table 10 presents the results from analyzing ranges of specific energy consumption among individual fluid-milk processing plants grouped by country or region (indicated in row) based upon available literatures that were reviewed in this study. The ranges of SEC values (based upon final energy use) were significant within the same country as well as across different continents. For example, the lowest total SEC (0.2 MJ/kg fluid-milk) in the USA is far less than its highest total SEC (6.0 MJ/kg fluid-milk), while data found in Canada and Australia exhibited a less yet significant spread, i.e., 0.4 to 1.1 MJ/kg fluid-milk, and 0.3 to 2.4 MJ/kg fluid-milk, respectively. In Europe, the SEC values ranged from 0.3 up to 12.6 MJ/kg fluid-milk, exhibiting difference of more than fifty times. The relative shares of fuel vs. electricity also changed from region to region. Apparently, magnitudes of the difference in SEC values in fluid-milk processing in each of the regions analyzed likely indicates significant opportunities or potentials for energy savings. Based on the SEC ranges, the lower end of the ranges noted could be used as a starting target for best practice and energy efficiency improvement in fluid-milk processing plants depending on the processes and product types.

Table 10 Ranges of final SEC values for the individual fluid-milk plants reviewed

SEC Range MJ/kg fluid-milk product	# plants	Total[a)]		Electricity[a)]		Fuel[a)]		Sources
		Low	High	Low	High	Low	High	
USA	17	0.2	6.0	0.1	3.2	0.1	3.1	IAC 2008
Canada	17	0.4	1.1	N/A	N/A	N/A	N/A	NRCAN 2001
Australia	n/a	0.3	2.4	N/A	1.2	N/A	1.1	Joyce & Burgi; 1993 Feitz et al. 2007;
Europe	n/a	0.3	12.6	0.2	2.5	0.2	1.5	IPPC 2006
Scandinavia	20	0.3	1.6	N/A		N/A		Korsstrom & Lampi 2002
Netherlands	15	0.5[b)]	5.9[b)]	N/A		N/A		Arcadis 2000

Notes:

a) Ranges in electricity and fuel consumption do not always add up to the ranges in total consumption because plants have varying distributions in electricity and fuel use.

b) Derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.385 for electricity and 1.0 for natural gas as used in Arcadis 2000. Fluid milk uses relatively a higher share of electricity so these numbers are on the higher end of the range.

In order to characterize and compare energy performance in dairy processes, it would be useful to quantify SEC values based upon process-step whenever possible (Xu et al 2009). For example, when following the process-step approach, processes with higher energy demand (i.e., higher SEC values) can be readily identified. In addition, process based SEC values can be used to compare a number of different facilities, even if their production methods and outputs may vary. Table 11 shows the average energy distribution of the process steps in 15 fluid-milk plants in the Netherland in 1998, and an energy benchmark distribution based on 17 fluid-milk plants in Canada in 2000. On average the primary energy intensity of fluid-milk plants in The Netherlands in 1998 was about approximately 1.06 MJ/kg fluid-milk, while the primary energy benchmark intensity based on Canadian plants in 2000 was about 0.68 MJ/kg fluid-milk (final SEC being 0.43 MJ/kg fluid-milk). In both countries, milk treatments accounted for 38-48% of total energy use in fluid-milk processing, followed by the main supporting processes (e.g., CIP ranged from 9% to 25%, refrigeration and cooling ranged from 2% to 19%).

Table 11 Average energy breakdown for fluid-milk plants in 1998 in the Netherlands (Arcadis, 2000) and benchmark value for Canadian plants (NRCAN 2001).

Process and System SEC (MJ per kg of final fluid-milk production		Netherlands, 1998 (primary energy)		Canadian benchmark (final energy)	
		MJ/kg	%	MJ/kg	%
Milk reception	Reception/thermization	**0.023**	2%	**0.018**	4%
	Storage	**0.076**	7%	**-**	-
Milk treatment	Standardization	**0.400**	38%	**0.018**	4%
	Pasteurization*			**0.189**	44%
Packing	Filling/packing	**0.090**	8%	**0.036**	8%
Supporting processes	Pressurized air	**0.002**	0%	**-**	-
	CIP	**0.100**	9%	**0.110**	25%
	Cooling/refrigeration	**0.200**	19%	**0.008**	2%
	Water provision	**0.060**	6%	**-**	-
	Building/HVAC	**0.095**	9%	**0.0180**	4%
	Other*	**0.014**	1%	**0.0310**	7%
Total Final SEC	**(MJ/kg fluid milk)**	**-**	-	**0.43**	(100%)
Total Primary SEC	**(MJ/kg fluid milk)**	**1.06**	(100%)	**0.68**[a)]	-

a) Primary energy calculated from final final energy by using the same conversion factors as used in the Dutch study by Arcadis (2000) (0.385 for electricity and 1.0 for fuel).

Fluid-milk processing plants included in Table 11 exhibited a national average primary SEC value of 1.06 MJ/kg in 1998, which was only slightly higher than the national average SEC value of 1.05 MJ/kg in 2002 in the Netherlands (Table 2). While differences in fluid-milk processes, types of final fluid-milk products, and other factors (e.g., plant characteristics, climate, energy prices, energy programs) contribute to different SEC values, higher national average of the fluid-milk energy intensity (i.e., final SEC value) in the USA (exhibited in Table 2) indicates that potential in energy savings could be very large because the processes that use most energy tend to be more homogeneous and that the fluid-milk market in the USA is significantly larger.

3.4.3 Discussion

Overall, the information presented tables 9 through 11has provided quantitative characterization of energy use in fluid-milk making industry by presenting the magnitudes of various energy intensity (SEC based on primary or final energy consumption) of fluid-milk processing plants, including SEC values for specific process steps. The availability of such

benchmarks based on reviews and analyses of the energy data gathered from fluid-milk processing plants around the world in this study is useful for assessing the relative efficiency of fluid-milk processing across regions, plants, or individual process steps. As a starting point, the quantitative data such as SEC values presented can be used to establish the performance target for best practices in fluid-milk processing sector. However, it is also clear that data from available open literatures that could be used to fully quantify SEC values for process-step is still limited and often fragmented for the regions and countries identified in this study. Apparently, 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 step as well as on the plant level through future energy benchmarking, including careful design of benchmarking tools and framework; and future international and regional collaboration in sharing the new data. Once more SEC values are determined through further benchmarking work, quantitative assessment of the energy efficiency for individual process steps and equipment can be made, after which the achievable energy-efficiency potential can be estimated. In this regard, developing an energy benchmarking tool that provides capability of comparing process-step energy use as well as plant energy performance appears to be the important step to address knowledge gap. Using the tool can not only facilitate gathering of energy data and but spur energy-efficiency investments in cost-effective measures. In fact, it will be useful to equip the industry with tools that could quantify energy use and the associated greenhouse emissions (e.g., carbon emissions), which may vary depending on the locations and energy sources used for fluid-milk processing. In addition, such a benchmarking can provide a dynamic performance target for best practices once new and sufficient field data have been obtained, analyzed, and integrated to the tool.

The exhibited magnitudes of energy intensity associated with different processing steps based upon this study and review suggests that future benchmarking framework should adopt process-step approach that allows the user to record detail energy-use information related to the important processes, i.e., the processes that are associated with higher SEC values, such as milk treatment (pasteurization), cooling, and clean-in-place. In addition, future benchmarking needs to account for technological change, and process improvements in the dairy processing industry over time.

3.4.3.1 Need for energy efficiency measures?

Identification and implementation of proven energy efficiency measures or emerging technologies can be cost effective, as demonstrated and studied for many industries. Using the SEC information through benchmarking, inefficient designs, processes, or systems within an individual plant can be identified by making process-specific comparisons between the energy used for each process at the plant and that used for the energy-efficiency target. Best practices can be recommended based upon SEC characterization and benchmarking. Once the inefficient designs or processes are identified, energy-efficiency technologies and measures could be identified, recommended, and implemented to improve the energy efficiency of the processes. The energy-saving measures should include cross-cutting measures that are common used in a variety of food processing or some other manufacturing industries (e.g., variable frequency control, leak repair in steam systems, and refrigeration systems), and potential process-specific measures that can be applicable to specific dairy processes (e.g., changes in production process

and pasteurization). Cross-cutting process measures may also include CIP warm water recycle, optimizing CIP cleaning, reducing electricity use cooling water pumps by better control, good-housekeeping, optimizing capacity control of cooling water pumps, increasing product capacity per unit of time within the same product line, and better use of pressurized air. Additional measures include changing cleaning cycle, reducing sterilization time, shutting down machines outside working hours, and reducing cleaning water temperature (SenterNovem 2007&2008). These crossing-cutting measures as well as process-specific measures should be included in benchmarking framework. The information made available will help the users to identify savings opportunities and assess benefits of new options of equipment, processing, and technologies over time.

3.4.3.2 Does plant size matter?

In our literature reviews, we have found that SEC values tended to correspond to the size of fluid-milk plants that exhibited similar characteristics. In the case of fluid-milk processing plants located in The Netherland exhibited in Arcadis (2000), for the five smaller plants with annual production capacity less than 50-kTon, the SEC values were mostly higher than 1 MJ/kg fluid-milk product, with the majority of the plants ranging between 2 MJ/kg and 5 MJ/kg fluid-milk product; for the eight plants with production capacity between 50-kTon and 200-kTon annual production, the majority of their SEC values were around 1 MJ/kg up to approximately 2 MJ/kg; and for the two largest plants with a production capacity between 200 and 250-kTon production, both SEC values were in the vicinity of 0.5 MJ/kg, well below the overall average SEC. While the correlation appears to be positive between the overall higher energy efficiency (i.e., lower SEC) and the larger plants, the data did not preclude the fact that some smaller plants were more efficient than the other plants. In fact, one out of the five smaller plants had a SEC value of slightly above 1 MJ/kg. Considering the similarity of fluid-milk products, processes, and climates, this indicates that while large size tended to benefit the energy efficiency-meaning that the systems and processes use energy more efficiently, significant opportunities exist for the majority of the plants to improve energy efficiency, for example, via optimizing sizes and allocation of resources of equipment, processes, and supporting systems.

3.4.3.3 Impacts of strategies and energy programs to improve energy efficiency and reduce carbon emissions in the global fluid-milk processing market – an effective example in the Netherlands

A recent study on cheese-making processes in various countries suggested that developing and promulgating an energy-benchmarking framework including process-step approach and efficiency measures should be recommended for evaluating energy performance and improving energy efficiency in cheese-making plants (Xu et al. 2009). In particular, the study has found that for cheese-making industry there was a positive association between implementation of energy-monitoring program or energy efficiency measures and the decreasing trends of specific energy consumption over time.

Similar to the cheese sector, the Dutch fluid-milk processing industry also committed itself to increasing energy efficiency through establishing energy programs that aim to assist the implementation of energy saving measures in the past decade. However, we have found from the analysis that national average primary SEC was 1.06 MJ/kg in 1998, which was only slightly higher than the national average of 1.05 MJ/kg in 2002. While the impact of energy program in The Netherlands on potential reduction of SEC could not be seemingly established if it were to be based solely on the SEC values quantified for 1998 and 2002 respectively, it is worthwhile

noting that in fact the low margins in the dairy sector have induced both a higher variety and amount of specialty products (i.e., non-drinking-milk) over the years. In fact, most of these specialty products can be found in the fluid milk sector, for example fermented products such as yogurts with different fruit flavors and packaging shapes have become more and more common in the Netherlands (SenterNovem 2007)

In summary, over the years the market share of these specialty fluid-milk products (e.g., non-drinking-milk) has increased relatively compared to the share of drinking milk, while processing specialty products in general requires additional steps than processing drinking milk, therefore, demands more energy per unit of product. Adding to the difference in processing steps was the smaller batch sizes and increased varieties in packages for the specialty products, which likely resulted in more energy use per unit of final product output. If without implementing new energy-saving measures or programs, one would expect that overall average SEC would have increased due to the increase in specialty fluid-milk products, which are known to be more energy intensive than processing drinking-milk products. Despite the fact that market demand entailed more non-drinking-milk products in the fluid-milk sector, which are more energy intensive than drinking-milk, the whole fluid-milk sector has apparently managed to curb the overall SEC average from increasing, supporting the indication that it has improved the sectoral energy efficiency and met efficiency targets (SenterNovem 2008). In addition, cutting production costs to increase the slim margins is another reason for strategically investing in cost-effective energy reduction measures (SenterNovem 2007). Based on the discussion, 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.

Mutual voluntary agreements between individual companies and the government (i.e., the Dutch Ministry of Economic Affairs) to improve energy efficiency in the dairy sector in The Netherlands exhibited improvement in the sector's energy efficiency over the last decade. New energy policy options (such as strategies, incentives, and programs) can be established based upon new energy information, dairy markets, processing technologies, and the local economies. Our reviews and analyses have shown that the Dutch dairy processing sector tends to be more energy efficient than its counterparts in a number of other countries despite the fact that it produces a lot of specialty products. Adding to the fact that the SEC varied significantly across individual fluid-milk processing plants as well as across the world, there appears to be a potential opportunity for most other countries to increase energy efficiency at a greater pace if similar policy options are developed and implemented.

Considering the vast number of factors that influence the actual energy performance and practices of fluid-milk processing plants, the significant difference exhibited in the values of SEC studied, and the limited and fragmented information available in literatures to date, it is important and necessary to develop benchmarking information, energy efficiency strategies, and energy programs as a way to improve energy efficiency, to mitigate carbon emissions and environmental impacts associated with energy wastes, while maintaining quality and supply of fluid-milk products.

3.5 Chapter Summary

This chapter has presented characterization results of energy use in fluid-milk processing based upon an extensive literature reviews and data compilation for fluid-milk production and energy use across continents, countries, or regions. Major conclusions are:

- In the fluid-milk processing industries across regions, the magnitudes of average end-use energy intensity also exhibited significant variations, with the SEC values ranging from 0.8 to 1.5 MJ per kg fluid-milk across a small number of regions and countries, a range similar to energy intensity ranging from 0.8 to 1.9 MJ per kg of raw milk processed found from several countries in a previous study.
- In the fluid-milk processing industries, the magnitudes of final energy intensity of individual plants exhibited even more significant variations, with the SEC values found ranging from 0.2 to 6.0 MJ per kg fluid-milk in the USA, and from 0.3 to 12.6 MJ per kg fluid-milk in Europe, while data found in Canada and Australia exhibited a narrower range within the scales.
- The large variations exhibited in specific energy use (final or primary) in the fluid-milk sector worldwide have indicated likely significant opportunities in energy savings in the fluid-milk-processing sector.

Because magnitudes of energy use are affected collectively by products (such as types and amount), processes, equipment, facility, plant size, location, and additional factors, significant variations in energy efficiency and energy intensity of fluid-milk processing have been identified across different countries and plants. Process-specific SEC values appear to be useful for assessing and identifying opportunities for energy savings in actual fluid-milk plants. Therefore, future benchmarking effort is recommended for expanding the energy database for characterizing SEC on the plant and process levels, which will become the base for identifying cost effective cross-cutting and process-related efficiency measures and developing new policy options for wider and global implementation.

The findings from this chapter provide a reference basis for developing and promulgating an energy-benchmarking framework including process-step approach and efficiency measures be pursued for evaluating energy performance and improving energy efficiency in fluid-milk-making industry. For example, a benchmarking tool with process-step approach should provide opportunities for the users to record detail energy-use information related to the processes that are associated with higher SEC values, such as milk treatment (pasteurization), cooling, and clean-in-place. The outcomes can be used in the integrated energy-benchmarking to be developed along with other processes in this project, including process-step approach. Available information on efficiency measures was also rather limited even though extensive literature reviews were conducted in the project.

4 CHAPTER 4: Benchmarking Butter, Milk Powder, Concentrated Milk, and Others

4.1 Introduction

We analyzed the trends of global production of raw milk (FAO 2009) and found that average annual growth rate of the world production of raw milk was approximately 1.8% during a recent decade. For the BEST-dairy project, we have found that the global cheese-making industry processes approximately one quarter of the total raw-milk production in the world (Xu et al., 2009), while the fluid milk industry processes approximately 60% of the total raw-milk production globally (Xu and Flapper, 2009).

In 2005 approximately 15% of total 645 million metric tons (MMT) global raw milk production was processed to produce other dairy products, such as concentrated milk, milk and whey powder, butter, and cream.

In addition, we performed a more detailed review of global dairy production based upon the new data (FAO, 2009; Flapper, 2009) on processing of concentrated milk, butter, and milk powder. Based upon the reviews and analyses, we hereby generated Table 12 to summarize the production and growth trends of global raw milk and its use for various dairy products, grouped by dairy product and continent or region. For example, concentrated milk and milk powder collectively accounts for more than ten percent of the total annual raw milk use globally.

According to a life cycle assessment (FOA, 2010), dairy processing industry across the globe entailed greenhouse gas (GHG) emissions, with the regional emission intensity ranging from 110- to 320-gram CO2-equivalent (CO2-eq.) per kg raw milk intake, corresponding to approximately 30- to 87-gram carbon-equivalent (C-eq.) per kg raw milk intake. Throughout this chapter, we will use carbon-equivalent values for quantifying GHG emissions associated with energy use in dairy processing across the regions. This table includes our estimated GHG emissions associated with energy use in the dairy processing sector, and indicates that the global dairy processing is responsible for over 35 million metric tons of carbon-equivalent GHG emissions annually, or 128 million metric tons of CO2 emissions annually.

Table 12 Global raw milk production used for various dairy products and carbon-equivalent GHG emissions from dairy processing in 2005

Quantity (share)	Unit	Africa	America (Northern)[a]	America (Latin)[a]	Asia[b]	Europe[c]	Pacific[d]	World[e] Total
Raw milk production	10^9 kg	32.3	88.1	66.9	217.9	215.4	24.8	645.3
	(%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)
Concentra-ted milk	10^9 kg	0.1	2.5	1.7	2.3	5.2	0.1	12.0
	(%)	(0.4%)	(2.9%)	(2.6%)	(1.0%)	(2.4%)	(0.2%)	(1.9%)
Cheese & whey	10^9 kg	7.6	42.1	8.0	12.1	85.7	5.9	161.4
	(%)	(23.7%)	(47.8%)	(11.9%)	(5.6%)	(39.8%)	(23.7%)	(25.0%)
Milk powder	10^9 kg	0.3	8.7	9.3	4.7	23.3	11.9	58.1
	(%)	(0.9%)	(9.9%)	(13.9%)	(2.2%)	(10.8%)	(47.9%)	(9.0%)
Fresh milk productsb	10^9 kg	20-24	22-37	40-48	175-196	71-106	3-8	331-419
	(%)	(63-75%)	(25-42%)	(60-72%)	(80-90%)	(33-49%)	(13-31%)	(51-65%)
Other	10^9 kg	1-3	2-9	1-7	4-22	4-22	0-2	13-65
	(%)	(2-10%)	(2-10%)	(2-10%)	(2-10%)	(2-10%)	(2-10%)	(2-10%)
GHG emissions	10^9 kg C-eq.	2	5	2	15	9	1	35

Notes:

a) Latin America includes Mexico; Northern America includes USA and Canada.

b) Asia includes China, India, Japan, among all others, except for Russia.

c) Europe include east and west European countries including Russia

d) Pacific refers to Oceania (i.e., Australia, New Zealand, Papua New Guinea, Fuji, etc.)

e) Data sources: FOA, 2009; FOA, 2010; Flapper, 2009; CBS, 2008; CMAB, 2008; DEFRA, 2009; EC, 2009; Feitz et al., 2007;PZ 2009; USDA 2009.

Based upon the data compiled for Table 12, we summarized the statistics of global dairy production and growth rates by dairy product type, which are tabulated according to continent or region (Table 13). First, annual global production of concentrated milk has been stable within the last decade, while positive growth trends are observed in Asia and Latin America coupled with negative growth rates in the other continents. Second, global butter and ghee production has been increasing at an average annual growth rate of 2.4% (similar to cheese), with a slightly decreasing rate in Europe alone. Third, annual growth rates of the global whey powder and milk powder production are in positive territories, exhibiting the annual growth rate at 1.9% and 0.5%, respectively.

Table 13 Global production and growth rates of various dairy products in 2005a

	Unit	Africa	America (Northern)	America (Latin)	Asia	Europe	Pacific	World Total
Concentrated milk	109 kg	0.0c	0.9	0.6	0.8	1.9	0.0c	4.3
	(%/yr)b	(-3.2%)	(-1.0%)	(4.1%)	(1.8%)	(-0.7%)	(-14.4%)	(0.0%)c
Butter & Ghee	109 kg	0.2	0.7	0.2	4.2	2.6	0.6	8.5
	(%/yr)b	(2.6%)	(0.2%)	(1.6%)	(5.9%)	(-1.0%)	(3.5%)	(2.4%)
Cheese	109 kg	0.9	4.9	0.9	1.4	9.9	0.7	18.7
	(%/yr)b	(4.1%)	(2.5%)	(1.3%)	(3.0%)	(2.2%)	(4.7%)	(2.5%)
Whey powder	109 kg	0.0c	0.5	0.0c	0.0c	1.6	0.1	2.2
	(%/yr)b	(1.4%)	(-2.0%)	(47.4%)	(63.5%)	(3.3%)	(5.1%)	(1.9%)
Milk powder	109 kg	0.0c)	0.8	1.1	0.5	2.4	1.3	6.1
	(%/yr)b	(-3.4%)	(0.9%)	(5.7%)	(0.1%)	(-2.6%)	(4.6%)	(0.5%)

Notes:

a) Data sources: FOA, 2009; Flapper, 2009.

b) Annual growth rate is calculated for the period 1995-2005

c) Not exactly zero, but smaller than 0.1

Because of complex treatment processes for making these dairy products, energy use in dairy processing can be very energy intensive. Compared to published energy studies on cheese and fluid-milk production (Xu et al. 2009; Xu and Flapper, 2009), little is known about the actual energy intensity levels associated with concentrated milk, butter, whey and milk powder processing. While variations in dairy processes associated with different products (e.g., concentrated milk, butter, cream, milk and whey powder, cheese, or fluid milk) are expected, energy use required for operating facility systems and processing equipment can be very different.

One would expect that along with the global production increase as exhibited in Table 13 is the increasing energy demand for the dairy processing plants that make concentrated milk, butter, and milk and whey powder. Yet there is limited availability of tools, references, or programs to address the energy concerns associated with dairy processing. Similar to cheese and fluid-milk processing sectors, our literature reviews indicate that current information on energy efficiency in the butter, concentrated milk, milk and whey powder sectors is limited and at best fragmented. In addition, there is a surprising lack of published data and research on developing strategies or tools to improve energy efficiency in these sectors. Given the significant energy use in dairy plants coupled with historic lack of programs or activities in improving efficiency, opportunities exist for energy savings through implementing crosscutting and process-specific measures.

To date, only a few dairy organizations have the staff, resources, guides, or tools to perform detailed assessments that are beneficial to identifying opportunities for reducing energy use and the associated GHG emissions. Therefore, it is important to develop an understanding of the state-of-the-art energy performance in the dairy sector. In this chapter, we built upon recent

studies on cheese and fluid milk processing (Xu et al., 2009; Xu and Flapper, 2009) and analyzed energy data from butter, concentrated milk, milk and whey powder production, with the goal of characterizing energy use and to evaluating energy savings potentials. Once energy usage in these major product groups is characterized, it will become possible to analyze various dairy sectors on an aggregate level. We can then develop appropriate methods to identify and compare SEC values on various levels (e.g., process, plant, regional, or global), which can also be subsequently used for energy benchmarking of various sectors. The outcomes would then be used to evaluate and quantify the potential in energy savings and the associated GHG-emissions reduction, and help to address the need for more data benchmarking and publication.

4.2 Chapter Objectives

The goal of the chapter is to develop information of energy use in production of various dairy products, with a focus on butter, concentrated milk and milk powder production, through performing literature reviews, conducting data compilation and analysis to characterize the production and energy usage associated with these dairy products. Subsequently, the sectoral findings will be integrated with findings from cheese and fluid-milk processing to be included in BEST-tool development. Major approaches and findings have been documented and published as a recent journal paper (Xu and Flapper 2011). In particular, this chapter will include the following major tasks:

1) Perform process analysis and modeling for various dairy products that included butter and milk powder
2) Analyze and characterize energy usage in existing global butter, concentrated milk, milk powder, and whey powder production
3) Assess and quantify the magnitudes of specific energy consumption (SEC) across countries, regions, individual plants, and processes to compare energy performance of these dairy processes
4) Summarize the information developed for integrated benchmarking framework for these sectors, including the assessing method for potential energy savings and carbon-emission reduction using the sectoral benchmark baselines developed from the lowest energy use intensity identified from the study samples.

4.3 Chapter Method

The main research method adopted in this chapter is an expansion of the methods employed in previous chapters on cheese processing and fluid-milk processing. In addition to dairy production data compiled through extensive literature reviews, we focused on the butter, concentrated milk, milk and whey powder processing industries to characterize the energy use associated with each dairy product group and its processing. Comparisons can then be made for identifying possible efficiency improvement opportunities. In addition, a metric for comparing energy intensity levels is developed for assessing potential in energy savings and carbon-emission reduction.

4.3.1 Specific energy consumption, or energy use intensity

Similar to the previous chapters, SEC in this chapter is defined as the energy use, in the form of either primary energy (i.e., source energy) or final energy (i.e., end-use energy), divided often by the production quantity of a dairy product output (e.g., butter, concentrated milk, milk powder, or whey powder). A SEC value can be applied to any specific process step within a plant (Equation 5), and can be used to quantify the overall energy use intensity of the whole plant (Equation 6). Sometimes, we may calculate the overall SEC based upon quantity of raw milk intake in lieu of dairy production as an additional way to understand actual energy intensity levels related to raw milk intake. .

$$SEC_i = \frac{E_i}{P_i} \qquad \text{Eq. (5)}$$

$$SEC = \frac{\sum_{i=1}^{n} E_i}{P} \qquad \text{Eq. (6)}$$

Where:

SECi = Specific energy consumption for process step i (MJ/kg)

Ei = Actual energy usage of process step i (MJ)

Pi = Production quantity for process step i (kg)

n = Number of process steps to be aggregated, unitless

P = Total production quantity of a dairy product (kg)

A plant or process with a lower SEC value would normally correspond to a higher level of energy efficiency when comparing with a similar plant or similar process.

4.3.2 Dairy processes analysis and modeling

A good understanding of detailed dairy processes is helpful for appropriately calculating SEC values for the butter, concentrated milk, and milk and whey powder processes and plants; however, our focus is to characterize energy use associated with typical processes and dairy plants. Therefore, in the following we only briefly summarize typical processes associated with the dairy products based upon the details described by Walstra et al. (2006) and personal communications (2009).

Butter Processing. Butter is produced from cream, which is produced out of raw milk, as illustrated in Figure 3 that we compiled from a literature review (Walstra et al., 2006). After going through milk reception and milk treatment processes, separated cream is produced for further treatment. Following standardization and homogenization of separated cream, the treated separated cream is pasteurized so that microorganisms are killed, making the cream a

better substrate for the starter bacteria. Following the cream treatment is the butter-making processing. First, a starter is added and the ripening process starts during which the cream is soured while the fat is crystallized. Then the churning process starts, during which butter grains and buttermilk are formed and separated (i.e., buttermilk is then drained off and butter grains are washed). Along with butter production is buttermilk byproduct. The subsequent working process (i.e., standardization) transforms butter grains into a continuous mass. Salt may be added to the butter grains during this process if desired. The butter can then be ready for packaging; or alternatively, it can be stored for a while followed by additional homogenization before final packaging. Cleaning-in-place (CIP) is commonly needed for dairy processing as illustrated within the boxes in Figure 3.

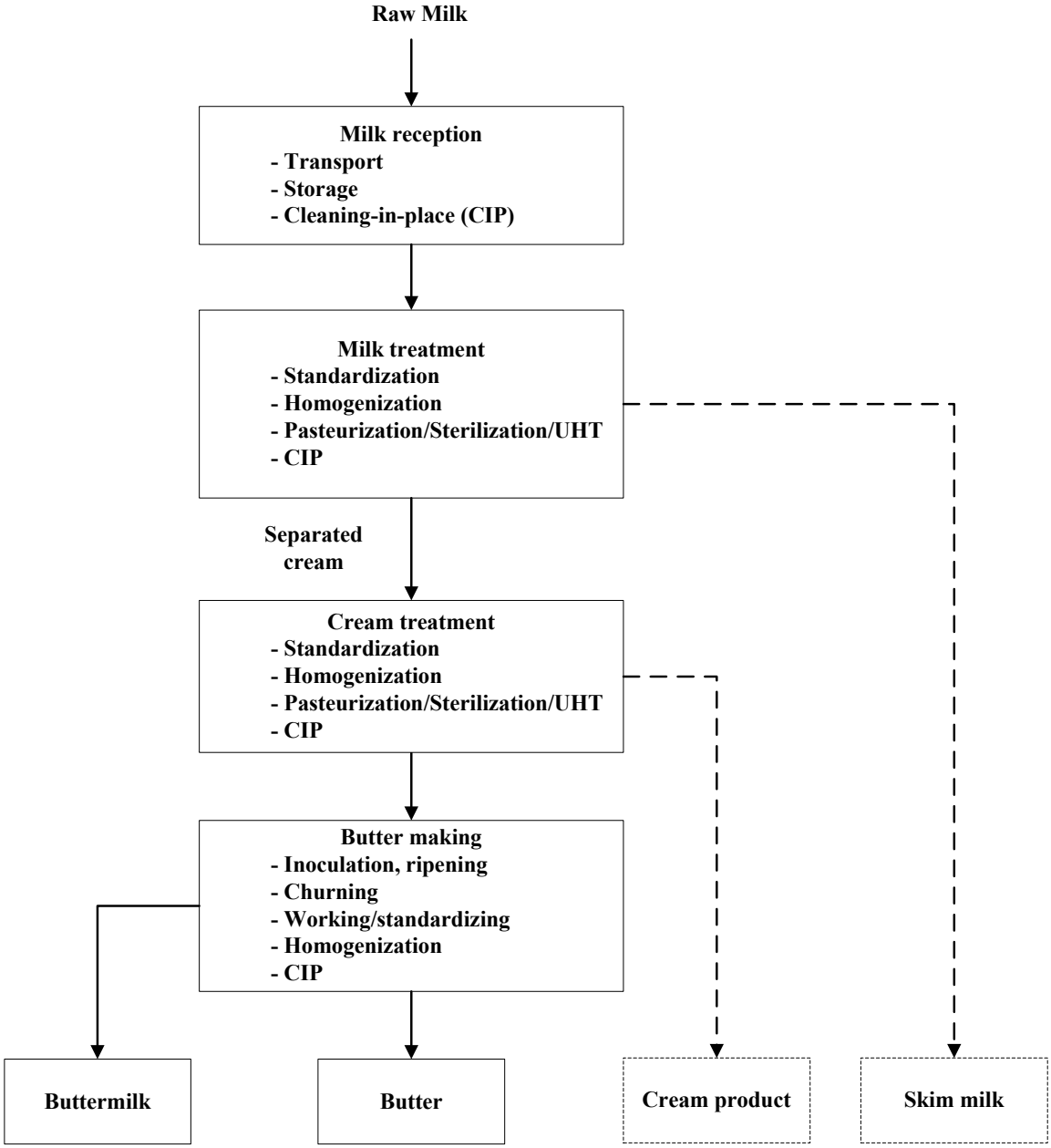


Figure 3 Analysis and modeling of dairy processing for butter products

Concentrated milk processing. Concentrated milks are fluid milk products with much lower water content than regular fluid milk. There are two different types of concentrated milk: evaporated milk and condensed milk (sweetened). Figure 4 includes major processes for concentrated milk production. The making of concentrated milk products starts with milk reception and milk treatment to produce pasteurized milk, followed by concentration processes to produce concentrated milk. The concentration processes typically include evaporation, homogenization, sterilization, and cleaning-in-place. The exact order of these treatments may differ (i.e., the steps included in the box for "concentration" in Figure 4). In addition, the pathways for in-bottle and ultra-heat treatment (UHT) sterilization can also differ, with the former being produced in the sequence of homogenization, stabilization, packaging and sterilization; while the latter being produced in the sequence of stabilization, sterilization, homogenization, and packaging.

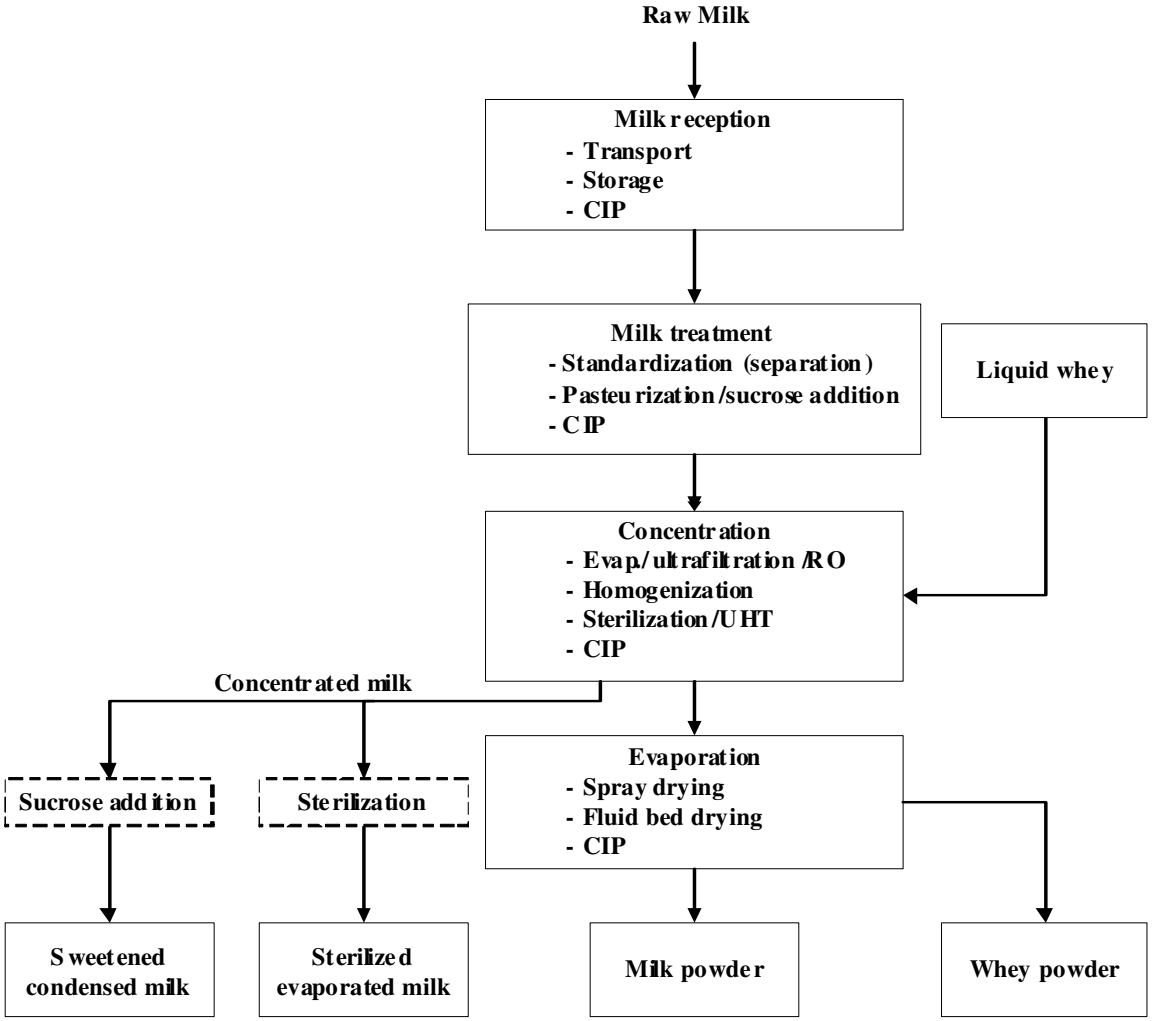


Figure 4 Analysis and modeling of dairy processing for concentrated milk and powder products

Evaporated milk is sterilized, concentrated and homogenized milk. Evaporated milk may first be heated to a certain temperature and be held for minutes or seconds pending the temperature, before undergoing vacuum evaporation, homogenization, re-standardization, and sterilization. Sweetened condensed milk is produced in a similar way to that of evaporated milk. After standardization, a preheating step using UHT is necessary to kill pathogens and spoilage organisms. Next, sweetened condensed milk is often homogenized. Subsequently, concentration is usually done by evaporation followed by addition of a concentrated sugar solution. The concentration process steps can be energy intensive (e.g., multi-effect evaporators and vapor re-compressors), so is cooling energy intensity for packaging and storage.

Milk powder. Milk powder is made from the liquid raw milk as a dairy product that can easily be kept for a long time without major quality loss or degrade. Milk powder can be made with different fat contents. The production process starts with raw milk reception, milk treatment (i.e., standardization with pasteurization), and milk concentration, as illustrated in Figure 4. After the milk concentration, water content is substantially reduced from the treated milk via evaporation. Prior to entering drying processes (evaporation), concentrated milk is heated up again to reduce milk viscosity. The subsequent drying step, generally spray drying, converts the concentrated milk into a powder, with fluid bed drying to further eliminate water contents from the milk powder. In addition, sometimes gas flushing can be used to remove oxygen from the powder. The milk powder can then be packed as the final product.

Whey powder. Whey powder is made from liquid whey drained off during the cheese-making process. Depending on the actual concentration level of liquid whey supplied from the cheese plant, it may need to be concentrated further before drying to become whey powder (Figure 4). Processing whey powder is largely similar to that of skim milk powder with a concentration and a drying step. Whey can be evaporated to at least 60% dry matter, but then crystallization of lactose readily occurs (Walstra et al., 2006). An alternative operation is to allow the lactose in the evaporated whey to crystallize as completely as possible before drying. In addition, lactose can be removed from the whey by ultra filtration before drying. This process also depends on the product specifications, e.g. desired lactose content in whey powder. Lactose extracted from the whey can be purified and made into powder trough crystallization. The obtained lactose powder can be an ingredient for pharmaceutical pills (Personal communications, 2009).

4.3.3 Energy Intensity Indicator

Energy use in processing butter, concentrated milk, milk powder, and whey powder typically uses thermal energy (mainly natural gas) and electricity to perform concentration (e.g., heating energy), separation (e.g., kinetic energy), temperature control, and hygiene requirements (e.g., CIP). Thermal energy is used in processes such as pasteurization, evaporation, and cleaning, while electricity is used for transportation (e.g., pumps), storage (e.g., refrigeration), control and separation.

In order to compare energy performance, we have further developed an aggregated approach in addition to calculating SEC values for individual dairy products or plants. The aggregation combined various dairy sectors for each region or country. As mentioned earlier, one approach is to divide the total energy use of a dairy sector by the total amount of raw milk used to produce various dairy products for an individual region. This approach can generate an aggregated SEC value based upon raw milk intake, termed as ERM (i.e., energy use per quantity of raw milk as shown in Equations Eq. (7) and Eq. (8). However, ERM cannot directly

indicate the true or accurate levels of SEC for an individual product across regions, because market shares of dairy products may vary from region to region. For instance, a region (country) with a larger portion of milk-powder production (than that of fluid milk) may easily exhibit a higher overall SEC per raw milk (i.e., ERM) than that of another country, which produces a larger portion of fluid-milk production (than that of milk powder).

$$ERM_j = \frac{E_j}{RM}, \qquad \text{Eq. (7)}$$

$$ERM_p = \frac{\sum E_j \times f_j}{RM}, \qquad \text{Eq. (8)}$$

Where:

ERMj = Fuel type j energy end use per quantity of raw milk - final energy intensity level indicated for fuel j based on quantity of raw milk processed within a certain time period (MJ/kg)

j = Fuel type j (i.e., electricity, fossil fuels)

Ej = Actual energy end-use of the dairy sector for fuel type j (MJ)

RM= Mass quantity of raw milk delivered for producing the dairy product (kg)

ERMp = Primary energy use per quantity of raw milk intake - total primary energy intensity level indicated for all fuels based on quantity of raw milk processed within a pre-determined time period (MJprim/kg)

fj = Conversion factor for fuel j - from final energy use to primary energy use.

Obviously, a simple comparison of the calculated ERM value is not necessarily sufficient to assess actual energy efficiency of dairy processing on the regional or national level. In order to compare the SEC levels and savings opportunities of all dairy sectors in different regions or countries, we need an additional approach that accounts for differences in product mixes across regions. In addition, simply using ERM alone, without taking into account the possible changes in dairy product mixes over time, can also bias the understanding of real efficiency developments even within the same region.

Similar to the method presented by Phylipsen et al. (1998) and Farla (2000), we established an energy intensity indicator (EII) that accounts for the product mix for a given region. The EII is defined as the actual energy use divided by a reference value of energy use for a product. A higher EII value indicates that the process or plant is more energy intensive than that of the reference case, and that energy savings potential for the same product may be higher. With the same production for a specific dairy product, actual SEC and reference SEC values for the product can be used to calculate the EII for the product.

In calculating the reference value of energy use for a region or country, the lowest SEC value of a specific dairy product may remain the same (e.g., assuming that no technological changes in

energy efficiencies would have taken place) while product mixes (e.g., physical product quantities) may change over time. In order to calculate EII corresponding to a fuel type, we first calculate the reference value of energy use for all products in a region, by summing the multiplications of an individual product's reference SEC value (i.e., the lowest SEC value identified from the samples compiled in this study) and its actual production quantity within the region (exhibited in Eq. (9) for fuel type j). We then divide the total actual energy use by this reference energy use to obtain EIIj for fuel type j, using Eq. (10). The calculated EII value indicates the degree of deviation of actual energy use from that of the reference case, with the latter being a theoretical value for a certain region. Applying this metric to dairy processing industry on a regional or national level can enable a simple comparison between countries with different product mixes, and may allow for further analysis of the efficiency progress over time.

In this chapter, we develop additional performance metric to characterize energy performance of dairy processing sector across countries, based upon the product primary SEC values and product mixes for each region selected. Eq. (11)and Eq. (12)show the calculations of reference primary energy use for each fuel (i.e., Fj,p for fuel type j) and primary EII (i.e., EIIp) values based upon primary energy use and product mixes for one selected region.

$$F_j = \sum P_i \times SEC_{ref\ i,j} \qquad \text{Eq. (9)}$$

$$EII_j = \frac{Actual\ energy\ end\ use\ for\ fuel\ j}{Reference\ energy\ end\ use\ for\ fuel\ j} \cong \frac{E_j}{F_j}, \qquad \text{Eq. (10)}$$

$$F_{j,p} = \sum_i (P_i \times SEC_{ref\ i,j} \times f_j) \qquad \text{Eq. (11)}$$

$$EII_p = \frac{\sum_j (E_j \times f_j)}{\sum_j F_{j,p}}, \qquad \text{Eq. (12)}$$

$$PES_j = E_j - \sum_i (P_i \times SEC_{ref\ i,j}) \qquad \text{Eq. (13)}$$

$$PES_p = \sum_j PES_j \times f_j \qquad \text{Eq. (14)}$$

$$PCR = \sum_j (PES_j \times e_j) \qquad \text{Eq. (15)}$$

Where:

i = Type of dairy product fuel (e.g., butter, milk powder, cheese, etc.)

j = Type of fuel (i.e., electricity, fossil fuels)

Fj = Reference final energy use for fuel j based on the reference SEC for each product and its production quantity.

Pi = Physical production quantity of dairy product i (kg)

SECref i,j = Specific energy consumption of a certain dairy product i and fuel j (e.g., in MJ final energy per kg of product i)

Ej = Actual final energy use of the dairy sector for fuel j (MJ)

EIIj = Energy intensity indicator for fuel j based on reference energy end-use calculated by the final product quantities, (dimensionless). A higher EIIj value tends to indicate a lower energy efficiency level.

Fj,p = Reference primary energy use for fuel j based on a reference SEC for each product and its production quantity.

fj = Conversion factor for fuel j from final energy use to primary energy

EIIp = Primary energy intensity indicator for all dairy products in a region (dimensionless). A higher EIIp value tends to indicate a lower energy efficiency level.

PESj = Potential Energy Savings for fuel j.

PESp= Potential primary energy savings in a region.

PCR = Potential carbon reduction in a region.

ej = Carbon emission factor for fuel j

Using the lowest SEC as the baseline reference, we can estimate potential energy savings (PES) and potential carbon reduction (PCR) of the dairy processing industry for each region or country. Eq. (13) calculates the potential energy savings for fuel j within a region or country using the lowest SEC as the reference within the region. Eq. (14) and Eq. (15) calculate the potential primary energy savings and the associated carbon reduction respectively within a region. Because the calculated EII is the ratio of actual energy use to the reference energy use that corresponds to the lowest energy intensity level identified from benchmarking samples within a region, it indicates the extent of potentials for energy savings in the region. A higher EII value indicates that there can be a higher degree of potential in energy savings for the selected country or region.

4.4 Energy Benchmark and Opportunity Assessment

4.4.1 Characterization of global and regional production and energy usage in butter, concentrated milk, milk powder, and whey powder sectors

As shown in Table 13, Asia and Europe are by far the largest annual butter producers in the world, with Asia being the lead. Asia also exhibits a strong annual growth rate (i.e., 5.9%), even stronger than its growth in raw milk production, while Europe is the only continent showing a declining rate in annual butter production (i.e., -1.0%). Second, Europe is the largest annual concentrated milk producer, albeit showing a slight declining rate. The production of concentrated milk is only increasing in Latin America and Asia. Third, as the largest milk powder producer, Europe experiences a noticeable declining rate (i.e., -2.6% per year) in annual production. Latin America and the Pacific regions show the highest annual growth rates (i.e., 4.6-5.7%). Finally, annual whey powder production is only significant in Europe and Northern America, with the former having a positive annual growth rate and the latter having a negative annual growth rate.

In this study, we consider all butter production as a byproduct from other dairy processes. Essentially butter production is made from cream that is a byproduct of fresh milk cheese, milk powder production. The following presents the results from our data compilation and analyses.

Table 14 shows that the European countries (except for Great Britain) exhibited a decline in annual butter production from 1995 to 2005. Along with a growing raw milk production, butter production in the USA and California exhibited positive annual growth rates. Table 3 also includes our estimation of final energy and primary energy intensity in butter processing across the regions selected. The primary SEC value was calculated using Eq. (6) based upon the energy data compiled from literature (Oldenhof, 2004). The final SEC value was estimated based upon the assumptions noted in Table 14("d"). From the searchable literature, we have found that only The Netherlands had relevant data for the SEC calculation and estimation, i.e., the primary SEC was 2.6 MJprim per kg butter, with the final SEC estimated as approximately 2.1 MJfinal per kg butter in 2002.

Table 14 Production and energy use for the butter sector (2005 unless stated otherwise)

Butter products sector	Unit	The United States USA	USA California USA-CA	Great Britain GBR	The Netherlands NLD	Denmark DNK	Norway NOR	Derived from
Butter production	10^6 kg	612	185	130	125	44	14	USDA (2009);
	(%/ year)[a]	(0.6%)	(1.6%)	(0.2%)	(-0.3%)	(-1.5%)	(-1.5%)	FAO (2009);
								CBS (2009);
								EC (2009);
Revenue[b,c]	10^6 $	$2000	n/a	n/a	$600	n/a	$80	US Census (2004c);
								CBS (2009);
								Statistics Norway (2009);
								XE (2009)
Final energy end use								
Total	TJ	n/a	n/a	n/a	249[d]	n/a	n/a	
Intensity or SEC	MJ / kg product	n/a	n/a	n/a	2.1[d]	n/a	n/a	
Primary energy use								
Total	TJ	n/a	n/a	n/a	308[e]	n/a	n/a	Oldenhof (2004)
Intensity or SEC	MJ / kg product	n/a	n/a	n/a	2.6[e]	n/a	n/a	Oldenhof (2004)

Notes

a) Annual growth rate derived from growth between 1995 – 2005

b) $ currency conversion rates of July 1st, 2005 have been used (XE, 2009)

c) Revenues numbers for butter in USA were for 2002 and therefore probably too low for 2005 due to inflation.

d) Energy end use for butter products in NLD is derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in Oldenhof (2004). Whenever data is available, actual fuel split and conversion factor should be used for each region or country.

e) Energy use values for butter products in NLD were for 2002.

Table 15 presents the production and energy use data, when available, of the selected regions for concentrated milk products in 2005. Table 15 shows that the annual concentrated milk production is declining in all countries studied, while only California exhibits a positive annual growth rate. Similar to the butter sector, Table 15 also includes our estimation of final energy and primary energy intensity in concentrated milk processing across the regions selected. The primary SEC value was calculated using Eq. (6) based upon the energy data compiled from literature (Oldenhof, 2004). The final SEC value was estimated based upon the assumptions noted in Table 15("f"). From searchable literature, we have found that only the Netherlands

had relevant data for the SEC calculation and estimation, i.e., primary SEC was 2.5 MJprim per kg concentrated milk product, with final SEC estimated as approximately 2.0 MJfinal per kg concentrated milk product in 2002.

Table 15 Production and energy use for concentrated milk products sector (2005 unless stated otherwise)

Concentrated milk sector	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from
Raw milk processed	10^6 kg	2370a	1340a	482	620	23b	30b	CMAB (2008); DEFRA (2009); PZ (2009)
Concentrated milk production	10^6 kg (%/ year)c	862 (-0.1%)	485d (1.1%)	143 (-2.4%)	292 (-1.4%)	9 (-3.3%)	11 (-9%)	USDA (2009); EC (2009); CBS (2009); FAO (2009)
Revenue	10^6 $	$2065e	n/a	n/a	n/a	n/a	n/a	Census (2004d)
Energy end use								
Total	TJ	n/a	n/a	n/a	614f	n/a	n/a	
Intensity or SEC	MJ / kg product	n/a	n/a	n/a	2,0f	n/a	n/a	
Primary energy use								
Total	TJ	n/a	n/a	n/a	758g	n/a	n/a	Oldenhof (2004)
Intensity or SEC	MJ / kg product	n/a	n/a	n/a	2,5g	n/a	n/a	

Notes

a) Raw milk to concentrated milk ratio for the USA is assumed to be similar to that of California. For California, the raw milk to concentrated milk ratio is taken in between that of GBR and NLD. In a report of CMAB (2008), the raw milk use for both concentrated milk and powder is stated. The raw milk use for condensed milk plus the raw milk use for milk powder in Table 5 compares well with this number.

b) A 2.6 times concentration as mention in Walstra et al. (2006) is used to calculate DNK and NOR raw milk use for concentrated milk.

c) Annual growth rate derived from growth between 1995 – 2005

d) Total concentrated milk production data for California was only available for 2007. Unsweetened data was available for the years 1995-2005. Total concentrated milk production is calculated by assuming that the split between sweetened (298 106 kg) and unsweetened (349 106 kg) concentrated milk has not changed.

e) Revenue was estimated based on 2005 revenue data for the concentrated milk and milk powder sector combined using the same split in 2002 revenue between those concentrated milk (2117 million dollars) and milk powder (4221 million dollars).

f) Energy end use for concentrated milk in NLD is derived from primary energy use and converted back to electricity and natural gas use, by using the same split as the entire dairy industry (due to lack of more detailed data information) and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in Oldenhof (2004). Whenever data is available, the actual fuel split and conversion factor should be used for each region or country.

g) Energy use values for concentrated milk products in NLD are from 2002.

The powder products mainly consist of milk powder for which production and energy data are presented in Table 16. Some European countries exhibited decreasing annual milk powder production (i.e., Great Britain, Denmark and Norway), while the USA and especially California exhibited considerable growth with the annual growth rate at 1.1% and 4.2%, respectively. Annual milk-powder production in the Netherlands was more or less stable over the years.

Table 16 also includes our estimation of final energy and primary energy intensity in milk powder processing across the regions selected. From searchable literature, we have found that only the Netherlands had relevant data for the SEC calculation and estimation. The primary SEC value was calculated using Eq. (6) based upon the energy data compiled from literature (Oldenhof, 2004). The final SEC value was estimated based upon the assumptions noted in Table 16("g"). The primary SEC was 12.8 MJprim) per kg milk powder, with final SEC estimated as approximately 10.3 MJfinal in 2002. This was higher than the SEC values applicable to all other dairy products (Xu et al., 2009; Xu and Flapper, 2009).

Table 16 Production and energy use for the milk powder sector (2005 unless otherwise specified)

Milk powder sector	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from
Raw milk processed	10^6 kg	7900a	3600a	1600	1400	900b	70	CMAB (2008); DEFRA (2009); PZ (2009)
Powder products production	10^6 kg	740	340d	168	160	109	7	FAO (2009);
	(%/ year)c	(1.1%)	(4.2%)	(-1.6%)	(0.1%)	(-2.0%)	(-1.3%)	USDA (2009); EC (2009); CBS (2009)
Revenuee	10^9 $	$4300f	n/a	n/a	$500	n/a	$20	Census (2006); Census (2004d); CBS (2009); Statistics Norway (2009)
Energy end use								
Total	TJ	n/a	n/a	n/a	1723g	n/a	n/a	
SEC	MJ / kg powder	n/a	n/a	n/a	10.3g	n/a	n/a	
Primary energy use								
Total	TJ	n/a	n/a	n/a	2127h	n/a	n/a	Oldenhof (2004)
SEC	MJ / kg powder	n/a	n/a	n/a	12.8h	n/a	n/a	

Notes

a) Raw milk to milk powder ratio for the USA, California and Norway is based on the ratio of skim and whole milk powder in GBR. For California this number plus the raw milk use for concentrated milk compares well with the raw milk use mentioned in a report of CMAB (2008).

b) Raw milk use for milk powder in Denmark is estimated to be slightly lower than the GBR ratio due to the amount of raw milk needed for other products. It is based on whole milk powder ratio as mentioned in Feitz et al. (2007) and the same skim milk powder yield as in GBR and was rounded.

c) Annual growth rate derived from growth between 1995 – 2005

d) Only skim milk powder production data of California are published. Therefore, the same split between skim and whole milk powder as in the USA is used. Since California produces almost 50% of all milk powder, this is a reasonable assumption. In addition, a change in whole milk production will not significantly change the total.

e) $ currency conversion rates of July 1st, 2005 have been used (XE, 2009)

f) Revenue data for the milk powder sector was only available for 2002, while revenue data for the dry and condensed milk sector was available for 2005. Revenue was estimated by using the same split in revenue as in 2002.

g) Energy end use for milk powder in NLD is derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in Oldenhof (2004). Whenever data is available, actual fuel split and conversion factor should be used for each region or country.

h) Energy use values for milk powder products in NLD are from 2002.

Table 17 shows whey powder production and its energy use data, when available, across the selected regions. It also includes our estimation of final energy and primary energy intensity in whey powder processing across the regions selected. From searchable literature, we have found that only the Netherlands had relevant data for the SEC calculation and estimation. The primary SEC value was calculated using Eq. (6) based upon the energy data compiled from literature (Oldenhof, 2004). The final SEC value was estimated based upon the assumptions noted in Table 17 ("c"). The primary SEC was 7.4 MJprim per kg whey powder, with final SEC estimated as approximately 6.0 MJfinal per kg whey powder in the Netherlands in 2002.

Table 17 Production and energy use for whey powder sector (2005 unless otherwise specified)

Whey powder sector	Unit	USA	USA-CA	GBR	NLD	DNK	NOR	Derived from
Whey powder production	10^6 kg	472	105b	56b	268	37	11b	FAO (2009);
	(%/ year)a	(-1.2%)	(n/a)	(1.0%)b	(0.7%)	(1.6%)	(n/a)	CMAB (2008); CBS (2009); EC (2009); Statistics Norway (2009)
Energy end use								
Total	TJ	n/a	n/a	n/a	4147c	n/a	n/a	
SEC	MJ / kg powder	n/a	n/a	n/a	6.0c	n/a	n/a	
Primary energy use								
Total	TJ	n/a	n/a	n/a	5154d	n/a	n/a	Oldenhof (2004)
SEC	MJ / kg powder	n/a	n/a	n/a	7.4d	n/a	n/a	

Notes

a) Annual growth rate derived from growth between 1995 – 2005

b) 2007 data for California, 2004 data (and growth based on 1995-2004) for GBR and 2002 data for Norway.

c) Energy end use for whey powder in NLD is derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.4 for electricity and 1.0 for natural gas as used in Oldenhof (2004). Whenever data is available, actual fuel split and conversion factor should be used for each region or country.

d) Energy use values for butter products in NLD are from 2002.

In summary, for the majority of the countries except for the Netherlands, no energy information was available, which deterred further analysis that would have been useful for the various dairy sectors and various countries. It is important to note that more activities should be promoted to establish benchmarking and to improve databases on energy across the world.

4.4.2 Specific energy consumption of butter, concentrated milk, milk powder, and whey powder at the plant or process levels

Similar to other dairy products such as cheese and fluid milk, dairy output of butter, concentrated milk, and powder is heterogeneous. Producing different varieties also have different energy requirements, resulting from variations in process conditions, such as equipment, temperature, cooking time, etc. Additional factors that influence the energy use of plants include production location (climate), plant size and age (Xu et al., 2009; Xu and Flapper, 2009; Flapper 2009). Using SEC as the performance metric at the plant or process levels allows simple comparisons and characterization of energy use through normalization.

Table 18 summarizes the results from analyzing the compiled data obtained via extensive literature research. The two sample butter plants in the US exhibited large SEC difference (by a factor of two). With regard to the data for different years in Australia, we noticed that the sample butter plants' SEC values decreased significantly over the decade (1982 to 2007). However, the 2007 study was on one plant while the previous study (Joyce and Burgi, 1993) was based upon the average SEC from a survey performed in 1982. We have also found that the SEC ranges for butter production exhibited a considerable range, i.e., from 1.0 to 3.7 MJ per kg butter even with a small sample size (for five plants within the Netherlands alone).

Table 18 Ranges of final SEC values for individual butter plants reviewed

SEC Range MJ/kg butter	# plants	Total Range	Electricity Range	Fuel Range	Sources
USA	2	1.0 – 2.0	0.5 – 0.8	0.5 – 1.2	IAC (2009)
Australia	n/aa,b	2.1a – 4.2b	0.5a – 0.7b	1.6a – 3.5b	Feitz et al. (2007); Joyce and Burgi (1993)
Netherlands	5	1.0c – 3.7c	N/A	N/A	Arcadis (2000)

Notes:

a) Based on the SEC of one plant (Feitz et al., 2007)

b) Based on average of a survey in 1982 (Joyce and Burgi, 1993)

c) Derived from primary energy use and converted back to electricity and natural gas use by using the same split as the entire dairy industry and a conversion factor from primary to final of 0.385 for electricity and 1.0 for natural gas as used in (Arcadis, 2000).

Table 19 presents the plant-level SEC values calculated for concentrated milk production among different countries and regions. A wide range among the SEC values is observed among the limited sample plants. For example, two plants in the USA had the SEC values that differed more than three times (1.8 MJ per kg concentrated milk vs. 7.5 MJ per kg concentrated milk), while the SEC values of seven plants in the Netherlands varied from 2.1 MJ / kg concentrated milk to 10.8 MJ / kg concentrated milk, showing a difference of more than four times.

Table 19 Ranges of final SEC values for individual concentrated milk plants reviewed

SEC Range MJ / kg conc. Milk	# plants	Total Range	Electricity Range	Fuel Range	Sources
USA	2	1.8a – 7.5b	0.4a – 0.8b	1.3a – 6.7b	IAC (2009); Morgan (2006)
Netherlands	7	2.1c – 10.8c	N/A	N/A	Arcadis (2000)

Notes:

a) Based on energy data of a plant presented by IAC (2009)

b) Based on energy data of a plant presented by Morgan (2006)

c) Converted back from primary energy using same split as for the entire Dutch dairy sector

Table 20 summarizes the final SEC values for individual milk powder plants in different regions. In Australia, the lowest final SEC was 4.6 MJ per kg milk powder, which was more than five times lower than its highest SEC value (i.e., 28.8 MJ per kg milk powder). In Europe, the final SEC values among selected plants ranged from 10.3 to 221.4 MJ / kg milk powder. In addition, 15 plants in Scandinavia had final SEC values ranging from 6.2 to 31.5 MJ/kg milk powder, while 12 milk powder plants in the Netherlands exhibited a narrower range, from 8.7 to 16.4 MJ/kg milk powder. It is interesting to note that even though Scandinavia and the Netherlands tended to be first in terms of using modern equipment and energy focused, and had relatively more homogeneous climates within the countries, their plants still exhibited wide ranges in the SEC values. The variations may partly be attributed to technological changes and implementation of environmental regulations in the last decade or more, among other factors.

Table 20 Ranges of final SEC values for individual powder plants reviewed

SEC Range MJ / kg powder	# plants	Total[a] Range	Electricity[a] Range	Fuel[a] Range	Sources
USA	1	11.1	1.9	9.2	IAC (2009); Morgan (2006)
Australia	n/a[b,c,d]	4.6b – 28.8[b]	1.4[c] – 1.4[d]	10.2[d] – 20.6[d]	Joyce & Burgi (1993); Feitz et al. (2007); Prasad et al. (2004)
Europe	n/a [e]	10.3 [e] – 221.4 [e]	0.6 [e] – 31.4 [e]	28.5[e] – 190.0	IPPC (2006)
Scandinavia	15	6.2 – 31.5	1.6[f]	12.6[f]	Korsstrom & Lampi (2002)
Netherlands	12	8.7 – 16.4	N/A	N/A	Arcadis (2000)
Great Britain	n/a	20.7[g]	N/A	N/A	ETSU (1998)
Kenya	1	12.7	0.9	11.8	Okoth (1997)

Notes:

a) Ranges in electricity and fuel consumption do not always add up to the ranges in total consumption because plants have varying distributions in electricity and fuel use.

b) Based on a range presented in Prasad et al. (2005) for Australian plants

c) Average consumption based on a survey in 1982 (Joyce & Burgi, 1993) among Australian plants.

d) SEC of one Australian plant (Feitz et al., 2007).

e) Range presented in IPPC (2006) for Europe. Lower end of the total energy range is a BAT level presented in this report. The other numbers are actual consumption levels found in plants.

f) The electricity and fuel consumption split for only one Scandinavian plant was reported in Korsstrom & Lampi (2002).

g) Average in the UK in 1998.

Overall, significant difference is observed among the plant-level SEC values within a region and across regions. We understand that a plant with the lowest SEC may not be always the most energy efficient. However, the existing literature generally fell short of providing detailed information such as locations, equipment, and processes; therefore, choosing the plants with the lowest SEC values among the available study samples is a starting point for defining a reference plant for comparisons. Such a reference plant is referred as "best existing practice" by exhibiting the lowest SEC value from the available samples in a given region. The identification and information of the reference plant should be expected to evolve over time, as more comparable information and samples are made available. The observed difference in plant-level SEC values

indicates that potential for energy savings is likely to be significant when comparing with the "best existing practice" reference plants derived from the study samples.

Table 21 shows calculated primary SEC values for milk powder processes in actual powder plants, based on the data compiled from the 12 milk powder plants included in Arcadis (2000). We have found that milk concentration and drying steps accounted for the majority of energy use in the powder plants compared to the rest of the processing steps. However, with the preliminary understanding that milk concentration and drying is among the major steps that use significant energy, it would be useful to perform more benchmarking to quantify the final SEC values for individual process steps in more plants to identify energy intensive steps. For milk powder processes, the major energy consuming steps (such as milk concentration and drying) should be first examined for potential energy efficiency improvement.

Table 21 Primary energy breakdown for milk powder plants in 1998 in the Netherlands

Ranges in total primary energy use	Process SEC[a]	Share of processes[b]
Milk reception and Milk treatment	0.2c – 0.4c	2% – 4%
Concentration	3 – 6.5	27 – 40%
Drying	3 – 7.5	27 – 45%
Packaging	0.1 – 0.2	1%
Other	n/a	10 – 43%
Total milk powder	9.5 – 18	100%

n/a – not available

a) Ranges are based on the published data from 12 Dutch powder plants (Arcadis, 2000)

b) The detailed method for this estimation was described in Flapper (2009).

c) The processes may also include thermization and pasteurization.

4.4.3 Dairy processing sector energy efficiency analysis on national level

4.4.3.1 National Energy Consumption per Raw-milk Quantity

In combination with the findings from prior energy studies on cheese and fluid milk (Xu et al., 2009; Xu and Flapper, 2009), the SEC values based upon raw milk quantity for various dairy products are calculated in this chapter to illustrate national SEC levels of the dairy processing sector across countries, without discerning the impact of different product mixes across countries. In particular, we use Eq. (7) to calculate the annual SEC levels (energy use per raw milk, ERM) for fuels (fuel and electricity) in each of the selected countries in this study from year 1996 to 2006. The data on fuel energy use and raw milk quantity per country was compiled based upon a recent study (Flapper, 2009). Figure 5 and Figure 6 show the dairy sector's annual final SEC (or ERM) on the national level between 1996 and 2006.

Annual fuel end use (i.e., equivalent natural gas) in a country's dairy processing sector is divided by the total raw milk processed for all dairy products in the country. From Figure 5, we

observe that the USA, the Netherlands and Denmark all exhibited relatively higher fuel SEC values than others did. For Figure 6, annual electricity end use in a country's dairy processing sector is divided by the total raw milk processed for all dairy products in the country. Figure 6 shows that Norway had the highest electricity use per kg raw milk, while the Netherlands clearly had the lowest electricity consumption per kg raw milk. Significant difference is observed in the final energy use (by fuel and electricity use, respectively) per kg of raw milk among the selected countries.

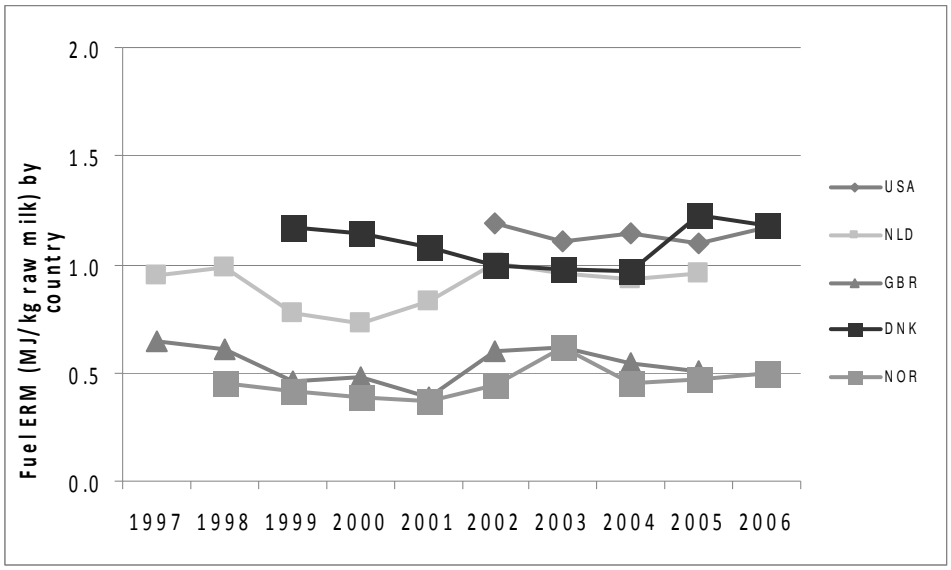


Figure 5 Fuel ERM of the dairy processing sector across selected countries

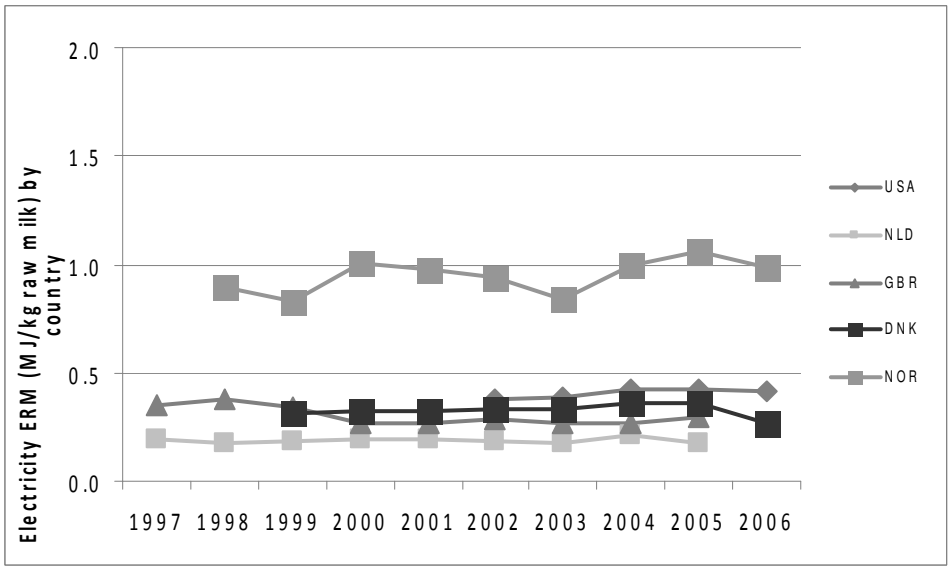


Figure 6 Electricity ERM of the dairy processing sector across selected countries

Applying Eq. (8) using the final energy end use and raw milk quantities per country allows estimation of national primary energy use per raw milk of the dairy processing sector across selected countries. Figure 7 shows the national primary SEC values (i.e., primary energy per kg of raw milk, or primary ERM) for the same set of countries, by converting final energy data to primary energy using a primary energy to electricity conversion factor of 0.4. It is plausible to use one conversion factor for all countries since the aim of this indicator is to address the energy intensity of the dairy sector regardless of the energy systems implemented. On the other hand, energy systems should be taken into account when carbon emissions associated with the energy use are estimated. The Norwegian dairy industry uses the highest level of primary energy annually per kg of raw milk, ranging from 2.5 to 3.2 MJprim/ kg raw milk), while USA and Denmark had the annual primary SEC values over 2.0 MJ / kg raw milk. It is interesting to note that with the highest annual primary energy consumption per kg of raw milk in the Norwegian dairy industry; its electricity is all generated by hydropower (IEA, 2008). Great Britain had the lowest annual primary SEC value with the Netherlands being the second lowest SEC value despite the fact that both countries had the highest fossil-fuel SEC levels. In addition, Canada had a total final energy intensity of 1.5 MJ per kg raw milk (FAO, 2009; NRCAN, 2001) in 1997, with the primary SEC being estimated in the range of 1.8-2.3 MJprim per kg raw milk. If the same split as for the benchmark plant in NRCAN (2001) is used, we estimated that the primary SEC was approximately 2.0 MJprim per kg raw milk.

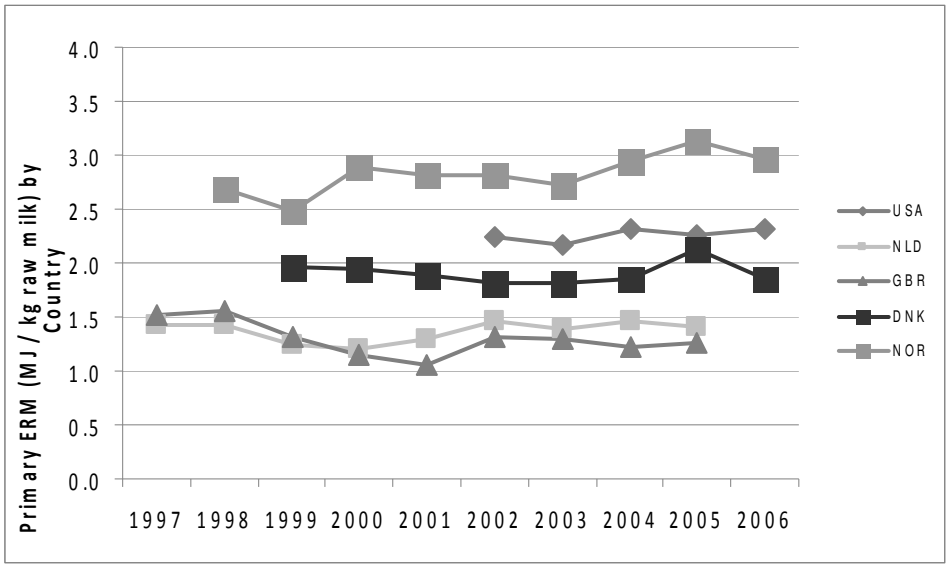


Figure 7 Primary energy use per kg of raw milk (ERM) of the dairy processing sector across selected countries

From Figure 7, we observe that the national primary SEC (or ERM) values for dairy processing had changed on the annual basis - mostly from 1997 to 2006. Denmark exhibited a negative annual ERM growth trend (except in 2005), while Norway showed a positive growth trend, and the other countries listed hovered more or less within a narrow range without displaying a clear trend in primary ERM changes over time. While primary ERM values calculated for the dairy processing sector based upon raw-milk intake can illustrate the levels of energy use intensity on the national level, they would not elucidate the impact of dairy product mix for the nation.

4.4.3.2 National Energy Intensity Indicator for Dairy-processing Sector

Because actual mix of dairy product types within each country is also a factor affecting actual energy shares (e.g., electricity or fuels) and energy usage, we first applied Eq. (11) to obtain reference primary energy use for each fuel. In calculating reference primary energy use, we used actual dairy product quantities (Pi) within a country, and the reference primary SEC for each dairy product group (SECref,i,j) as the required input. The actual dairy product quantities in the selected countries, and primary SEC values for each dairy product used for the calculation are based upon the findings presented in Table 14 through Table 17 in this chapter, Xu et al. (2009), and Xu and Flapper (2009).

Because there is no national primary SEC value available for all countries except for the Netherlands, as a starting point, we used the primary SEC values from the Netherlands as the reference SEC to establish the reference value of primary energy use for each country. Based upon the reference primary energy use and actual energy use in each country, we then applied Equation 8 to calculate the energy intensity indicator based upon primary energy (EIIp). Figure 8 presents the primary EIIp values for each of the selected countries from 1997 to 2006, accounting for changes in product mixes across countries in each year. Figure 8 illustrates that there was slight increasing trend in EII p values in some of the selected countries.

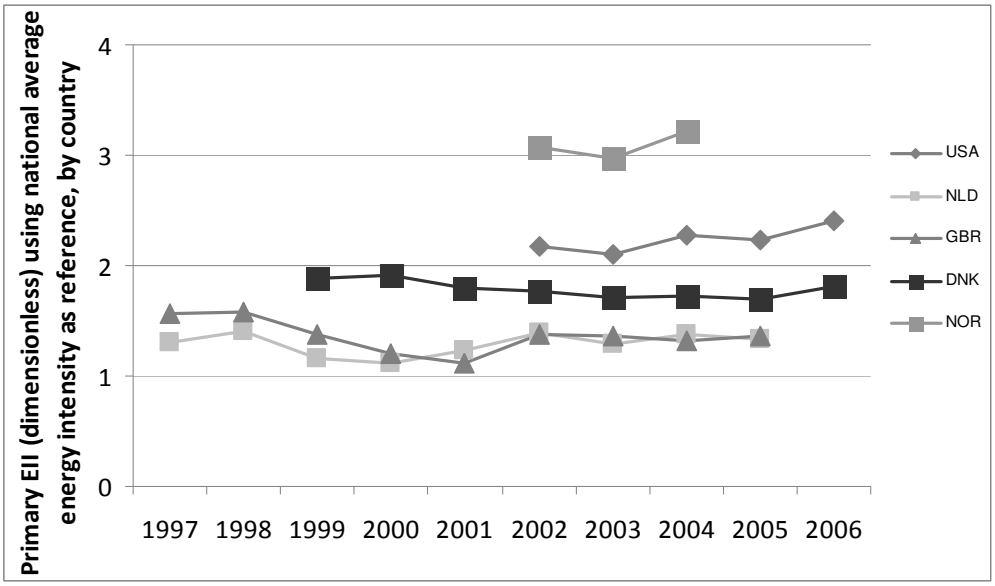


Figure 8 Primary EII values accounting for product mixes across the selected countries

Comparing and correlating EIIp values from Figure 8 with ERM values in Figure 7 (i.e., for which no product-mix correction was applied) may enable us to assess the influence of changes in product mixes on actual energy use, which can in turn provide more insight in identifying efficiency improvement opportunities. In fact, Figure 8 shows that the Netherlands exhibited lowest primary EIIp from 1997 to 2006 – indicating the highest degree of energy efficiency; while Figure 7 shows that Great Britain exhibited the lowest primary ERM values from 2001 to 2006 – indicating that its dairy-processing industry used the least energy per raw milk intake.

This comparison infers that the actual dairy product mixes and their associated processes in the Netherlands could be less energy-intensive from 2001 to 2006, which is confirmed by correlation with the production data.

In addition, Norway exhibited the highest primary energy use intensity, which corresponded to the highest share of electricity use in its dairy sector. It is worth noting that although its electricity is generated by hydro power plants, there are some negative environmental impacts and GHG emissions, e.g., methane (IPCC 2007). For the purpose comparing SEC of the national dairy-processing sector, the use of the same primary energy to electricity energy ratio of 0.4 (in Norway) is assumed. Except for Norway, USA dairy processing industry exhibited the highest energy intensity for both fossil and electricity energy use (i.e., highest annual ERM values in Figure 5 and Figure 6). In addition, Figure 7 indicates that USA's primary ERM values were among the highest from 2002 to 2006 regardless of product mixes. Figure 8 shows that the primary EII levels in the USA appeared to be trending slightly higher over time (from 2.2 in 2002 to 2.4 in 2006), corresponding to a trend of decreasing energy efficiency for the dairy sector when compared to the reference efficiency level in 2002.

4.4.4 Assessment of Potential Energy Savings and Carbon-emission Reduction in Dairy-processing Industry

In this section, we first assess the magnitudes of EIIp based upon a global baseline reference (i.e., the lowest plant-level primary SEC values among global plants included in this study), and then assess the magnitudes of potential energy savings and potential carbon reduction in the dairy processing industry for the selected countries.

Different from the previous section, the lowest primary SEC values from global plants in this chapter were used to calculate reference energy use (Eq. (11), energy intensity indicator (Eq. (12), PES and PCR (Eq. (13), Eq. (14), and Eq. (15). The plant-level reference SEC values are summarized in Table 22, which also includes the findings on cheese by Xu et al. (2009) and fluid milk by Xu and Flapper (2009).

Table 22 Reference SEC values based upon global dairy plant samples (the lowest SEC values)

Global SEC (MJ / kg product)	Electricity	Fuel	Total	Primary	Sources
Fluid milk	0.1	0.1	0.2	0.4	IAC (2009); Xu&Flapper (2009)
Other fresh milk	0.2	0.2	0.4	0.7a	Korsstrom & Lampi (2002)
Butter	0.1b	0.9b	1.0b	1.1b	Arcadis (2000)
Cheese	0.8	1.0	1.8	2.9	Xu et al. (2009); Feitz et al. (2007)
Concentrated milk	0.4	1.3	1.8	2.4	IAC (2009)
Milk powder	0,6	4,0	4.6	5.4c	Prasad et al. (2004)
Whey powder	0.4	2.7	3.1	3.7d	Arcadis (2002)
Other, lactose, casein	0.6	4,1	4.7	5.6e	Oldenhof (2004)

Notes:

a) A mixed fresh milk product dairy plant is included for calculating this intensity

b) Primary energy in Arcadis (2000) is calculated using 0.385 instead of 0.4 for electricity conversion. Electricity and fuel values are derived from primary energy use and converted back to electricity and fuel use by using the same product split as the entire dairy industry.

c) Calculated using same split between electricity and fuel as for another Australian milk powder plant

d) Estimated value. It is assumed that whey powder in The Netherlands is produced by a similar process as milk powder. The lowest SEC value for milk powder was over a factor 2 lower than the average value in the Netherlands. Therefore, best existing practice for whey is estimated to be half of the Dutch average in 2002.

e) Year 2002 average in the Netherlands. No data available for other plants and little insight in the actual products produced. This is probably higher than potential.

4.1 National Primary Energy Intensity Indicator

By definition, an EII value could be different pending the selection of reference SEC values for the same country or region. In this section, we applied the lowest plant-level SEC values presented in Table 11 into Eq. (11) to calculate the reference case energy use for each country. We then applied Eq. (12) to calculate the magnitude of the national primary EII value, which is a relative indicator for actual energy use for the whole dairy-processing industry in one country compared to the reference case based upon the lowest SEC identified from global dairy plants to date.

Figure 9 shows the annual primary EII values for the selected countries. A higher primary EII value in Figure 9 indicates larger energy savings potential for the country's dairy-processing industry. Such a national EII value indicates the degrees of energy-savings potential for a country. For example, an energy intensity indicator of two (i.e., EII value = 2) indicates that it is possible that the dairy sector of the country could use half of the energy that the sector is consuming, if the global best existing practices (i.e., the lowest primary SEC of a plant) could be implemented throughout the dairy sector in that country.

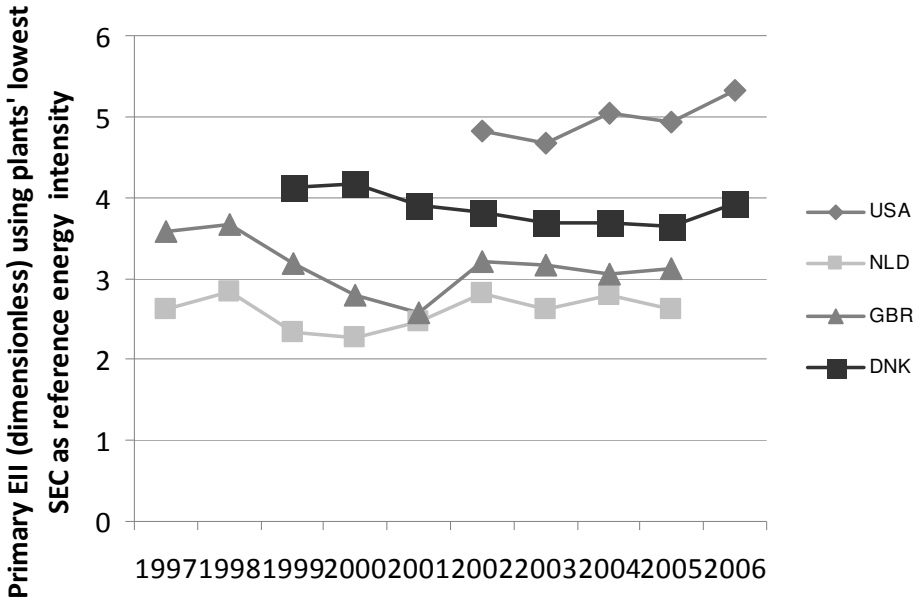


Figure 9 Primary EII using the lowest primary SEC values as reference.

The Netherlands has demonstrated that its dairy processing industry deviated least from the lowest SEC (global level) in that it exhibited the lowest annual EII values, corresponding to the fact that its annual SEC values were the lowest. It is also clear that although the relative energy-savings potential was the lowest, the potential in energy savings can still be significant - with primary EII values in the range of 2.3 to 2.8, corresponding to potential savings from 57% to 64%. The other countries exhibited higher savings potential, with primary EII values ranging from 2.5 to over 5.0 or higher, corresponding to potential savings from 60% to over 80%. It is clear that vast energy savings potential may be possible by implementing measures to reduce the SEC values for the dairy plants throughout all countries.

We have found that large energy savings potential is likely to exist in the dairy-processing industry for all the countries in this study. Such potential can be realized, e.g., via measures such as technological changes, supporting energy and climate-change policies that include standards, regulation, and programs to realize such potential. Encouraging news is that more and more countries are working on programs to lower energy use and GHG emissions from the dairy processing sectors.

4.4.5 Potential Energy Savings and Carbon-emission Reduction

Similarly, using the lowest plant-level SEC as the baseline reference, we calculate potential primary energy savings and potential carbon reduction by applying Eq. (13), Eq. (14), and Eq. (15) for the selected countries. Table 23 includes the estimated potential carbon-emission reduction associated with the calculated potential primary energy savings for each of the countries selected.

Table 23 Potential carbon-emission reduction and associated potential primary energy savings for each of the selected countries by year.

PCR, kT Ca PESp, PJ	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
USA PCR						1950	1886	2085	2100	2229
USA PESp						136.5	131.1	143.9	144.3	154.4
NLD PCR	151	161	128	121	137	160	151	164	147	
NLD PESp	10.4	11.0	8.6	8.1	9.2	10.8	10.2	11.0	10.0	
GBR PCR	243	250	208	160	143	201	198	180	188	
GBR PESp	15.5	15.8	13.0	10.2	9.0	12.9	12.8	11.5	12.0	
DNK PCR			100	96	94	89	90	92	109	93
DNK PESp			6.7	7.0	6.5	6.3	6.1	5.9	5.9	6.1

Notes:

Sims et al. (2003) estimated average carbon emissions of 42 g C / MJ for electricity in 2010 globally. California Public Utility Commission (CPUC) estimated that in California it averaged 26 g C / MJ in 2008 (E3, 2010). In this study, we used 42 g C / MJ is used to estimate carbon-emission reduction, with the understanding that actual emission reductions could be higher or lower because of actual coal and natural gas fired power plants for the locations or regions. Carbon-emission factor for natural gas is approximately 14 g Carbon/ MJ (EIA, 2009). Carbon-emission factor for electricity highly depends on the primary energy systems and locations.

From the estimated results, the largest potential in carbon-emission reduction from dairy processing plants can be expected in the USA, as it hosts the largest dairy–processing industry while exhibiting relatively higher primary EII values (shown in Figure 9).

From the ranges of EIIp values in Figure 9, we can see that the potential of SEC reduction ranges from approximately 57% (e.g., corresponding to EIIp of 2.3 for the Netherlands) to approximately 80% (e.g., corresponding to EIIp of 5 for USA). If we assume that half of global dairy processing plants could reduce its SEC level or ERM by 50% to 80% across the continents and regions included in Table 12, we can expect that a potential carbon-emission reduction of 9-14 million metric tons would be possible, corresponding to approximately 32-51 million metric-ton reduction in CO2 emissions.

Using the methods developed in this study, it is possible to quantify the potential energy savings and the associated potential carbon reduction on the country, regional, and global levels in more details, if more benchmarking data becomes available.

4.5 Discussion

Overall, the information collectively presented from Table 14 to Table 21 has provided characterization of energy use in butter, concentrated milk and milk powder production. Whenever available data permits, we have quantified SEC values based on primary or final energy consumption on national or plant levels, and in some cases, SEC values for specific process steps (e.g., milk powder). The availability of benchmarks is useful for assessing the relative energy intensity levels in processing butter, concentrated milk, and milk powder across regions, plants, or individual process steps. However, the available benchmarked data that enable calculation of energy intensity for dairy processing is still very limited. Therefore, some assumptions were needed for estimation in the characterizations. Using the methods presented in this chapter, such estimation should become more robust once more data becomes available in the future. In general, uncertainties of the data (including plant or process level data) compiled could not be quantified because no such information is available from the literature that we reviewed. In addition, we understand that a number of factors such as actual plant size, climate, or location could affect the applicability of the reference plants (with the lowest SEC values) to other plants within a country and across countries. While the scale of EII values may indicate energy-savings potential based on defined reference energy intensities and known product mixes, there is a caveat that the calculated EII values should be treated with care, because the reference energy intensity identified from the lowest SEC values from the small samples in this study may not necessarily be applicable to every plant. For example, one dairy product made in one plant of a specific region may not be necessarily or easily duplicated for other plants or in other countries due to variations in a number of determinants, such as locations, seasons, climates, technologies, countries, and plant sizes. It was reported that location and country may affect types of energy and water supplies (DEFRA, 2007), and wastewater treatment, which in turn would affect final energy intensity. Solids content of raw milk vary across locations, seasons and climates, which may affect the yields and hence energy intensity required for dairy to processing (Flapper, 2009). In this aspect, it is important to identify the determinants that are changeable as well as those that are non-changeable per location. On one hand, non-changeable determinants will determine the minimum reference SEC achievable for plants and nations and the relative difference across nations and plants; on the other hand, changeable determinants will be useful to achieve efficiency improvement. First,

changing processes into more efficient ones that yield the same product will reduce SEC. Such technological changes and advancement may bring two fold of impacts: 1) reducing SEC and total amount of energy required, and 2) change the requirements for the types of fuels. The availability of additional benchmarks on plant and process levels and their accuracies would be necessary for future update of the reference SEC levels. In order to identify applicable best existing practices for each dairy products, there is a need to develop standard protocols for reporting of data on energy use of dairy processing plants, which should include information on energy, production, product types, location, size, and actual processes, etc. Overall, regional and plant level energy data could be compared with best existing practice energy intensity via additional bottom-up analysis, e.g., reference performance data associated with high-performance plant, technologies and process equipment to be identified. Taking product mixes into account, we estimated potential energy savings and the associated GHG reduction, which appeared to be significant for the global dairy processing sector. In the future, carrying out detailed levels of energy benchmarking will help to provide more comprehensive and accurate data that can serve as reference data, which is expected to be evolved and updated over time.

In addition to replacing technologies and equipment in dairy processes, energy programs, policies of energy and water usage, and effluent generation and management can help in reducing energy intensity. Furthermore, good house-keeping, behaviors and controls (e.g., switching off lights and appliances), improving insulation, good maintenance, maintaining optimal conditions, eliminating leaks, heat or water integration (COWI, 2000) can reduce SEC. Regulations of carbon emission targets can also add to actions for realizing potential energy savings as well as carbon-emission reduction.

4.6 Chapter Summary

This chapter has presented characterization results of energy use in various dairy sectors across countries, regions, and plants based upon available data that were compiled from the study samples. Major findings and conclusions are:

- In this study, sectoral SEC values on the national level were only available for the Netherlands for butter, concentrated milk and milk powder sectors. The SEC values exhibited large variations across dairy products – final SEC values being 2.1 MJ/kg (butter), 2.0 MJ/kg (concentrated milk), 6.0 MJ/kg (whey powder), and 10.3 MJ/kg (milk powder); primary SEC being 2.6 MJ/kg (butter), 2.5 MJ/kg (concentrated milk), 7.4 MJ/kg (whey powder), and 12.8 MJ/kg (milk powder).
- Plant-level SEC values have exhibited significant variations within a country and between countries, e.g., final SEC ranging from 1.0 to 4.2 MJ per kg of butter; from 1.8 to 10.8 MJ per kg of concentrated milk; and from 4.6 to 221.4 MJ per kg of powder among the limited samples in this study.
- We have found that energy–savings potential in the selected nations' dairy processing industry can be significant, with primary EIIp ranging from 2.3 to 5 or higher when using the plants with lowest SEC values as the reference plants from the limited study samples.
- The estimated range of potential carbon-emission reduction from global dairy-processing industries would be approximately 9-14 million metric tons if measures were implemented to lower SEC values by 50-80% in half of global dairy processing plants,

with USA being the largest market and having biggest potential in carbon–emission reduction on the country level.

Even though extensive reviews have been conducted in this study, we have found that energy information for dairy processes is still rather fragmented and limited across the world, including the State of California. Apparently, more energy and dairy plant data need to be collected and made available to the public and research, so that one can use the methods presented in this chapter to update and further quantify the potential energy savings and potential carbon reduction for the regions of her interests. In order to identify applicable best existing practices for each dairy product, there is a need to develop standard protocols for reporting of data on energy use of dairy processing plants, which should include information such as energy use, production, product types, location, size, and actual processes.

Development of BEST-Dairy benchmarking and analytical tool benefits such effort and will be helpful for further assessing magnitudes of sectoral, regional, national and global potential in energy savings and carbon-emission reduction.

5 CHAPTER 5: Development of BEST-Dairy Tool and Technology Transfer Activities

5.1 BEST-Dairy tool development

Using the models and analyses performed in this project, we have developed this BEST-Dairy benchmarking tool that is intended for industrial users to compile data on energy and water usage in their own dairy processing plants, to compare the efficiency levels with those of best references, and to assess potential and opportunities of energy/water savings from the dairy processes/plants.

The BEST-Dairy benchmarking tool is essentially a computer-based program using MS Excel and VBA, which allows a user to calculate energy and water use intensity and obtain a benchmarking score(s) for the selected plant, as compared with the best available references that we have identified from literature search nationally and globally.

With the best references as the baseline, a higher benchmark score normally means higher savings potential from future efficiency improvement in your plant. The BEST-Dairy is intended to serve as a quick assessment of relative energy and water efficiency, which may also help to identify potential savings opportunities in the plant and processes. Users of the BEST-Dairy are advised that additional information and evaluation of the technologies be needed when considering system upgrades.

5.1.1 BEST-Dairy Tool Structure

The BEST-Dairy tool provides benchmarking for each of the four dairy products (cheese, fluid milk, butter, and milk powder). For each product, benchmarking options are provided to the user to select in terms of levels of details, i.e., dairy plant level, process level, or block level (grouped process steps). Selection of such options depends on the user preference and need for understanding energy / water use in the dairy processing facilities. The tool has integrated a calculator developed for unit conversions that are desired by the industrial users in the U.S.

The actual schematic of BEST-Dairy tool structure is shown in Figure 10. The tool is designed to allow the user to input detailed information and data on energy use, water use, and production into the benchmarking tool, so that the operating performance can be compared to best available reference on regional, national, and international levels, and potential savings from energy and water usage can be estimated and identified.

The calculation of benchmarking scores for each level of details is also depending on availability of best reference data for the relevant processes and products, which have been analyzed in Chapters 2 through Chapter 4. For example, best reference data for calculating EII values are available for fluid-milk sector on the process, process-block, and plant levels. Users can calculate EII scores for each of the three levels. Sometimes a benchmarking EII score cannot be calculated because of unavailability of best reference data for certain processes or dairy products. For example, no reference data was available for process-level EII calculation for cheese, butter, or milk powder products, while there are reference data for plant level calculations. In all cases, plant-level EII and WII scores are calculated for each product in the results of BEST-Dairy tool.

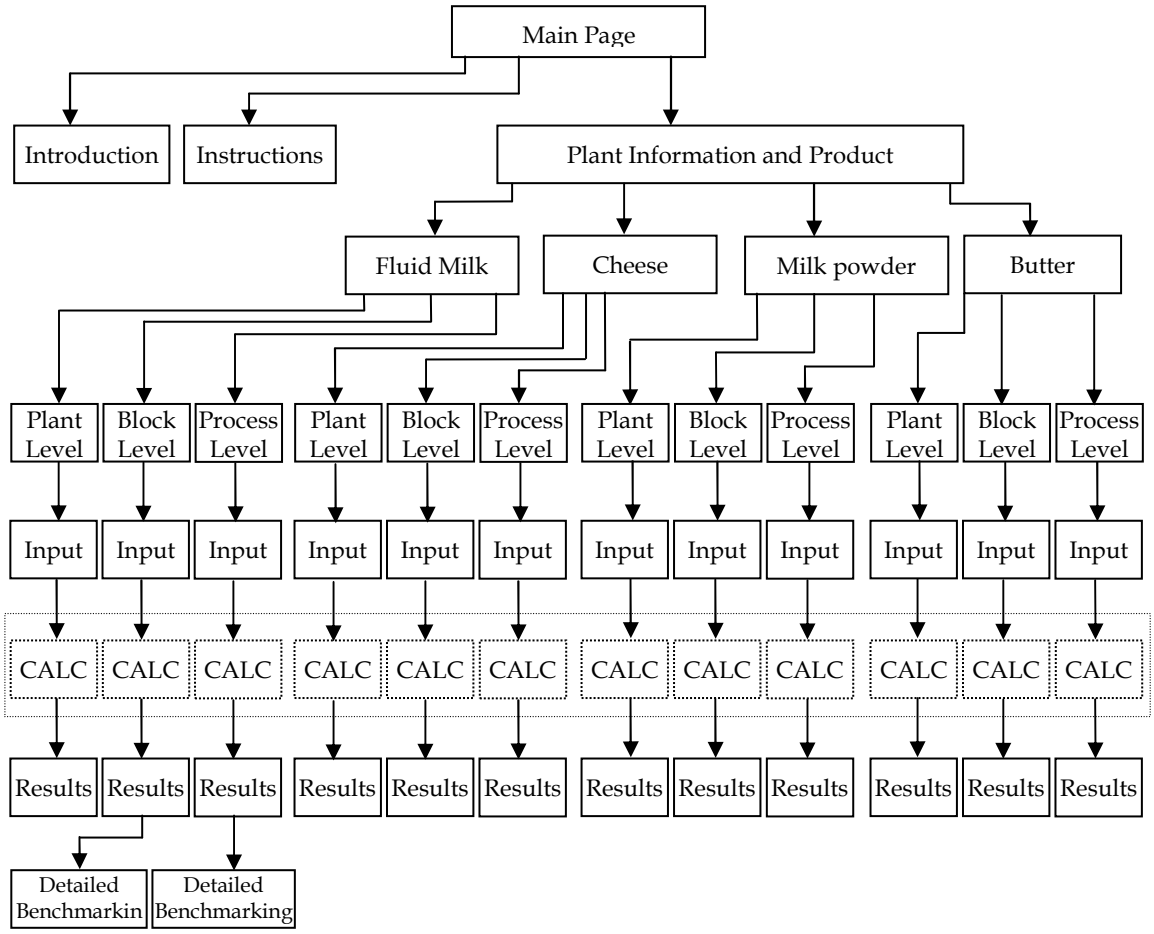
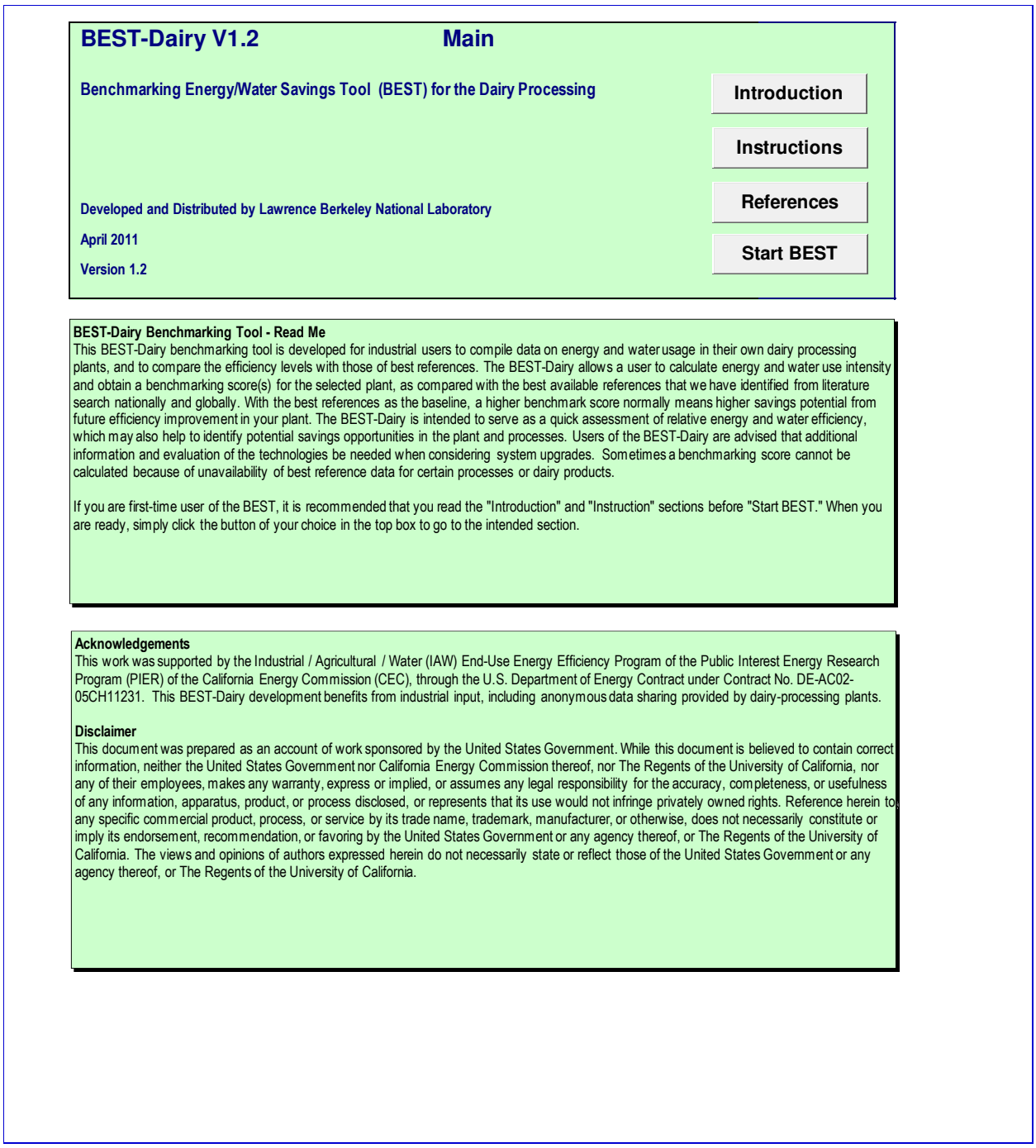


Figure 10 Schematic of BEST-Dairy tool structure (Calculation is abbreviated as "CALC" in the figure)

5.1.2 BEST-Dairy Tool User's Manual

The BEST-Dairy benchmarking tool comes with a User's Manual (Xu et al. 2011), which has been published along with the publication of BEST-Dairy tool. It recommends the users of the BEST-Dairy to familiarize the tool first, by reading the "Introduction" and "Instruction" sections before performing "Start BEST."

Figure 11 exhibits the opening page of the BEST-Dairy tool.



BEST-Dairy V1.2 **Main**

Benchmarking Energy/Water Savings Tool (BEST) for the Dairy Processing

Introduction

Instructions

References

Start BEST

Developed and Distributed by Lawrence Berkeley National Laboratory

April 2011

Version 1.2

BEST-Dairy Benchmarking Tool - Read Me

This BEST-Dairy benchmarking tool is developed for industrial users to compile data on energy and water usage in their own dairy processing plants, and to compare the efficiency levels with those of best references. The BEST-Dairy allows a user to calculate energy and water use intensity and obtain a benchmarking score(s) for the selected plant, as compared with the best available references that we have identified from literature search nationally and globally. With the best references as the baseline, a higher benchmark score normally means higher savings potential from future efficiency improvement in your plant. The BEST-Dairy is intended to serve as a quick assessment of relative energy and water efficiency, which may also help to identify potential savings opportunities in the plant and processes. Users of the BEST-Dairy are advised that additional information and evaluation of the technologies be needed when considering system upgrades. Sometimes a benchmarking score cannot be calculated because of unavailability of best reference data for certain processes or dairy products.

If you are first-time user of the BEST, it is recommended that you read the "Introduction" and "Instruction" sections before "Start BEST." When you are ready, simply click the button of your choice in the top box to go to the intended section.

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Figure 11 Main (opening) page of BEST-Dairy tool

5.2 Technology Transfer Activities

In the course of the project, we had engaged dairies from California and dairy organizations such as the International Dairy Foods Association (IDFA), not only to obtain input, but also communicate to them the project status and findings. In particular, several California dairies

and three major public utility companies have been participated as PAC members and were informed of the development and outcomes of BEST-dairy.

Upon completing Alfa-testing of the BEST-Dairy tool, we distributed the BEST-Dairy tool to dairy industries via interactions with PAC members and IDFA. During the beta-testing of BEST-Dairy, we had engaged a number of dairy plants inside and outside California. Questions and suggestions from the beta-testing users (i.e., dairy plant professionals) were addressed in the final publication and distribution of BEST-Dairy version 1.2.

We have participated in several workshops organized by Dairy-processor Carbon Reduction through Energy Efficiency Initiative (i.e., D-CREE Initiative), which is brought by Innovation Center for U.S. Dairy, an organization that brings together the leadership of nearly 70 percent of the dairy supply chain, including processors, farmer organizations, dairy cooperatives, manufacturers and brands. A presentation on introducing BEST-Dairy was made via webinar/conference call on July 8, 2010.

We also participated in the Annual IDFA Dairy Sustainability Summit on May 25, 2011, and made a presentation to dairy industry that introduced BEST-Dairy tool, the conference presentation is included in the Appendix.

- The BEST-Dairy tool has been posted on the internet for free download from http://best-dairy.lbl.gov/ since May 2011.

The project team also worked with public affairs of LBNL news release and media to inform the community of the BEST-Dairy tool. Additional technology transfer activities included several press releases from LBNL. The contents of press releases are available from the following websites:

- http://today.lbl.gov/2011/05/27/berkeley-lab-releases-best-dairy-energy-efficiency-benchmarking-tool/, May 27, 2011. Berkeley Lab releases BEST Dairy Energy Efficiency Benchmarking Tool.
- http://eetd.lbl.gov/newsletter/nl36/eetd-nl36-3-bestdairy.html Berkeley Lab Benchmarking Tool Helps Dairy Processors Find Energy and Water Savings.

6 Chapter 6: Summary of Outcomes and Recommendations

In this project, we first performed extensive literature reviews and data compilation, and conducted process analysis and modeling for various dairy products that included cheese, fluid milk, milk powder, butter and concentrated milk. Then we assessed energy and water efficiency opportunities in dairies, and developed an integrated benchmarking tool. We have performed and completed alpha- and beta-testing (field testing) of the BEST-Dairy tool, through which feedback from voluntary users in the U.S. dairy industry was gathered to validate and improve the tool's functionality. BEST-Dairy v1.2 was formally published in May 2011, and has been made available for free downloads from the internet (i.e., http://best-dairy.lbl.gov). A user's manual has been developed and published as the companion documentation for use with the BEST-Dairy tool.

A user's manual has been developed and published with documentation for use with the BEST-Dairy tool. In addition, we also carried out technology transfer activities by engaging the dairy industry in the process of tool development, including field testing, technical presentations, and technical assistance throughout the project. In addition, we also carried out technology transfer activities by engaging the dairy industry in the process of tool development and testing, including field testing, technical presentations, and technical assistance throughout the project.

The BEST-Dairy tool is an easy-to-use, computer-based tool (with a companion handbook) that can be used by facility engineers, energy managers, project developers, research institutions, industrial associations, and government agencies to evaluate the energy and water efficiency and GHG mitigation potential of individual dairy facilities or processes. The tool can be used to assist decision makers in planning facility improvement projects related to achieving energy efficiency and GHG mitigation goals or targets in California and other part of the nation. The BEST-Dairy tool developed in this project provides three options for the user to benchmark each of the dairy product included in the tool, with each option differentiated based on specific detail level of process or plant, i.e., 1) plant level; 2) process-group level, and 3) process-step level. For each detail level, the tool accounts for differences in production and other variables affecting energy use in dairy processes. The BEST-Dairy tool can be applied to a wide range of dairy facilities to provide energy and water savings estimates, which are based upon the comparisons with the best available reference cases that were established through reviewing information from international and national samples. To date, users from more than ten countries in addition to those in the U.S. have downloaded the BEST-Dairy from the LBNL website.

It is expected that the use of BEST-Dairy tool will advance understanding of energy and water usage in individual dairy plants, augment benchmarking activities in the market places, and facilitate implementation of efficiency measures and strategies to save energy and water usage in the dairy industry. Industrial adoption of this emerging tool and technology in the market is expected to benefit dairy plants, which are important customers of California utilities. Wider

use of this BEST-Dairy tool and realization of potential in energy and water savings will reduce the actual consumption of energy and water in the dairy industry sector. The goal of this tool development and its outcomes comply very well with the goals set by the AB 1250 for PIER program.

Because this new BEST-Dairy tool is expected to allow a facility to be compared to best available reference dairy plant or process, the use of the BEST-Dairy tool will also enable the provision of information on quantified savings potential and energy efficiency options when available for the facility. Despite of the benefits from benchmarking and the tool made available to the industry, how to promulgate its wider adoption in the market remains a challenge against maximizing the values from benchmarking. It is therefore recommended that demonstration and deployment activities to be carried out in the future to facilitate commercialization of the product. Wider use of BEST-Dairy and its continuous expansion (in functionality) will allow users to identify or evaluate efficiency improvement opportunities for individual process or process-group measures that will save money, energy or water, or some combinations of these savings; and allow the dairy to develop an implementation priorities plan for potential efficiency improvements.

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8 Appendices

8.1 Technology Transfers

News Releases May 27, 2011. Berkeley Lab releases BEST Dairy Energy Efficiency Benchmarking Tool

– by Allan Chen of LBNL

A benchmarking tool to help dairy owners and operators use energy and water as efficiently as possible in their facilities is now available. BEST Dairy was developed by scientists in the Environmental Energy Technologies Division. The BEST Dairy tool allows users to calculate energy and water use intensity, and get an energy efficiency score for the facility, compared to baseline national and global dairy facilities, and it identifies measures to improve energy and water efficiency.

Berkeley Lab Benchmarking Tool Helps Dairy Processors Find Energy and Water Savings

—by Mark Wilson of LBNL

As the nation's largest milk producer, California dairy farms constitute one of the most important sectors of the state's economy. Because dairy processors are energy- and water-intensive, the Industrial / Agricultural / Water Energy-Use Energy Efficiency group of the California Energy Commission's Public Interest Energy Research (PIER) Program began to work with Lawrence Berkeley National Laboratory (Berkeley Lab) to help dairy processors identify areas where they could trim costs by saving energy and water.

Journal articles of the work were published in Energy and Energy Policy, and the project culminated in the development of BEST-Dairy, a tool for benchmarking energy and water use. BEST-Dairy helps the processors compile their energy and water use data and compare it to the best references in the tool. It provides a quick assessment of relative energy and water efficiency that dairy processors can use to identify savings opportunities, in the plant and in individual processes.

"We conducted an extensive literature search of public data in many countries, looking at the energy intensity for each product, the process, and the process steps," says Environmental Energy Technologies Division (EETD)'s Investigator Tengfang Xu, who led the project team and developed the tool with Jing Ke, with assistance from Joris Flapper, Klaas Jan Kramer, and Jayant Sathaye. "Given that there has been very limited data available from California dairy processors, we compiled and used national and international data as the reference data for the tool."

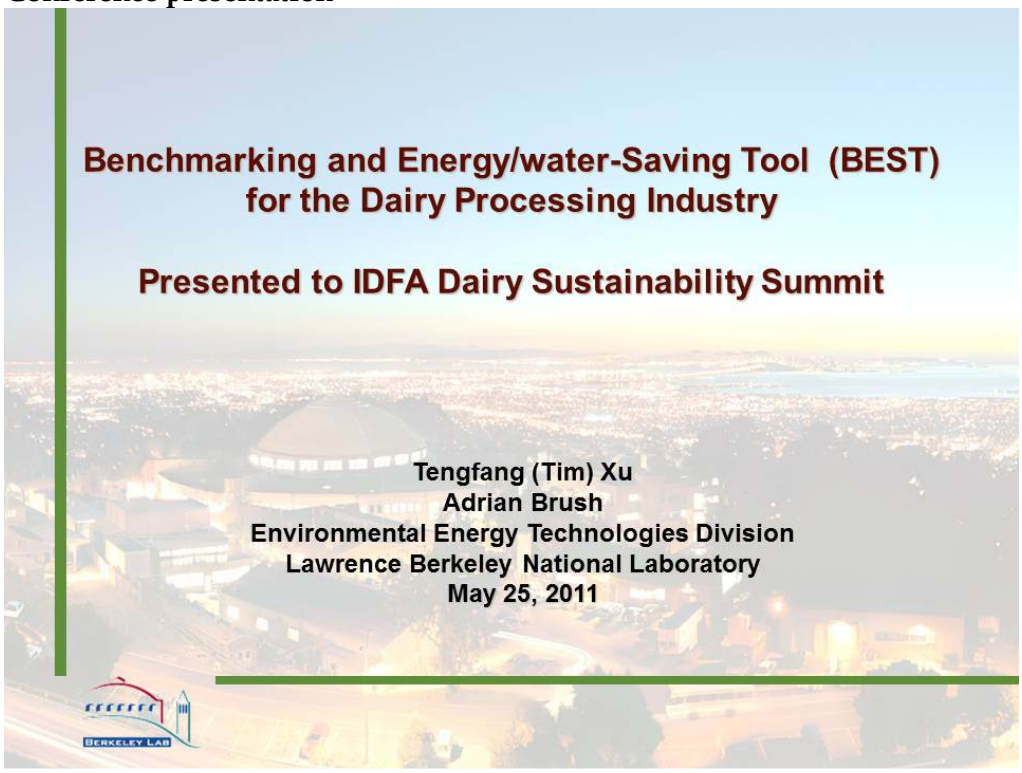
Focusing on four products (fluid milk, butter, cheese, and powder milk), the team decided to offer users three assessment options: (1) plant-level (requiring only overall energy and water use data), (2) process block-level (requiring data for a series of steps, or "blocks," and (3) process step-level (requiring detailed data at every process step).

The tool, which was released in mid-May, is free. Users simply enter 12 months of data into an Excel spreadsheet, and it automatically compares the plant's energy and water use to that of the best available reference; showing benchmarking scores for water and energy use, as well as

their potential savings and associated cost savings. Xu envisions that dairy processors also can use the tool to assess changes in their energy and water use efficiency over time or, if a company has several plants, they can benchmark their plants against each other, identify the most efficient, and implement the most efficient processes among all their dairies. The dairy processor energy studies and the BEST-Dairy tool are attracting interest from European and South American companies, as well as from Californian and U.S. dairy processing plants. Xu would like to see the tool used much more widely, which eventually will benefit the dairy processing industry in California and in other countries.

"We're in a diligent search for more data," says Xu. "There are still not nearly enough—especially from California dairy processors. We encourage all users to contribute their data to help populate more reference data in the tool. Any data we receive are confidential and presented anonymously."

Conference presentation



About BEST

- Tool for self analyzing energy and water use, and highlighting potential improvement areas
- Provides a benchmark score for each plant indicating its distance from "best reference" case by comparing with a hypothetical plant that uses "best practices"
- Evaluations indicate which processes have most potential for likely improvement and savings
- BEST has already been developed for other industries
  - BEST – Winery (California)
  - BEST – Cement (International)
  - BEST - Steel

- Slide 2

Project Timeline and Outcomes

- Timeline:
  - Kick-off meeting in late April 2008
  - Formed Project Advisory Committee (PAC) and communications – Dairy industry, academia, utilities, and sponsor to provide input for tool development
  - Tool development April 2008 – May 2011, supported by California Energy Commission
  - No additional funding support after tool is completed and published
- Outcomes
  - Tool alpha and beta tested in Summer 2010. Feedback received by Dec. 2010 incorporated into tool
  - Tool and manual released for public access in May 2011
  - 3 journal articles: Energy Policy (2) and Energy (1), Xu et al.

- Slide 3

Project Goals

- **Develop and apply BEST-Dairy for use in the California dairy industry (funded by California Energy Commission, CEC)**
  - Computer-based tool with a companion manual/handbook
  - Targeted users: Facility engineer, energy manager, project developer, research institution, industrial association, consultant, government agency
  - Evaluation of energy/water efficiency savings potential
- **BEST-Dairy components**
  - Benchmarking
  - Identification and quantification of energy/water efficiency improvement potential
- **BEST-Dairy for four sectors**
  - Cheese
  - Fluid milk
  - Powder milk
  - Butter and others

- Slide 4

Building Technical Knowledge

- Process analysis and modeling
  - Process mapping and flow diagrams for 4 dairy products
  - Determination of how to account for water and energy at plant level, and process level when possible
  - Determination of proper metric (e.g., energy use per unit milk product)
- Assessment of energy/water efficiency opportunities in dairies
  - Review of literature and case studies to find water/energy saving measures and associated savings
  - Determination of most efficient, yet realistic, "best practices" and associated energy use levels

- Slide 5

Building the Tool

- Integrated benchmarking tool development
  - Easy to use format – MS Excel
  - Translating technical knowledge into Excel formulas and macros
  - Allowing for multiple resolution levels: plant level, process block level, and process level
- Field testing
  - By dairies in each of 4 products used
  - Incorporating feedback into tool
- Technology transfer
  - Publish on internet, free for download and use

- Slide 6

Most Effective use of BEST

- Quick and easy identification of savings potential
- As a comparison between plants in same company
- To monitor self performance over time
- To compare to national/international averages and "best practices" identified
- As a screening tool for energy/water efficiency opportunities

- Slide 7

Potential Future Improvement

- Gives savings potential based on generic "best reference" identified from open literature
  - Uncertainties in savings potential or measure feasibility for specific plants
    - E.g., Resolutions to compare industries using different techniques for same product (ex. Roller Drying versus Spray Drying in powdered dairy products)
- The "best reference" data may be updated with real-life energy/water use data in the U.S. and California
  - More data from U.S. dairies would allow a better picture of true energy/water savings potentials
  - Help identify factors involved in energy/water use variations amongst plants (i.e. equipment used, weather, etc.)

- Slide 8

Potential Future Improvement (Cont.)

- Weighing energy versus water efficiency
  - Potential for measures with conflicting energy and water use effects
  - Determining right balance between energy efficiency versus water efficiency
- With more information and data to be made available from the dairy industry, the BEST – Dairy tool could be used as an effective competitive benchmarking tool, allowing dairy producers to compete for a lower energy/water use

- Slide 9

ENERGY STAR Dairy Guidebook

- Guidebook detailing water and energy efficiency measures applicable to the dairy processing industry
  - Cross-cutting measures
  - Process specific measures
- Focuses on proven, commercially available, and financially feasible measures, including savings and payback data wherever possible.
- Initial draft just released and soliciting feedback from industry
- Final draft will be available by August
- ENERGY STAR for Industry website:

- Slide 10

BEST-Dairy Demo

Resources:

- **BEST Tool and Manual:**
- **ENERGY STAR Guide:**

- **Questions, follow up?**
- **Potential** future partnerships for **technical assistance or tool enhancement?**

Address to Dr. Tim Xu, TTXu@LBL.gov; 510.486.7810

For questions regarding the ENERGY STAR Guidebook, or to give feedback for guide,

Contact: Adrian Brush, ABrush@lbl.gov; 510.495.2025

Eric Masanet, ERMasanet@lbl.gov; 510.486.6794

- Slide 11

8.2 BEST-Dairy Manual

USER'S MANUAL FOR BEST-DAIRY: BENCHMARKING AND ENERGY/WATER-SAVING TOOL (BEST) FOR THE DAIRY PROCESSING INDUSTRY (VERSION 1.2)

LBNL – 4778E

ABOUT THE USER'S MANUAL

This User's Manual summarizes the background information of the Benchmarking and Energy/water-Saving Tool (BEST) for the Dairy Processing Industry (Version 1.2, 2011), including "Read Me" portion of the tool, the sections of Introduction, and Instructions for the BEST-Dairy tool that is developed and distributed by Lawrence Berkeley National Laboratory (LBNL).

BEST-DAIRY BENCHMARKING TOOL – READ ME

This BEST-Dairy benchmarking tool (V1.2, 2011) is developed for industrial users to compile data on energy and water usage in their own dairy processing plants, and to compare the efficiency levels with those of best references.

The BEST-Dairy allows a user to calculate energy and water use intensity and obtain a benchmarking score(s) for the selected plant, as compared with the best available references that we have identified from literature search nationally and globally. With the best references as the baseline, a higher benchmark score normally means higher savings potential from future efficiency improvement in your plant. The BEST-Dairy is intended to serve as a quick assessment of relative energy and water efficiency, which may also help to identify potential savings opportunities in the plant and processes. Users of the BEST-Dairy are advised that additional information and evaluation of the technologies be needed when considering system upgrades. Sometimes a benchmarking score cannot be calculated because of unavailability of best reference data for certain processes or dairy products.

If you are first-time user of the BEST, it is recommended that you read the "Introduction" and "Instruction" sections before "Start BEST." When you are ready, simply click the button of your choice in the top box to go to the intended section.

INTRODUCTION

California's dairy processing industry is primarily comprised of four segments: fluid milk, butter, cheese, and powder milk products. According to the California Department of Food and Agriculture (CDFA 2006; 2009) and the California Milk Advisory Board (CMAD 2008), California has been the nation's largest milk producer since 1993, followed by Wisconsin, New

York, Pennsylvania, and Idaho. With the increasing economic and environmental pressures and consequences of increased energy and water usage in California, making energy and water efficiency improvement will be an essential part of the business for dairy processing sectors.

Benchmarking is a useful tool for gathering data and understanding energy and water consumption patterns in dairy-processing plants and for designing potential programs and policies to improve energy and water efficiency. Energy and/or water benchmarking allows energy and/or water performance of an individual plant or an entire sector of similar plants to be compared against a common metric that represents "standard" or "optimal" performance. It may also allow comparisons of the energy and/or water performance of a number of plants with each other.

Benchmarking Energy/Water Savings Tool (BEST) for the Dairy Processing, or BEST-Dairy (version 1.2), is developed and distributed by Lawrence Berkeley National Laboratory.

In this BEST-Dairy tool, energy (or water) intensity is calculated to measure energy (or water) use per unit of output (e.g., fluid milk, cheese, butter, milk powder), or sometimes per raw milk input. While benchmarking provides insights into the relative energy and water performance of the plant, it is also a good starting point for analysis of additional improvement opportunities. With funding support from California Energy Commission, LBNL has developed this BEST-Dairy tool for the four dairy processing sectors. For each dairy product, the BEST-Dairy tool is designed to provide users with three options to accommodate their benchmarking needs and availability for actual data: 1) plant level; 2) process-block level (i.e., grouping certain process steps into one block); and 3) process-step level. The major advantage of including process-step and process-block level is that the key process steps can be identified and performance comparisons can be performed for each step or block.

This BEST-Dairy tool requires the user to compile and input a cumulative of 12-month energy and water use data gathered for a diary processing plant (including individual processes or process blocks). An embedded software calculator is included in the BEST-Dairy tool for your use of energy and water unit conversion. The BEST-Dairy tool allows the user to evaluate savings potentials from possible energy and water efficiency improvements. In addition, BEST-Dairy also provides the capability of assessing cost-saving potential compared to reference cases. The information produced from the tool can help the user in developing an implementation plan to achieve savings in energy and water use in dairy plants.

After the required cumulative 12-month data is input into the BEST Dairies, the energy and water performance of your dairy plant or processes is then compared to a reference counterpart representing best references. The benchmarking scores of your dairy processing will be calculated and expressed as an Energy Intensity Indicator (EII). EII values are unitless relative values based upon the reference benchmarks that represent best available references, which are identified through extensive literature reviews and analysis in our study. A benchmarking score is normally expected to exceed 100 points, with a higher benchmarking score representing bigger energy and water savings potential in your plant or processes. If you obtain a benchmarking score lower than 100 points, this means that your dairy plant/process is probably more efficient than the ones that we have identified as best available reference (globally or regionally). Pending the data availability of best references, benchmark scores for some process steps or process blocks may not be always computable and will be shown as "-"

instead. In any case, the tool developer (LBNL) is appreciative if you can share your benchmark data for consideration for formulating a reference point for future inclusion in the tool. We expect such a reference point can evolve over time if more data is made available.

Note: If you would like to contribute your data for developing new best practice reference points, simply save the BEST-Dairy Excel workbook as an Excel file after you input all data, and email the file to TTXu@LBL.Gov. Your data will be kept confidential.

The BEST-Dairy (V1.2) tool has been developed by Lawrence Berkeley National Laboratory (LBNL), with research funding support of the California Energy Commission (CEC). LBNL is a research laboratory of the U.S. Department of Energy managed by the University of California. LBNL develops free tools and studies to reduce the environmental impact of energy and water use. The BEST-Dairy is free to public.

INSTRUCTIONS

The BEST-Dairy (V1.2) tool allows you to evaluate the energy and water efficiency of your dairy processes by benchmarking energy and water intensity against a known reference dairy processing. The reference dairy process is based on existing and proven practices and technologies identified either from open global literatures or proprietary information with anonymous identity (Xu et al. 2009a; 2009b, 2011). The reference dairy process is deemed to emulate the processing of the same or similar dairy products using the characteristics that you enter for your dairy process; however, with the highest efficiency identified so far. The comparisons of the energy intensity of your dairy process to that of the reference dairy processes will provide a benchmark score, called the Energy Intensity Index (EII).

The benchmark score values can be used to indicate relative performance of your dairy process compared to the most efficient process identified from LBNL studies based upon extensive literature research. For example, a score value of 100 means that the energy or water intensity level of your dairy process is in par with the most efficient process identified, and a score value over 100 means that the energy or water intensity level of your dairy process is higher than the most efficient ones identified so far, corresponding to a lower efficiency level. By the same token, if you achieve a benchmark score under 100, that means your plant or processes are less energy (or water) intensive than the one that has been identified to be the least energy (or water) water intensive.

The outcomes from comparisons may become a basis for you to evaluate savings potential and to consider future improvements.

Applicability

BEST-Dairy is designed for typical dairy processors that produce common cheese, fluid milk, butter, milk powder, and additional dairy products.

Computer Requirements

BEST-Dairy is designed for use in MS Excel using a PC with Windows 2000 or Windows XP. Compatibility with Mac computers is not known. BEST Dairy is an MS Excel file that uses macros to carry out many of the calculations and to make the program more user-friendly.

After opening the original BEST-Dairy file, you may save the BEST-Dairy file with a different file name on your computer.

Using BEST-Dairy (V1.2)

This BEST-Dairy tool is an Excel workbook consists of a number of worksheets. Users are expected to have knowledge of typical dairy processes, and provide production and energy (water) data for a 12-month period in the input spreadsheets. The data supplied by the user will then be used for calculations throughout the workbook.

Important Note to the User: BEST Dairy uses macros to carry out many of the calculations and to make the program more user-friendly. During the process of opening a file, some versions of Excel ask whether the user wants to enable or disable macros, while others may automatically disable macros through a security setting. In order to use BEST Dairy, the user must enable macros. If no dialogue box appeared asking you to enable or disable macros, select Tools --> Macro --> Security and click on medium or low. If medium security is chosen, every time BEST Dairy is opened, a dialog box will appear asking the user if macros should be enabled or disabled.

After completing input into a worksheet, you will be automatically transferred to the next worksheet by pressing "Next" button on the worksheet. You can go back to the previous worksheet by pressing "Previous" button. In the following, we will walk through the worksheets of BEST-Dairy step-by-step.

It's recommended that you save the file after completing all the input.

Main Sheet

In "Main" worksheet, important "Read Me" information is provided for you to familiarize with the BEST-dairy tool. From the "Main" sheet, you can open the "Introduction" and "Instruction" sheets to obtain more useful information about the BEST-Dairy tool by clicking the selected buttons.

If you are familiar with BEST-Dairy tool, you can directly press "Start BEST" button to start the benchmarking input.

Introduction Sheet

The "Introduction" worksheet provides a brief introduction to the BEST tool. After you read the introduction, press the "Return to Main" button to go back to the "Main" worksheet.

Instructions Sheet

The "Instructions" worksheet provides more detailed instructions for how to use BEST-Dairy tool. After you read the instructions, you can press the "Return to Main button" to go back to the "Main" worksheet. You can access to the "Instructions" worksheet anytime during the benchmarking by returning to the "Main" worksheet first and then press the "Instructions" button.

References Sheet

The "References" worksheet provides all references used in BEST-Dairy. After you read the references, you can press the "Return to Main" button to go back to Main sheet.

Product Selection Sheet

BEST-Dairy tool allows independent benchmarking activities for four types of dairy processes, i.e., fluid milk, cheese, milk powder, and butter. User should choose one of the products from this worksheet by pressing one of the product buttons provided on this product selection sheet.

If you have completed benchmarking for one of the four product types, and wish to benchmark for another new product type, you can choose to open a new BEST-Dairy file, or choose to come back to this worksheet and select the new product to continue. The BEST-Dairy file is designed to store and calculate all the data that you've input.

If you have more than one plant making the same dairy product, you should create a different BEST-Dairy file for each of the plants.

After pressing one of the product selection buttons, you will be entering a new dairy-processing benchmarking worksheet, named as "Selection-[product name]."

Benchmarking Level Selection Sheet

For each dairy product, BEST-Dairy provides three assessment options for you to choose, based on your benchmark need and your data availability. In the "Selection-[product name]" worksheet, you will be asked to select from one of the three options:

(1) Plant Level Assessment: This is the most common (and easiest) benchmark to perform, especially when you don't have energy and water data per process step or block.

(2) Process-block Level Assessment: This will be a more detailed benchmark (than plant-level benchmark) to perform. Data input is for block-level assessment, especially when you have access to more energy data details than plant level, but don't have individual process-step energy data.

(3) Process Level Assessment: This is the most detailed (but often most challenging) benchmark to perform, for individual process steps. Data input requires that you have access to detail energy data for each process step.

After pressing one of the three options provided, you will be entering a new worksheet for data input, named as "Input - [product name & level]."

Input Sheet

In the Input sheet, you are required to enter all essential information to enable effective energy and water benchmarking in your dairy plants and/or processes.

Important Note #1:

Only fill in the yellow cells! Cells with other colors are calculated values from input data.

Important Note #2:

This BEST-Dairy tool adopts metric units in input and all benchmark calculations. For your convenience, we have developed a "Unit Conversion Calculator" for your use to convert US customary units to metric units. The "Unit Conversion Calculator" is available for use on the "Input" worksheet. Simply click "Unit Conversion Calculator" on the top right of the "Input" worksheet, select the parameters (Energy, Mass, Volume) of your choice and convert your raw data into required unit for manual input to the yellow cells on the "Input" worksheet.

(1) You will need to enter the annual production in your dairy plant. Note that the input should be a cumulative value for a 12-month period. The input should be based on actual production, not the entire capacity of your dairy plant. For "Process Level Assessment" or "Process-block Level Assessment," the annual product volumes in the plant should correspond to each individual process step or each process-block.

(2) You will need to fill in the annual energy end use categorized by electricity and fuel types, as well as water usage. The cumulative energy and water end use data should be for a 12-month period that is consistent with the production data. For "Process Level Assessment" or "Process-block Level Assessment," the annual energy and water end use input should correspond to each individual process step or each process-block.

(3) If you input energy and water price information, this BEST tool can help you to assess potential energy cost savings from improving your system efficiency, using best practice benchmarks as the reference. You may skip this portion (e.g., its yellow cells) if you don't have price data to enter.

(4) After you fill in all the yellow cells in this worksheet, save your file then press "Next" button located on the top of the "Input" Worksheet. You will be entering a new worksheet named as "Results-[product name] plant/block/process."

Results Sheet

The "Results" worksheet for plant level assessment:

The "Results-[[product name] plant" worksheet presents the overall benchmarking scores, i.e., Energy Intensity Index (EII), for your dairy plant.

In addition, this worksheet also includes the actual energy/water use intensity that is calculated automatically based upon your input data.

The worksheet has included a reference plant's energy/water use intensity obtained from literature research and analyses - When such data is available, it is categorized into three groups to represent best practices (international, USA, and California).

Both actual data from your dairy plant/process and the reference plant/process data have been used to calculate your plant's benchmarking scores (EII). The EII is a unitless value comparing the total production energy intensity of your dairy with that of the reference-plant's energy/water use intensity (the reference plant can be on international, USA, or California levels). In addition, BEST-Dairy tool generates estimation of technical energy/water saving potential and the associated cost savings in your dairy plant. In another word, BEST Dairy provides an estimate of the potential for annual energy savings, energy costs savings, water savings, and water cost savings if your dairy would perform at the same performance level as the "reference" dairy plant pre-defined by the tool.

Note that Although SI units were required for input, the output data in "Results-[product name] plant" worksheet is presented in both SI and IP units for easy understanding.

Normally the benchmarking scores should be expected to be over 100 points. A higher score indicates greater savings potential in your dairy plant. A score lower than 100 points indicates that your plant is less energy intensive compared with the least energy intensive dairy that we have found by the time this BEST-Dairy tool was completed. Sometimes, no score can be given because of unavailability of reference data by the time this BEST-Dairy tool was completed.

Plant level assessment ends at this worksheet. Make sure to save the Excel file for your own record.

The "Results" worksheet for process-block and process level assessment:

The "Results-[product name] block/process" worksheet for process-block or process level assessment will first generate a Result page, named "Results-[product name] block/process" that will show overall benchmarking scores, EII, and technical savings potential for energy and water use, similar to the outcomes for plant level assessment. For more detailed assessment, please press the "Detailed Benchmarking Scores" button on the top of worksheet to enter detailed benchmarking results worksheet, named "Detailed-[product name] block/process."

Detailed Benchmarking Score Sheet

The detailed benchmarking sheet, named "Detailed-[product name] block/process," will show the Energy Intensity Index (EII) for each process step (for process level benchmarking) or process-block (for process-block level benchmarking). Once the actual energy intensity and benchmark energy intensity of each process step or process block have been input and calculated, they are used to calculate the detail EII values corresponding to individual process or process-block. The EII is a measurement of the production energy intensity of your dairy process step or process block compared to reference energy intensity. The detailed benchmarking scores - EII can be used to gauge energy-savings potential of each process step or process block.

Process-block or process level assessment ends at this worksheet. Make sure to save the Excel file for your own record.

For questions, comments, and contributions, please contact

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