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Energy Efficiency Improvement and Cost Saving Opportunities for Breweries

An ENERGY STAR[®] Guide for Energy and Plant Managers

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Environmental Energy Technologies Division

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ABSTRACT

Annually, breweries in the United States spend over \$200 million on energy. Energy consumption is equal to 3 – 8% of the production costs of beer, making energy efficiency improvement an important way to reduce costs, especially in times of high energy price volatility. After a summary of the beer making process and energy use, we examine energy efficiency opportunities available for breweries. We provide specific primary energy savings for each energy efficiency measure based on case studies that have implemented the measures, as well as references to technical literature. If available, we have also listed typical payback periods. Our findings suggest that given available technology, there are still opportunities to reduce energy consumption cost-effectively in the brewing industry. Brewers value highly the quality, taste and drinkability of their beer. Brewing companies have and are expected to continue to spend capital on cost-effective energy conservation measures that meet these quality, taste and drinkability requirements. For individual plants, further research on the economics of the measures, as well as their applicability to different brewing practices, is needed to assess implementation of selected technologies.

Energy Efficiency Improvement and Cost Saving Opportunities for Breweries

Table of Contents

1. Introduction	1
2. The Brewery Market	2
3. Process Description	5
4. Energy Use	9
4.1 Energy Consumption and Expenditures.....	9
4.2 Energy Intensity	11
5. Options for Energy Efficiency	13
6. Process-Specific Measures	19
6.1 Mashing and Lauter Tun Processes	19
6.2 Wort Boiling and Cooling.....	19
6.3 Fermentation	24
6.4 Technologies for Beer Processing	25
6.5 Technologies for Packaging.....	27
7. Cross-cutting Measures	28
7.1 Boilers and Steam Distribution.....	28
7.2 Motors and Systems that Use Motors	31
7.3 Refrigeration and Cooling.....	33
7.4 Other Utilities.....	35
8. Material Efficiency Opportunities.....	39
9. Future Technologies	43
10. Summary & Conclusions	44
11. Acknowledgements.....	47
12. References.....	48

Tables

Table 1. Major brewery products and shipments value, 1997	3
Table 2. 1994 Primary energy consumption and expenditures in malt beverages.....	9
Table 3. Uses and sources of electricity in the brewery sector, 1994.....	10
Table 4. Estimated percentage energy use for various brewing processes	11
Table 5. Process-specific energy efficiency measures for the brewing industry	14
Table 6. Cross-cutting and utilities energy efficiency measures for the brewing industry	15
Table 8. Specific primary energy savings and estimated paybacks for process specific efficiency measures	45
Table 9. Specific primary energy savings and estimated paybacks for efficiency measures for utilities	46
Appendix I. Locations and capacity of large breweries.....	56
Appendix II. Employee tasks for energy efficiency	57
Appendix III: Energy management system assessment for best practices in energy efficiency	58
Appendix IV. Support programs for industrial energy efficiency improvement.....	60

Figures

Figure 1. U.S. Beer production 1980-1999..... 2
Figure 2. U.S. brewers’ production 1987-1999 4
Figure 3. Process stages in beer production..... 7
Figure 4. Physical primary energy intensities for beer production for selected countries
and companies 12
Figure 5. 1998 Energy consumption for German breweries by size..... 12
Figure 6. Main elements of a strategic energy management system 17

1. Introduction

As U.S. manufacturers face an increasingly competitive global business environment, they seek opportunities to reduce production costs without negatively affecting product yield or quality. Uncertain energy prices in today's marketplace negatively affect predictable earnings, a concern for publicly-traded companies in the beer industry. For public and private companies alike, increasing energy prices are driving up costs and decreasing their value added. Successful, cost-effective investment into energy efficiency technologies and practices meet the challenge of maintaining the output of a high quality product despite reduced production costs. This is especially important, as energy-efficient technologies often include "additional" benefits, such as increasing the productivity of the company.

Energy efficiency is an important component of a company's environmental strategy. End-of-pipe solutions can be expensive and inefficient while energy efficiency can often be an inexpensive opportunity to reduce criteria and other pollutant emissions. Energy efficiency can be an effective strategy to work towards the so-called "triple bottom line" that focuses on the social, economic, and environmental aspects of a business.¹

Voluntary government programs aim to assist industry to improve competitiveness through increased energy efficiency and reduced environmental impact. ENERGY STAR[®], a voluntary program managed by the U.S. Environmental Protection Agency (EPA), stresses the need for strong and strategic corporate energy management programs. ENERGY STAR provides energy management tools and strategies for successful corporate energy management programs. The current report describes research conducted to support ENERGY STAR and its work with the beer industry. This research provides information on potential energy efficiency opportunities for breweries. ENERGY STAR can be contacted through www.energystar.gov for additional energy management tools that facilitate stronger energy management practices in U.S. industry.

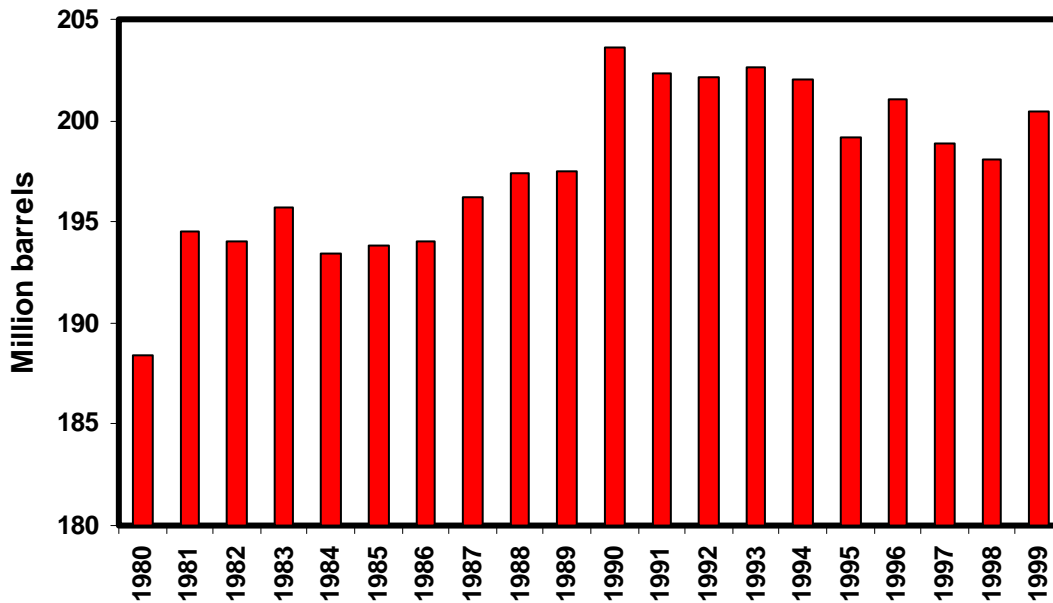
¹ The concept of the "triple bottom line" was introduced by the World Business Council on Sustainable Development (WBCSD). The three aspects are interconnected as society depends on the economy and the economy depends on the global ecosystem, whose health represents the ultimate bottom line.

2. The Brewery Market

The U.S. brewery sector (SIC code 2082 or NAICS 312120) is composed of about 500 companies and produces about \$20 billion worth of shipments (DOC, 1999). The major product class is canned beer and ale case goods. Production facilities are distributed throughout the country. While production processes have mostly remained unchanged, the sector is increasingly moving to economies of scale. Large establishments with more than 250 employees account for roughly half of the value added in the sector (DOC, 1999). As of 1998, there were 43 large breweries that accounted for the majority of production among the country's more than 2,000 brewing establishments (see Appendix I) (Real Beer, 2000). The number of breweries is now at the highest level since prohibition ended in 1933 (Hein, 1998), underlining the dynamic development in the malt beverages industry.

Brewery products primarily consist of beer (lager and ale). Figure 1 shows the historical production of beer in the U.S. Production peaked in 1990, in part due to changes in tax regulations that took effect in 1991, adding an excise tax on brewery products. Annual production has ranged around 200 million barrels² for most of the 1990s.

Figure 1. U.S. Beer production 1980-1999 (million barrels)



Note: Data from 1990-1999 reflect calendar rather than fiscal year data.
Source: Beer Institute, 2000. 1999 is an estimate from the Beer Institute.

While U.S. beer production peaked in 1990, the long-term (1980-1999) shows a slightly declining per capita trend. U.S. Beer consumption per capita in 1999 was 22 gallons, down from 23 in 1980. However, trends vary by state (Hein, 1998). Factors that affect

² A barrel of beer is 31 gallons or 1.2 hectoliters.

beer consumption are weather (precipitation, temperature), population growth and distribution, economic development and competition with other drinks. Future consumption trends will be affected by competition with other ethanol drinks (wine, spirits) and non-alcoholic drinks. Of these, wine and soft drinks show the highest growth in recent years (Hein, 1998).

The production of beer in bottles and cans dominates the market. As Table 1 indicates, canned beer accounts for half the value of shipments for the industry, with bottled beer accounting for a third.

Table 1. Major brewery products and shipments value, 1997

Product	Shipments (\$billion)
Canned beer and ale case goods	9.6
<i>12 ounce cans</i>	8.4
<i>16 ounce cans</i>	0.7
<i>Other</i>	0.4
Bottled beer and ale case goods	6.2
<i>12 ounce bottles (returnable)</i>	0.8
<i>Less than 12 ounce (returnable)</i>	< 0.1
<i>Other sizes (returnable)</i>	< 0.1
<i>12 ounce bottles (non-returnable)</i>	4.2
<i>Less than 12 ounce (non-returnable)</i>	0.1
<i>32 ounce (non-returnable)</i>	0.3
<i>Other sizes (non-returnable)</i>	0.6
Beer and ale in barrels and kegs	1.1
<i>One half barrel size</i>	1.0
<i>Other size</i>	0.1
All other brewing products	0.6
Malt beverages, not specified by kind	0.5
Total Brewery Products	18.1

Source: DOC, 1999

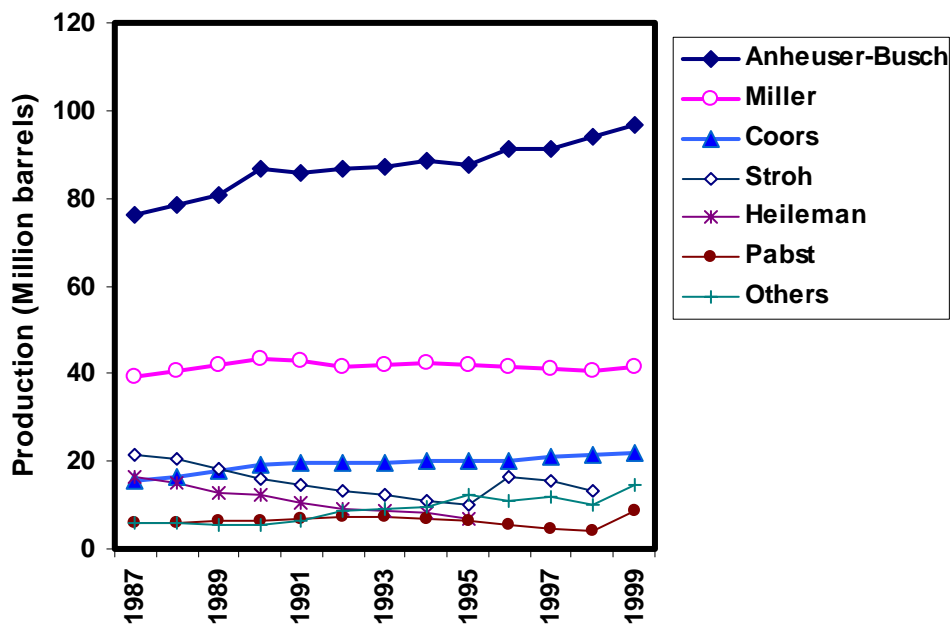
Figure 2 identifies production by selected companies between 1987 and 1999. Together, Anheuser-Busch, Miller and Coors companies account for 83% of total U.S. production. Within these companies, the largest selling brands are Budweiser (20% share), Bud Light (14%), Miller Franchise (8%), Coors Light (8%) and Busch (5%). The share of light beer continues to grow and currently has captured a third of the market. While growth in domestic beer production for the main brands has been relatively flat, the craft brewing³ segment of the industry has begun to show stronger growth that should continue, although the base of production is still relatively small (Edgell Communications, 2000). The top five craft brews accounted for less than 3 million barrels (2.6 million hl) in 1999. Imports account for about 7% of the current beer market in the U.S., and continue to grow (Hein, 1998). The main exporters to the U.S. are Mexico, Canada, the Netherlands, United Kingdom, Germany and Ireland. The U.S. beer industry exports beer mainly to

³ Craft brewing is defined here as not more than one-third owned by another large non-craft brewing company of greater than \$50 million revenue.

the Asian market (Japan, Taiwan, Hong Kong), the Americas (Brazil, Canada, Mexico) and Russia. Exports were growing until 1995 when they began decreasing, due to the economic developments in Asia, Brazil and Russia.

Value-added reflects the value of shipments less the cost of inputs required for producing the products. Value added in the brewing industry increased at an average of 6.5% per year from \$3.7 billion in 1980 to \$11.2 billion in 1998 (DOC, 2000). During the same period, employment dropped by 1.6% per year from 43,000 to 32,000 employees. This puts the breweries sector among the top ten industrial sectors in terms of value-added per employee. The decreased employment in the U.S. brewery sector may suggest an increasing level of mechanization.

Figure 2. U.S. brewers' production (million barrels) 1987-1999



Source: Edgell Communications, 2000; Hardwick, 1994

3. Process Description

The brewing process uses malted barley and/or cereals, unmalted grains and/or sugar/corn syrups (adjuncts), hops, water, and yeast to produce beer. Most brewers in the U.S. use malted barley as their principal raw material. Depending on the location of the brewery and incoming water quality, water is usually pre-treated with a reverse osmosis carbon filtration or other type of filtering system. Figure 3 outlines the main stages of production for U.S. breweries.

The first step of brewing, *milling and carbon filtration*, takes place when malt grains are transported from storage facilities and milled in a wet or dry process to ensure that one can obtain a high yield of extracted substances (UNEP, 1996). Sometimes the milling is preceded by steam or water conditioning of the grain.

The mixture of milled malt, gelatinized adjunct and water is called mash. The purpose of *mashing* is to obtain a high yield of extract (sweet wort) from the malt grist and to ensure product uniformity. Mashing consists of mixing and heating the mash in the mash tun, and takes place through infusion, decoction or a combination of the two. During this process, the starchy content of the mash is hydrolyzed, producing a liquor called sweet wort. In the infusion mashing process, hot water between 160-180°F (71-82°C) is used to increase the efficiency of wort extraction in the insulated mashing tuns. The mashing temperature is dictated by wort heating using steam coils or jackets. In decoction mashing, a portion of the mashing mixture is separated from the mash, heated to boiling and re-entered into the mash tun. This process can be carried out several times, and the overall temperature of the wort increases with each steeping. Part of this mash is evaporated. This process requires an estimated 12-13 kBtu/barrel⁴ for medium-sized breweries (Hackensellner, 2000). The type of mashing system used depends on a number of factors such as grist composition, equipment and type of beer desired, although decoction mashing appears to be the preferred system in North America (Hardwick, 1994). Infusion mashing is less energy intensive than decoction mashing requiring roughly 8-10 kBtu/barrel of fuel (Hackensellner, 2000).

Following the completion of the mash conversion, the wort is separated from the mash. The most common system in large breweries is a lauter tun or a mash filter (O'Rourke, 1999b). A more traditional system is the use of a combined mash tun/lauter tun, usually termed a mashing kettle or vessel. In the combined mashing vessel, the wort run off is directed through a series of slotted plates at the bottom of the tun. The mash floats on top of the wort. This tends to be the slowest wort separation system although it is the lowest cost in terms of capital outlay (O'Rourke, 1999b). With the use of the lauter tun, the converted mash is transferred to a lautering vessel where the mash settles on a false bottom and the wort is extracted. Lautering is a complex screening procedure that retains the malt residue from mashing on slotted plates or perforated tubes so that it forms a

⁴ In the U.S., energy use in beer brewing is commonly expressed in kBtu/barrel. To convert from kBtu (higher heating value, HHV) to MJ multiply by 1.055 MJ/kBtu. To convert from barrels of beer to hectoliter (hl) divide by 0.85 barrel/hl.

filtering mass. The wort flows through the filter bed (Hardwick, 1994). In both the combined mashing vessel and the lauter tun, the grains are also sparged (i.e. sprayed and mixed) with water to recover any residual extract adhering to the grain bed. The extracted grain, termed “spent grain,” is most often used as animal feed. In a mash filter, the mash is charged from the mash mixer. The filter is fitted with fine pore polypropylene sheets that forms a tight filter bed and allows for very high extract efficiency (in excess of 100% laboratory extract) (O’Rourke, 1999b). However, the quality of the filtered wort may be affected through the use of a mash filter process and may not be applicable for all types of brewing.

The next step, *wort boiling*, involves the boiling and evaporation of the wort (about a 4-12% evaporation rate) over a 1 to 1.5 hour period. The boil is a strong rolling boil and is the most fuel-intensive step of the beer production process. Hackensellner (2000) estimates 44 to 46 kBtu/barrel is used for conventional wort boiling systems in Germany. The boiling sterilizes the wort, coagulates grain protein, stops enzyme activity, drives off volatile compounds, causes metal ions, tannin substances and lipids to form insoluble complexes, extracts soluble substances from hops and cultivates color and flavor. During this stage, hops, which extract bitter resins and essential oils, can be added. Hops can be fully or partially replaced by hop extracts, which reduce boiling time and remove the need to extract hops from the boiled wort. If hops are used, they can be removed after boiling with different filtering devices in a process called hop straining. As with the spent mashing grains, some breweries sparge the spent hops with water and press to recover wort. In order to remove the hot break, the boiled wort is clarified through sedimentation, filtration, centrifugation or whirlpool (being passed through a whirlpool tank). Whirlpool vessels are most common in the U.S.

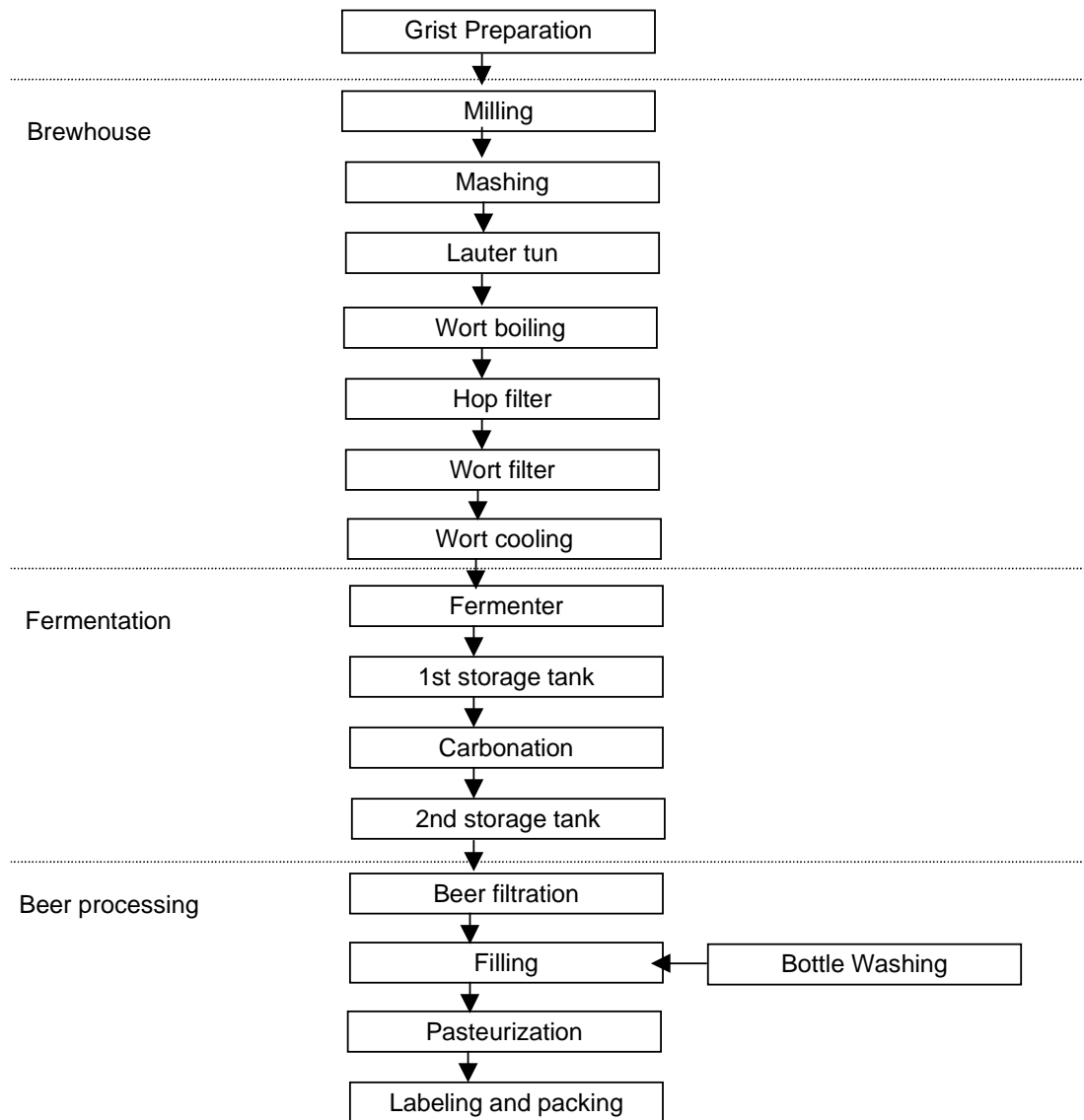
After clarification, the cleared hopped wort is cooled. Cooling systems may use air or liquids as a cooling medium. Atmospheric cooling uses air stripping columns (used by Anheuser-Busch) while liquid cooling uses plate heat exchangers. Heat exchangers are of two types: single-stage (chilled water only) or multiple-stage (ambient water and glycol). Wort enters the heat exchanger at approximately 205 to 210°F (96-99°C) and exits cooled to pitching temperature. Pitching temperatures vary depending on the type of beer being produced. Pitching temperature for lagers run between 43-59°F (6-15°C), while pitching temperatures for ales are higher at 54-77°F (12-25°C) (Bamforth, 2001). The amount of heat potentially recovered from the wort during cooling by a multiple stage heat exchanger is 35-36 kBtu/barrel (Hackensellner, 2000). Certain brewers aerate the wort before cooling to drive off undesirable volatile organic compounds. A secondary cold clarification step is used in some breweries to settle out trub, an insoluble protein precipitate, present in the wort obtained during cooling.

Once the wort is cooled, it is oxygenated and blended with yeast on its way to the fermentor.⁵ The wort is then put in a fermentation vessel. For large breweries, the cylindrical fermentation vessels can be as large as 4,000-5,000 barrel tanks (Bamforth, 2001). During fermentation, the yeast metabolizes the fermentable sugars in the wort to produce alcohol and carbon dioxide (CO₂). The process also generates significant heat

⁵ Oxygen is essential to the development of yeast cell plasma membranes.

that must be dissipated in order to avoid damaging the yeast. Fermenters are cooled by coils or cooling jackets. In a closed fermenter, CO₂ can be recovered and later reused. Fermentation time will vary from a few days for ales to closer to 10 days for lagers (Bamforth, 2001). The rate is dependent on the yeast strain, fermentation parameters (like the reduction of unwanted diacetyl levels) and taste profile that the brewer is targeting (Bamforth, 2001; Anheuser Busch, 2001).

Figure 3. Process stages in beer production



Source: UNIDO, 2000

At the conclusion of the first fermentation process, yeast is removed by means of an oscillating sieve, suction, a conical collector, settling or centrifugation. Some of the yeast is reused while other yeast is discarded. Some brewers also wash their yeast. Some brewing methods require a second fermentation, sometimes in an aging tank, where sugar or fresh, yeasted wort is added to start the second fermentation. The carbon dioxide

produced in this stage dissolves in the beer, requiring less carbonation during the carbonation process. Carbonation takes place in the first fermentation also. Yeast is once again removed with either settling or centrifugation.

Beer aging or conditioning is the final step in producing beer. The beer is cooled and stored in order to settle yeast and other precipitates and to allow the beer to mature and stabilize. For beers with a high yeast cell count, a centrifuge may be necessary for pre-clarification and removal of protein and tannin material (UNEP, 1996). Different brewers age their beer at different temperatures, partially dependent on the desired taste profile. According to Bamforth (1996), ideally, the beer at this stage is cooled to approximately 30°F (-1°C), although this varies in practice from 30°F to 50°F (-1°C to 10°C) (Anheuser Busch, 2001). Beer is held at conditioning temperature for several days to over a month and then chill proofed and filtered. A kieselguhr (diatomaceous earth) filter is typically used to remove any remaining yeast. Brewers use stabilizing agents for chill proofing. Coloring, hop extracts and flavor additives are dosed into the beer at some breweries. The beer's CO₂ content can also be trimmed with CO₂ that was collected during fermentation. The beer is then sent to a bright (i.e. filtered) beer tank before packaging. In high gravity brewing (see also discussion in efficiency measures section), specially treated water would be added during the conditioning stage. This can be a significant volume, as high as 50% (Anheuser Busch, 2001).

Finally, the beer must be cleaned of all remaining harmful bacteria before bottling. One method to achieve this, especially for beer that is expected to have a long shelf life, is pasteurization, where the beer is heated to 140°F (60°C) to destroy all biological contaminants. Different pasteurization techniques are tunnel or flash pasteurization. Energy requirements for pasteurization can vary from 19-23 kWh per 1000 bottles for tunnel pasteurization systems (Hackensellner, 2000). Other estimates are 14-20 kBtu/barrel (Anheuser Busch, 2001). An alternative approach is the use of sterile filtration (Bamforth, 2001). However, this technology is new, and some believe these systems may require as much extra energy as they save (Todd, 2001).

A large amount of water is used for cleaning operations. Incoming water to a brewery can range from 4 to 16 barrels of water per barrel of beer, while wastewater is usually 1.3 to 2 barrels less than water use per barrel of beer (UNEP, 1996). The wastewater contains biological contaminants (0.7-2.1 kg of BOD/barrel).⁶ The main solid wastes are spent grains, yeast, spent hops and diatomaceous earth. Spent grains are estimated to account for about 16 kg/barrel of wort (36 lbs/barrel), while spent yeast is an additional 2-5 kg/barrel of beer (5-10 lbs/barrel) (UNEP, 1996). These waste products primarily go to animal feed. Carbon dioxide and heat are also given off as waste products.

⁶ BOD or Biological Oxygen Demand reflects a measure of the concentration of organic material. BOD, unless otherwise indicated, is measured for a five day period (UNEP, 1996)

4. Energy Use

4.1 Energy Consumption and Expenditures

The Food and Kindred Products group (SIC 20) consumed roughly 1585 TBtu (1.7 MJ)⁷, equal to roughly 7% of total manufacturing primary energy in 1994 (EIA, 1997). Of the food processing energy use, breweries consumed about 4%, equal to 67 TBtu (0.7 million TJ) and 40% of the beverage manufacturing energy, which also includes sectors such as soft drinks, wineries and distilleries.

Natural gas and coal account for about 60% the total primary energy consumed by the malt beverages industry. These fuels are primarily used as inputs to boilers to produce steam for various processes and to generate onsite electricity (see Table 2). Other uses include direct process uses, such as process heating, cooling, refrigeration and machine drive, and direct non-process uses such as facility heating. Net electricity consumption, including generation losses, was 36% of primary energy requirements (see Table 2).

Total energy expenditures for malt beverages in 1994 were \$221 million, with electricity accounting for 56% of expenditures, even though net electric energy consumption, including losses, is 36% (EIA, 1997). 1998 data from the Annual Survey of Manufactures shows that expenditures remained relatively constant at \$210 million—even though output increased—with electricity's share at 58% (DOC, 2000). Although overall energy expenditure data exist for more recent years, 1994 is the last year when detailed energy consumption and energy expenditure statistics were published for the breweries sector by the Energy Information Administration (EIA, 1997 and 2001). In the United Kingdom, energy expenditures account for roughly 3-8% of total production costs (Sorrell, 2000; McDonald, 1996). Anheuser-Busch suggests that energy expenditures account for about 8.5% (Anheuser-Busch, 2001). The largest production costs are packaging materials, raw production materials (grains) and malt (Sorrell, 2000).

Table 2. 1994 Primary energy consumption⁸ and expenditures in malt beverages

	Consumption		Expenditures	
	TBtu	(%)	\$Million	(%)
Net electricity (purchased)	8	12%	123	56%
Electricity losses	16	24%	--	--
Distillate fuel oil	0	0%	0.5	0%
Natural gas	22	33%	59	27%
Coal	17	25%	28	13%
Other fuels	4	6%	11	5%
Total	67	100%	221	100%

Source: EIA, 1997

⁷ To convert from TBtu (higher heating value, HHV) to TJ multiply by 1.055×10^{-9} TJ/TBtu.

⁸ Final energy is the purchased energy by the final user (or plant). Primary energy is calculated using the average efficiency for public power generation to estimate the fuels used to generate the power consumed by the brewing industry. We use an average efficiency of 32% based on U.S. consumption of fuels at power plants. Hence, primary energy is roughly three times final energy.

The relative importance of electricity costs, in addition to the high steam demand in the sector, prompted investment into the generation of onsite electricity at various manufacturing facilities. Cogenerated electricity (the production of both heat and power, also called combined heat and power or CHP) in 1994 was 644 million kWh (EIA, 1997). Accounting for all of the electricity uses (net demand), cogenerated electricity accounts for 22% of the total electricity used onsite⁹. This share of cogenerated electricity is relatively high compared to other industries in the U.S. The largest uses of electricity are in machine drives for the use of pumps, compressed air, brewery equipment, and process cooling (see Table 3).

Table 3. Uses and sources of electricity in the brewery sector, 1994

Uses	Million kWh	Percent
Boiler/hot water/steam generation	59	2%
Process cooling/refrigeration	943	32%
Machine drive (pumps, compressors, motors)	1,360	46%
Facility heating, ventilation, air conditioning (HVAC)	201	7%
Lighting	214	7%
Other	198	7%
Total	2,975	100%
Sources	Million kWh	Percent
Purchases	2,323	78%
Cogeneration	644	22%
Other (on-site generation)	8	0%
Total	2,975	100%

Source: EIA, 1997

Table 4 identifies energy use for specific brewery processes based on surveys conducted by the Energy Technology Support Unit (ETSU) in the United Kingdom for a kegging brewery (Sorrell, 2000). As the table indicates, the vast majority of thermal energy is used in brewing operations and pasteurization, while electricity consumption is more evenly divided among fermentation, beer conditioning and space and utilities. Anheuser-Busch estimates that 64% of thermal energy is used in brewing (Meyer, 2001).

⁹ Net demand accounts for the total uses of electricity onsite and reflects the fact that some of the purchased fuels are used to produce electricity for internal consumption. In 1994, net electricity use (purchases) was 8 TBtu (2,311 Million kWh) while net demand was 10 TBtu (2,975 Million kWh).

Table 4. Estimated percentage energy use for various brewing processes

Thermal Energy	Brewhouse	30-60%
	Packaging	20-30%
	Space heating	<10%
	Utilities	15-20%
Electrical Energy	Refrigeration	30-40%
	Packaging	15-35%
	Compressed air	10%
	Brewhouse	5-10%
	Boiler house	5%
	Lighting	6%
	Other	10-30%

Source: Sorrell, 2000

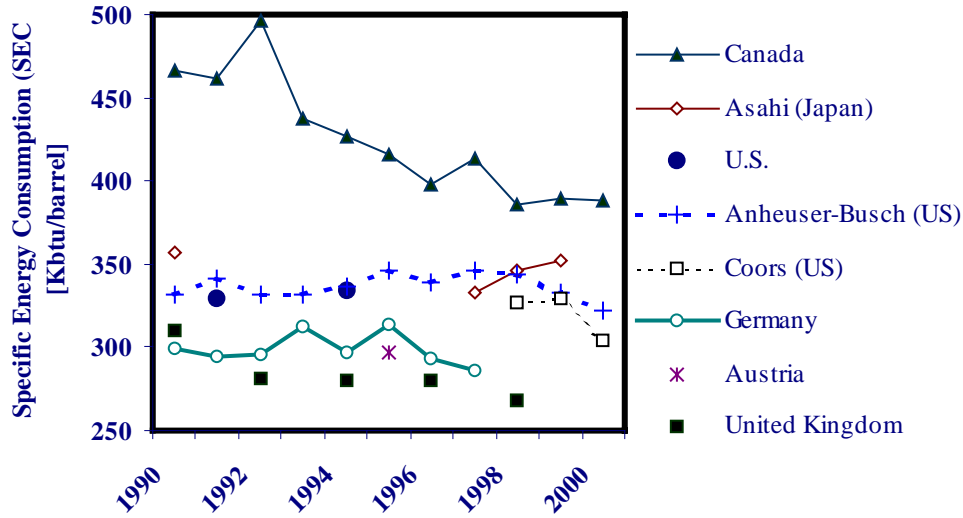
4.2 Energy Intensity

Energy intensity, or specific energy consumption, reflects the amount of energy required per unit of output or activity. Barring changes in the composition of output, declining energy intensities can reflect technology improvements. In the breweries sector, energy intensity can be measured using both physical and economic indicators as the output denominator. Figure 4 depicts average physical primary energy intensities for beer production for the U.S. and other countries (The electricity consumption includes losses in transmission and distribution.).

As Figure 4 indicates, there is a wide range of unit energy consumption for the various countries. U.S. national data is based on 1991 and 1994 Energy Information Administration energy data and output data provided by the Beer Institute (EIA, 1994 and 1997; Beer Institute, 2000). (Brewery energy consumption was not reported in the most recent EIA energy survey for 1998.) In addition to U.S. national data, we included a time series for Anheuser-Busch data (Anheuser-Busch, 2001) and for Coors data (Coors, 2001), which combined produce over 60% of the beer in the U.S.

The variation in intensities is partly influenced by the type of product being produced. In the United Kingdom for example, almost 80% of beer produced is draught beer that has much lower energy requirements than other types of beer since it is not pasteurized (Lom and Associates, 1998). Intensities will also vary depending on the size of the brewery. Figure 5 depicts the range of specific energy consumption (in kBtu/barrel) for German breweries of various sizes. Class V contains the largest breweries (greater than 500,000 hectoliters (hl) annual production) and has the lowest specific energy consumption.

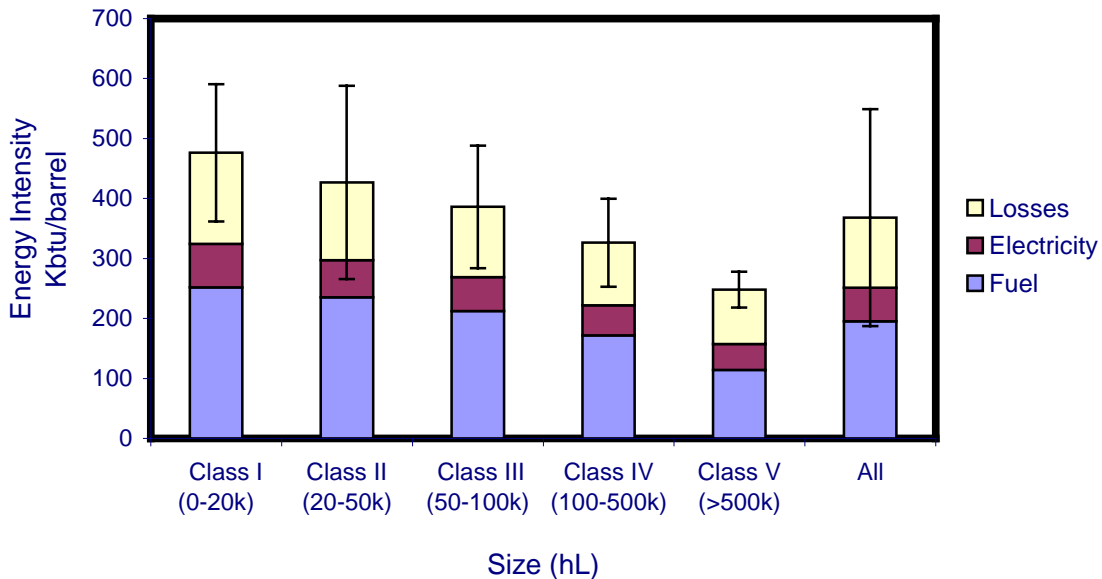
Figure 4. Physical primary energy intensities for beer production for selected countries and companies (kBtu/barrel)



Note: Primary intensity reflects the accounting of transmission and distribution losses in electricity use. We use a factor of 3.08 to convert final electricity consumption to primary electricity consumption.

Sources: U.S. (EIA, 1997; Beer Institute, 2000), 1998 brewery energy consumption was not reported for 1998 (EIA, 2001); Coors (U.S.) (Coors, 2001); Anheuser-Busch (Anheuser-Busch, 2001); Canada (Lom and Associates, 1998; Nyboer and Laurin, 2001); Austria (EC, 1998; Bkontakt, 2000); Asahi in Japan (Asahi Breweries, 2000); U.K. (Sorrell, 2000); Germany (Hackensellner, 2000)

Figure 5. 1998 Energy consumption for German breweries by size



Source: Schu et al., 2001

5. Options for Energy Efficiency

A variety of opportunities exist within breweries to reduce energy consumption while maintaining or enhancing the product quality and productivity of the plant. Improving energy efficiency in a brewery should be approached in several ways. First, breweries use equipment such as motors, pumps and compressors. These require regular maintenance, proper operation and replacement with more efficient models, when necessary. Thus, a critical element of plant energy management involves the careful control of cross-cutting equipment that powers the production of a plant. A second and equally important area is the proper and efficient operation of the process. Process optimization and ensuring the most productive technology is in place are key to realizing energy savings in a plant's operation.

If a company operates several breweries, energy management can be more complex than just considering the needs of a single plant. Whether for a single plant or an entire corporation, establishing a strong organizational energy management framework is important to ensure that energy efficiency measures are implemented effectively.

Table 5 lists energy efficiency measures that have been identified as process-specific to mashing, wort boiling and cooling, fermentation, processing and packaging. Table 6 lists measures that are cross-cutting, i.e. they affect many operations, or that concern utilities, such as the production of steam or electricity or cooling. The payback period estimates are based on the implementation of individual technologies. Combining several technologies in a single project or changing management practices may reduce the costs and hence improve the productivity of an investment.

Table 5. Process-specific energy efficiency measures for the brewing industry

	Typical payback periods	
	1-3 years	> 3 years
Mashing and Lauter Tun		
Capture of waste heat energy		
Use of compression filter (mashing)		
Wort boiling and cooling		
Vapor condensers		
Thermal vapor recompression ¹		
Mechanical vapor recompression		
Steinecker Merlin system		
High gravity brewing		
Low pressure wort boiling		
Wort stripping		
Wort cooling-additional heat recovery ²		
Fermentation		
Immobilized yeast fermenter		
Heat recovery ³		
New CO ₂ recovery systems ⁴		
Processing		
Microfiltration for clarification or sterilization		
Membranes for production of alcohol-free beer		
Heat recovery-pasteurization ⁵		
Flash pasteurization		
Packaging		
Heat recovery washing		
Cleaning efficiency improvements		

Notes:

1. Payback period may be longer; 2. Payback period depends on systems used currently and could be shorter; 3. Payback period depends on makeup/exhaust airflow, weather conditions and electricity rates; 4. Small water pump size and low cost of purchased CO₂ would create a longer payback period; 5. Payback periods based on a retrofit (Anheuser-Busch, 2001).

Table 6. Cross-cutting and utilities energy efficiency measures for the brewing industry

Measure	Typical payback periods	
	<2 years	>2 years
Boilers and Steam distribution		
Maintenance		
Improved process control ¹		
Flue gas heat recovery		
Blowdown steam recovery		
Steam trap maintenance		
Automatic steam trap monitoring		
Leak repair		
Condensate return ²		
Improved insulation of steam pipes ³		
Process integration		
Motors and Systems that Use Motors		
Variable speed drives ⁴		
Downsizing of motors, pumps, compressors ²		
High efficiency motors, pumps, compressors ²		
Refrigeration and cooling		
Better matching of cooling capacity and cooling loads		
Improved operation of ammonia cooling system		
Improve operations and maintenance		
System modifications and improved design		
Insulation of cooling lines ⁵		
Other utilities		
Lighting		
Reduce space heating demand		
Anaerobic waste water treatment ²		
Membrane filtration wastewater		
Control and monitoring systems ²		
Combined heat and power		
CHP combined with absorption cooling		
Engine-driven chiller systems		

Notes:

1. Payback period depends on tuning conditions of existing systems; 2. Payback periods may be longer; 3. Payback periods depend on existing conditions; 4. Savings depend on how often the motor is run at less than full speed; 5. Payback period varies depending on purging of the system before and how careful the operators performed pumpouts (Anheuser-Busch, 2001).

The values presented in the following review provide an average estimate or a set of specific data points; only a detailed study of a specific location can produce reliable estimates for that plant. Actual energy savings will likely vary by plant size and operation characteristics. Throughout our review, where possible, we provide an estimate of the range of savings found under varying conditions. We acknowledge that for some measures, particularly new technologies, there may not be sufficient information (e.g. a larger set of experiences) to estimate average industry savings and payback. For these, we have provided the information that was available. We also acknowledge that payback

periods vary from country to country and from brewery to brewery and that a measure may have been adopted by some individual breweries but not all of them. In addition, for those measures only reducing electricity or gas consumption, payback periods will vary with utility rates. To account for these differences in payback periods, we sought comments from U.S. brewers, adapted the data to U.S. conditions where feasible and adjusted our ranges to incorporate their experiences.

Although technological changes in equipment can help to reduce energy use, changes in staff behavior and attitude also can have a great impact. Staff should be trained in both skills and the company's general approach to energy efficiency for use in their day-to-day practices. Personnel at all levels should be aware of energy use and objectives for energy efficiency improvement. Often this information is acquired by lower level managers but not passed to upper management or to other staff (Caffal, 1995). Programs with regular feedback on staff behavior, such as reward systems, have had good results. Though changes in staff behavior, such as switching off lights or closing windows and doors, save only small amounts of energy at a time, when taken continuously over longer periods, they may have a much greater effect than more costly technological improvements. Most importantly, companies need to institute strong energy management programs that oversee energy efficiency improvement across the corporation. An energy management program will ensure all employees actively contribute to energy efficiency improvements.

Participation in voluntary programs like the EPA ENERGY STAR program, or implementing an environmental management system such as ISO 14001 can help companies track energy and implement energy efficiency measures. One ENERGY STAR partner noted that combining the energy management program with the ISO 14001 program had a large effect on saving energy at their plants.

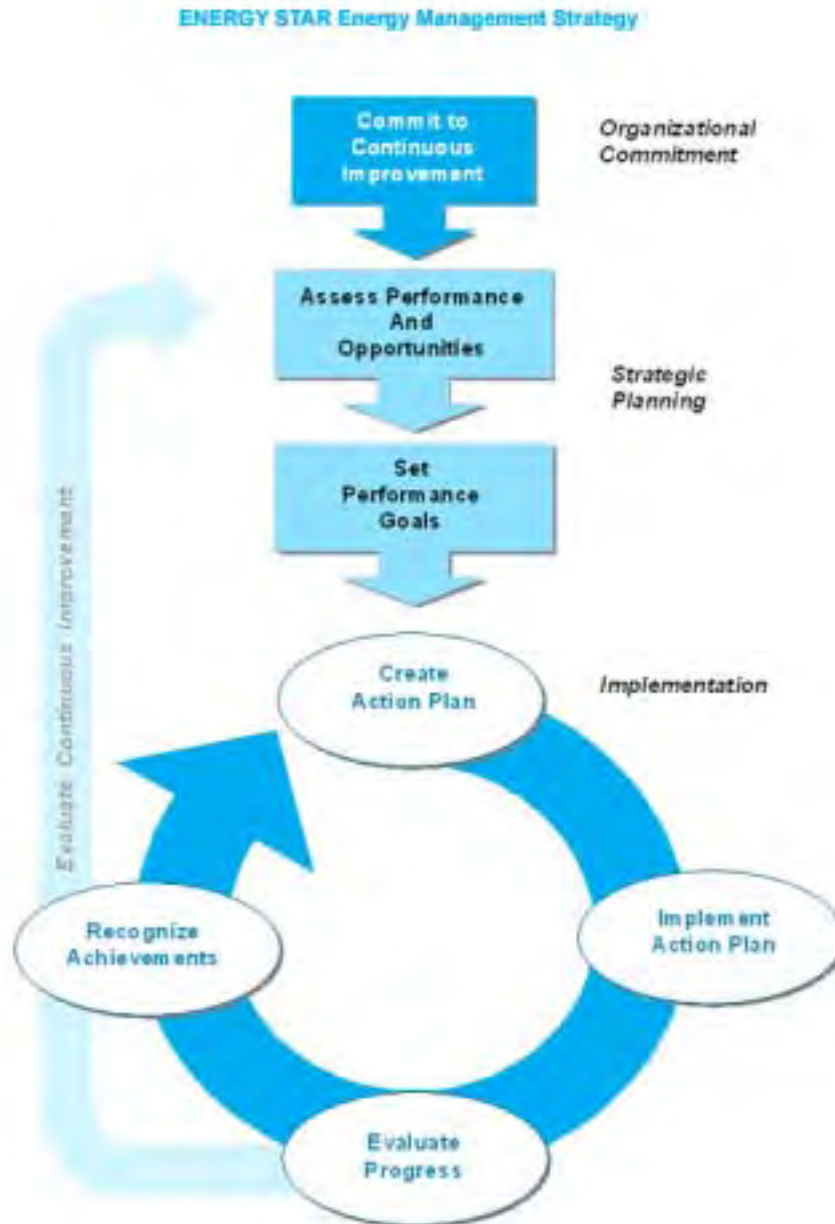
5.1. Energy Management Systems.

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

An energy management program creates a foundation for improvement and provides guidance for managing energy throughout an organization. In companies without a clear program in place, opportunities for improvement may be unknown or may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures or perceived change from the status quo. Even when energy is a significant cost for an industry, many companies still lack a strong commitment to improve energy management.

EPA, through ENERGY STAR, has worked with many of the leading industrial manufacturers to identify the basic aspects of an effective energy management program.¹⁰ The major elements are depicted in Figure 6.

Figure 6. Main elements of a strategic energy management system



A successful program in energy management begins with a strong commitment to continuous improvement of energy efficiency. This typically involves assigning oversight and management

¹⁰ See Guidelines for Energy Management at www.energystar.gov.

duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance, through regular reviews of energy data, technical assessments and benchmarking. From this assessment, an organization is then able to develop a baseline of performance and set goals for improvement.

Performance goals help to shape the development and implementation of an action plan. An important aspect for ensuring the successes of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high performers. Some examples of simple employee tasks are outlined in Appendix II.

Evaluating performance involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Establishing a strong communications program and seeking recognition for accomplishments are also critical steps. Strong communication and recognition help to build support and momentum for future activities.

A quick assessment of an organization's efforts to manage energy can be made by comparing the current program against the table contained in Appendix II.

Energy monitoring systems.

Energy monitoring and process control systems can play important roles in energy management and in reducing energy use. These may include sub-metering, monitoring and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency and optimize process operations. Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems. These savings apply to plants without updated process control systems; many U.S. plants may already have modern process control systems in place to improve energy efficiency.

Support for a business energy management program can come from outside sources as well. Some utility companies work with industrial clients to achieve energy savings. In these cases, utility personnel work directly with managers onsite to better identify and implement programs and measures that are more effective for the particular situation of the facility.

6. Process-Specific Measures

Table 5 lists the process specific measures that we have identified for the beer brewing industry along with their typical payback periods. Below, we describe each of the measures in more detail.

6.1 Mashing and Lauter Tun Processes

Capture of waste heat energy

In the mashing process, waste heat can be captured from the mash or from the hot water tank. This heat can be used for either mashing or for other processes. Some breweries use a hot water tank of roughly 170°F (75°C) to inject the water into mashing operations. This tank has an overflow stream that can be used during pasteurization to heat the water to 140°F (60°C). If more heat is needed, steam or hot water can be blended to make water at the temperature needed (UNIDO, 2000). Hackensellner (2000) notes that steam at a temperature of 340°F (170°C) is used to heat the mash vessel. However, hot water of 200-210°F (95-98°C) generated from heat recovery can be used to partially heat the mash thereby reducing steam or hot water generation requirements at the facility. The mash tun needs to be refitted with a heat transfer area to recover this waste heat.

Use of compression filter in mashing process

The Brand brewery (the Netherlands), with annual production of about 1 million hl (0.9 million barrels) replaced a plate filter with a compression filter in its mashing process. The compression filter reduces cleaning costs by reducing the need to rinse the filter with water (since it is cleaned by air). The process also increased yield and reduced water use. Energy savings for this measure were 16 billion Btu (16.8 TJ) of gas (lower heating value), or 18.6 kBtu/barrel (16.8 MJ/hl) (NOVEM, 1999a). The cost of the installation of the filter was \$620,000 (1.3 million Dfl) and the payback period was about 2 years. Proponents of this measure claim that the use of mash filter technology can reduce cycle times, reduce spent grain moisture, increase wort concentration (particularly important for high gravity brewing), and increase the number of brews per day to up to 12 (Stewart, 1999). We acknowledge that while this technology is new and its adoption will take time, sufficient data are not yet available to support all claims and potential impact on taste must be further evaluated.

6.2 Wort Boiling and Cooling

Heat recovery using vapor condensers

Given the high fuel requirements for wort boiling in breweries, several opportunities exist to recover thermal energy and use it in various brewery operations. High-grade heat may be recovered from kettle vapors using either spray condensers or heat exchangers (Sorrell, 2000). The heat from the vapor can be used to pre-heat the incoming wort, while the heat from the vapor condensate can be used to produce hot water for cleaning, space heating, keg washing or other applications in the brewery. Such systems can recover up to 60% of the energy required for wort boiling (Sorrell, 2000).

In 1991, a Grolsch brewery (the Netherlands) installed a waste heat recovery system in its continuous wort boiling operations. Overall energy savings were 35 billion Btu. The

system also reduced water, maintenance and operation costs. The payback period for the energy savings alone was 3.5 years, however, if water and operation and maintenance costs are included, the payback period was 2 years (NOVEM, 1991a). In a related technology, the Bavaria brewery in Lieshout (the Netherlands) installed a system in which the wort vapor is mixed with the steam from the heating coils. The mixture is fed to a condenser and the condensation heat is used to heat a water circuit, which provides heat to the wort pre-heaters as well as to several other departments like filtering and bottling divisions. Net savings from the system are 1,144,000 m³/year natural gas equivalent (i.e. natural gas savings of 1,171,700 m³ but an increased electricity use of 72,000 kWh/year). This translates into a net savings 22 kBtu/barrel (0.02 GJ/hl). The project had a payback period of 5.5 years (CADDET, 1993a; NOVEM, 1993a). A Japanese brewery that installed wort pan condensers to recover condensate as hot water was able to reduce significantly annual steam use. Steam savings resulted from shortening the wort heating time by preheating the incoming wort (900 tons), reducing the steam input into the wort pan container hot water tank steam inline heater (670 tons), and by reducing mixing time. Savings were estimated to be 1.3% of steam consumption (UNIDO, 1995). Heat recovery from kettle and wort boiling and wort cooling in the New Belgium Brewing Company (Colorado) generates enough hot water for all brewing and some cleaning requirements (Farrell, 1998; Heyse et al, 1996; and UNIDO, 2000).

Wort boiling using thermal vapor recompression

Vapor recompression is an established technology for reducing energy costs in evaporation. In a vapor recompression system, the wort is boiled externally to 216°F (102°C) using compressed vapors up to 1.25 bar. In thermal vapor recompression, a portion of the evaporated water vapor is compressed by high-pressure steam and reused. The wort expands in the kettle at 212°F (100°C). Vapor-condensate is collected in the condensate tank and the heat (used to preheat water) is recovered through a plate heat exchanger (UNIDO, 2000). These systems work best when operating under constant running conditions for long periods (Sorrell, 2000). Thermal recompression plants have been operating in breweries since 1991. Thermal recompression provides for less costly machinery than straight steam heated designs but requires higher pressure steam (Dedert, 2001). In a thermal vapor recompression system by Huppmann, a portion of the vapors (20-40%) is condensed for hot water generation and a portion (60-80%) is sucked into the steam jet compressor being forced by steam of at least 6 bar pressure. The discharge steam at 1.3-1.4 bar is used to then heat the external boiler (Hackensellner, 2000). Energy requirements for operating the thermal vapor compressor are estimated at 120 kBtu per barrel of evaporated water (Hackensellner, 2000). A disadvantage of this system is that condensate cannot be sent back to the steam plant as it is contaminated by the vapors given off by the wort (Sorrell, 2000). There are however, vapor condensate purification systems that have been shown to have a payback period of two years (Hackensellner, 2000).

In a variation on this technology, the Löwenbrauerei in Schwaebish Hall (Germany) installed a low pressure (0.8 bar) steam vapor recompression 300 hl brew kettle with an interior cooker along with computer automation (Klein-Carl and Reichert, 1991). This study showed the system saved a significant amount of energy (40%) increasing the

efficiency of the heat transfer, reducing the need for a circulation pump and reducing boiling times (Klein-Carl and Reichert, 1991). Primary energy requirements for generating steam for the milling, mashing, and wort boiling are reduced to 27 kBtu/barrel (6.7 kWh/hl), a savings of 16-18 kBtu/barrel (4-4.5 kWh/hl) (Klein-Carl and Reichert, 1991; Heyse et al. 1996).

Wort boiling using mechanical vapor recompression

Vapor recompression is an established technology to reduce energy costs for evaporation. In a vapor recompression system, the wort is boiled to 216°F (102°C) externally using compressed vapors up to 1.25 bar. The wort expands in the kettle at 212°F (100°C). Vapor condensate is collected in the condensate tank and the heat (used to preheat water) is recovered through a plate heat exchanger (UNIDO, 2000). Mechanical vapor recompression (MVR) systems have been used in breweries since 1980 and can achieve energy savings because the generated useful heat contains more energy than the electricity required to compress the steam (Hackensellner, 2000; Kidger, 2001). MVR systems work best when operating constantly for long periods (Sorrell, 2000). Manufacturers claim MVR systems reduce the aroma emissions almost entirely, provide a gentle boiling process by lowering the pressure of the compressed vapor and in many cases, significantly reduce or eliminate other steam requirements (Steineker, 2001).

In MVR, the evaporator components are similar to steam-powered machinery with the addition of a mechanical compressor. Mechanical energy supplied via a compressor or fan compresses the vapor to a higher pressure where it may be reused. Vapor from the wort kettle is drawn in by a compressor and compressed by 0.25-0.4 bar above atmospheric pressure. The compressed vapor can be reused for heating an external or internal boiler (Hackensellner, 2000). Steineker notes a reduction in evaporation requirements from 9.9% for conventional boiling to 8.7% for MVR, and estimates fuel consumption as low as 14 kBtu/barrel (Steineker, 2001; Weinzierl et al., 2000). However, MVR systems will have increased electricity requirements to run the compressor and circulating wort pump. Electricity consumption is estimated to range from 0.3 to 2.8 kWh/barrel (0.1 to 0.7 kWh/hl) evaporate (Hackensellner, 2000; Weinzierl et al., 2000). One of the main operating challenges is to maintain an air-free system for wort boiling. This evaporator is generally more costly than thermal vapor recompression, but operating costs are significantly less. Estimates for operating costs are around 2-7% of the investment costs (Hackensellner, 2000).

Steineker Merlin wort boiling system

The Merlin wort boiling system is an external wort boiling system. It is designed such that the wort is contained in a whirlpool holding vessel and is continuously fed into a steam heated cone container. It consists of a whirlpool and an evaporation vessel with boiling equipment whereby the wort passes through both vessels in a circulatory loop (Steineker, 2001). The increased surface area and exposure of the wort to heat limits the required evaporation. Steineker claims that the system has a total evaporation requirement of 4% (compared to 8% in conventional systems), and reduces fuel requirements by up to 65-75%. In addition to energy savings, proponents claim the Merlin system improves product quality with reduced caramelization and reduced fobbing,

provides more brews between cleanings and realizes better vessel utilization (O'Rourke, 1999a; Weinzierl et al., 2000). Potential impacts on beer taste would reduce effectiveness of this measure. An operable system for a 370 hl (315 barrel) operation was installed in the Flensburg Brewery (Germany) in 2000, but no systems have yet been installed in the United States. An analysis of the Scherdel brewery in Hof (Germany) found a savings potential of 31 kBtu/barrel compared to a wort boiling system without heat recovery from the boiling vapors (Steineker, 2001). Another analysis of the Merlin system found fuel consumption of 22 kBtu/barrel, compared to 36 kBtu/barrel for conventional systems (Weinzierl et al., 2000). When an energy storage unit is added to the Merlin system, fuel use drops further to 12.3 kBtu/barrel, for a total savings of 23.7 kBtu/barrel. In all cases, electricity use increases to 0.02 kWh/barrel (Stippler and Felgentraeger, 1999; Weinzierl et al., 2000). As of last year, there were at least four operating Merlin plants worldwide and more expected to be built. Depending on energy prices, paybacks for the installation of a system can be as low as 2 years (Finkeldey, 2001).

Brewing at high specific gravity

Specific gravity is the "heaviness" of a substance compared to water. Beer may be brewed at a higher specific gravity and diluted with water after final filtration to bring it to the desired alcohol concentration (Hardwick, 1994; Sorrell, 2000). Claims of energy savings vary between 18% and 30% in the brewhouse (Sorrell, 2000; Muller, 1996). This technology was first applied in the U.S. right after the Second World War (Muller, 1996). Now it has become a standard technology in the large and some of the medium-sized breweries. In North America today, more beer is produced by high gravity brewing than through conventional means (Stewart, 1999). High gravity brewing can defer capital expenditures, may increase brewing capacity (with more efficient use of plant facilities) and may improve product quality (better consistency and character have been reported, although the impact on flavor is an obvious concern) (Muller, 1996; Stewart and Russell, 1998). Anheuser-Busch has implemented high gravity brewing to gain brewery capacity (Meyer, 2001). Other benefits include increased flexibility of beer type, reduced product losses, reduced water use and reduced labor and cleaning costs (Stewart, 1999; Muller, 1996). Some of the possible disadvantages, in addition to possible flavor changes, include decreased brewhouse material efficiency, reduced kettle hop utilization, decreased foam stability and adverse effects on yeast performance (Stewart, 1999). Because of the many additional benefits that accompany these systems, paybacks can be rapid (Muller, 1996).

Low pressure wort boiling

In low pressure wort boiling, the boiling vessel is designed for a maximum operation pressure of 0.6 bar, which corresponds to a temperature of 235°F (113°C) (UNIDO, 2000). Lower temperatures and pressures are also used (Herrmann, 1998). Low pressure wort boiling has been employed by breweries since 1979, while a variant of this approach, dynamic low pressure wort boiling, has been commercially available since 1996 (Hackensellner, 2000). In dynamic low pressure wort boiling, an evaporation rate of 4.5% to 6% is sufficient to produce high quality beers. In some cases, energy can be recovered from a vapor condenser and be used to pre-heat the wort before entering the low pressure boiling system (Hermann, 1998). In brewhouses with large cast wort quantities (e.g. 8-12 brews/day), investment in these systems becomes more cost-

effective. Steam consumption is estimated to range from 26-28 kBtu/barrel cast wort for mashing and boiling (Hackensellner, 2000; Weinzierl et al., 2000). Compared to conventional systems, fuel savings range from 43 to 54%, depending on the amount of evaporation. Electricity use, however, doubles for these systems to 0.02 kWh/hl from 0.01 kWh/hl (Hackensellner, 2000; Vollhals, 1994; Hackensellner, 2001).

Wort stripping systems

Interbrew introduced a modification to its wort boiling system that they claim halves steam consumption. The system is a two-part system. In the first phase, wort is kept at wort boiling temperature in a conventional kettle without significant evaporation. In the second phase, after clarification and before wort cooling, the wort is sent to a wort stripping column. In counterflow with the falling wort, live steam is injected at a flow rate of 0.5-2.0% of the wort flow rate. The steam flows up the column, condenses and leaves after having collected the same level of wort volatiles that are evaporated with conventional boiling (Seldeslachts, 1999; Anonymous, 1998; Meura, 2000). Total evaporation of the wort is generally kept below 2% of the total wort volume (Seldeslachts, 1999). Cooking time of the wort is reduced from 65 to 40 minutes with no changes in color, foam stability or flavor (Jacob et al., 2001). Dimethyl sulfate (DMS) and other unwanted compounds are controlled and stripped in order to reduce them to desired levels (Seldeslachts, 1999). Energy savings come from significant reductions in evaporation requirements and not having to heat up the wort to as high a temperature (Seldeslachts, 1999). Data from trials at Interbrew showed a reduction in energy consumption of 42 kBtu/barrel (92 kBtu/barrel to 50 kBtu/barrel) for conventional mashing and wort boiling, equivalent to a reduction of 46% (Seldeslachts, 1999). Other studies have demonstrated fuel consumption of 31-42 kBtu/barrel for wort boiling, equivalent to fuel savings of 30-40% for wort boiling in the brewhouse compared to conventional technology (Jacob et al., 2001; Seldeslachts et al., 1997).

Additional heat recovery from wort cooling

Wort cooling can be one of the most significant energy savings measures in the brewery, as efforts are made to recover as much hot water as possible from the cooling system (Kidger, 2001). Wort is usually cooled through plate heat exchangers. Heat exchangers are of two types: single-stage (chilled water only) or multiple-stage (ambient water and glycol). Wort enters the heat exchanger at approximately 205-210°F (96-99°C) and exits cooled to pitching temperature, 41-48°F (5-9°C) for bottom fermented beers and 59-64°F (15-18°C) for top fermented beers. The spent cooling water at about 185°F (85°C) can be reused as process water for the next mash (UNIDO, 2000). The input energy requirement is less with two-stage cooling than with one-stage cooling system (Goldammer, 2000). Cooling electricity consumption can range from 0.24 kWh/barrel for a single stage heat exchanger to 0.18 kWh/barrel for a two-stage ammonia based system (Hackensellner, 2000). A European brewery with a production of 1 million hl annually installed a new wort cooler. The new cooler reduced fuel oil consumption by 17 kBtu/barrel, water consumption by 40,000 m³, and had a simple payback of approximately 3 years (Lom and Associates, 1998).

6.3 Fermentation

Immobilized yeast fermenter for accelerating fermentation

Pilot plants for continuous fermentation were developed in the 1970s. However, this process was not widely adopted by brewers except for one brewery in New Zealand, as the systems did not perform up to flavor specifications (Stewart and Russell, 1998). Since that time, further developments in this technology have made it a more attractive option (Nedovic et al., 1999). Immobilized cell systems are those physically confined to a certain defined region of space with retention of their catalytic activity and viability. The most widespread technique is entrapment within a matrix (Stewart and Russell, 1998). Meura-Delta (Belgium) has recently developed a new bioreactor process that they claim has the capacity to accelerate the fermentation process from 5-7 days to one day. The reactor works by having the yeast immobilized on a ceramic carrier that increases the contact between the wort and the yeast, thereby increasing the fermentation reaction speed. The Finnish national research council developed a system where green beer is passed through an immobilized yeast reactor reducing maturation time from 10-14 days to two to three hours (Stewart, 2000). The technology has also been piloted in Japan, where they found a two to three day fermenting time (Stewart and Russell, 1998). These systems can have lower capital costs than existing fermenting systems (Stewart and Russell, 1998). The system can yield material savings through the reuse of yeast, and reductions of kieselguhr required for later filtration (Nedovic et al., 1999). Additionally, the process quality control is improved (Masschelein and Andries, 1996; Meura, 2000).

Heat recovery

In 1999, Moosehead breweries announced that they intended to install a heat recovery wheel in cellars to reduce refrigeration losses when CO₂ exhaust fans are automatically engaged at high CO₂ levels (Moosehead, 1999). Based on the use of other applications of heat wheel technology, we estimate a payback of roughly 2-3 years (CADDET, 1996a; CADDET, 1998).

New carbon dioxide recovery systems

In the fermentation process, the yeast feeds on the wort to produce carbon dioxide and alcohol. This carbon dioxide can be recovered with closed fermentation tanks and used later in the carbonation process. The fermentation process generates about 8-10 lbs/barrel wort (3-4 kg CO₂/hl) (Lom and Associates, 1998). Typical CO₂ scrubber operations require 2 kg of water per kg of carbon dioxide (Dell, 2001). A large brewery can become self-sufficient for CO₂ if a well-designed plant is installed to recover CO₂ from fermentation. The U.S. market is almost saturated with standard recovery systems at large brewers. However, the technology is now becoming increasingly attractive for micro-, small- and medium-sized breweries where 2-3 year paybacks are achievable. Witteman, one of the major companies developing CO₂ recovery technology, has recently developed a new recovery system design that combines the dryer and deodorizer tower, which could be applicable for medium and large breweries. The new systems operate on a single pass-through for the CO₂ scrubber because the packing configuration was modified. This new "structured packing" eliminates the need for a motor to operate a recirculating pump. A typical motor size runs in the 3-5 hp range. According to vendors, while paybacks based on energy savings are greater than three years compared to older technology, the new

systems require less capital, have much lower O&M costs, especially for cleaning the packing, and reduce water consumption by 50% for the scrubbing systems (Dell, 2000). Accounting for the additional benefits, vendors believe these systems have paybacks of closer to 2 years (Dell, 2001). Anheuser-Busch estimates payback to be higher than 3 years for CO₂ recovery systems for U.S. breweries depending on the size of the system and cost of CO₂ (Meyer, 2001).

6.4 Technologies for Beer Processing

Microfiltration for sterilization and clarification

Various separation processes are required in beer processing. While pasteurization is the traditional approach to sterilize beer, an alternative approach is the use of filtration systems. Diatomaceous earth filters are the standard in the industry for final clarification before packaging. This material has been recently classified as hazardous waste and disposal costs can be high (Fillaudeau, 1999). Membrane filtration can significantly reduce the amount of waste material, thereby reducing disposal costs. Energy consumption for typical microfiltration applications is approximately 0.15-0.25 kWh/gallon (PG&E, 2000).

One system, crossflow microfiltration, uses a membrane in conjunction with a high velocity tangential process stream flow in a narrow channel above the membrane. Filtrate is driven by applied pressure through the membrane. This technology has not yet been widely accepted due to concerns about fouling, the quality of the product and filtrate flux (O'Shaughnessy and McKechnie, 2000; Osmonics, 1992). It has potential applications in mash separation, beer clarification, tank bottoms recovery, and in flash pasteurization or membrane cartridge filtration (O'Shaughnessy and McKechnie, 2000). The most promising applications are in the bottom filtration of tanks, rough beer clarification, and cold-sterilization of clarified beer, yet they are not yet economically viable (Fillaudeau, 1999). Investigations into the use of oscillatory flow in crossflow microfiltration for beer clarification found energy savings ranging from 15-40% as compared to standard microfiltration due to reduced pumping requirements (Blanpain-Avet et al, 1998). The installation of improved yeast collection systems such as microfiltration can ultimately reduce energy requirements for wastewater treatment later in the process. However, we have found that paybacks of 2-4 years are possible with the use of membrane technologies in other food processing applications, even though we do not have specific data on the cost-effectiveness in breweries (Martin et al., 2000a). Still, some manufacturers believe current cross flow membrane filtration systems may require as much extra energy as they save (Todd, 2001).

Production of alcohol-free beer using membranes

Non-alcoholic beer is becoming increasingly popular in the U.S. and abroad. The main dealcoholization processes are manipulated fermentation or alcohol separation after fermentation. Today the bulk of low-alcohol beer is produced using processes in which the wort content is reduced to start from a lower level of fermentable components or fermentation is interrupted when the desired level of alcohol is achieved (Stein, 1993). Other common approaches are falling film evaporation and the use of membranes. Membrane processes appear most promising in the long term (Stein, 1993).

One example of a membrane system is the Heineken brewery at s'Hertogenbosch (the Netherlands). The brewery produces 120,000 hl/year of non-alcoholic beer, by removing alcohol and water from ordinary beer, using a reverse osmosis filter. In 1997, the filters were replaced by "spiral wound" units, where the filter membranes are shaped like tubes and are configured according to the cross-flow principle. This means that the beer flows through the filters at a high velocity and at a high pressure. The pump energy for the new process is about 550,000 kWh/year less than in the previous situation, and the water demand of the entire process is about 24,000,000 liters/year less than in the former process. Specific energy savings are 5.6 kWh/barrel (4.6 kWh/hl of beer). The cost savings are on the order of \$50,000/year (NLG 101,000/year), and the payback period is about 4 years (CADDET, 1999a; NOVEM, 1997). It is predicted that reverse osmosis (RO) filtration will become an established separations technology over the next decade.

Costs play an important factor in the selection of a system. Alcohol separation processes require an additional process step (as opposed to manipulated fermentation) and are done to improve taste. Estimates of utilities costs (energy and water) for RO membranes were estimated to cost \$2.40/barrel (\$2.04/hl) as compared to \$4.10/barrel (\$3.49/hl) for dialysis, while maintenance costs for RO systems are slightly lower than dialysis (\$0.6/barrel as compared to \$0.75/barrel) (Stein, 1993).

Heat recovery in pasteurization

While all modern pasteurizers use some form of internal heat regeneration, the heat contained in the rejected water can be recovered using heat pumps or heat exchangers (Sorrell, 2000). The operation of the heat pumps can be matched to the heating and cooling requirements of the bottle washer. A brewery in Canada was able to recover 0.6 kBtu/barrel from its pasteurization process (Singleton, 2000).

Flash (plate) pasteurization

Flash pasteurization is used for in-line heat treatment of beer prior to filling the kegs and smallpack for the purposes of microbiological stability. According to Goldammer (2000), flash pasteurization is not widely used by breweries in North America, though it is very popular with the dairy and juice industries. Flash pasteurization has been widely adopted by brewers in Europe and Asia. Flash pasteurization rapidly heats the liquid for a short period of time to a high temperature and then rapidly cools the product. As opposed to conventional tunnel pasteurization, flash pasteurization requires less space, steam, electricity and coolant. The optimum heat recovery is 94-96%, but plate systems tend to require trim chilling of the beer before packaging (Kidger, 2001). Energy consumption is estimated at roughly 3-7 kBtu/barrel, estimated to be 1/3 of the energy used in tunnel pasteurization (Hackensellner, 2000; Singleton, 2000; Dymond, 1997). Because of the relative compactness of flash pasteurization systems as compared to tunnel systems, initial investment costs are lower, and run roughly \$30/barrel (\$26/hl), or about 15% those of tunnel systems (Battaglia, 2001; Hyde, 2000). Operation and maintenance cost estimates for flash pasteurization systems were estimated to be \$0.25/barrel (\$0.2/hl), compared to \$1.7/barrel (\$1.4/hl) for tunnel pasteurizers (Dymond, 1997). Since flash pasteurization is integrally linked to the purchase and use of sterile filling technology, the use of flash

pasteurization may include significant additional costs associated with sterile filtration requirements.

6.5 Technologies for Packaging

Heat recovery - washing

Opportunities exist to recover heat in the bottle washing and keg washing processes. One study noted that the installation of a heat recovery system from a keg washer saves an estimated 40% of keg cleaning energy and recovers 85% of the heat required for heating incoming water (Sorrell, 2000). Moosehead breweries (Canada) installed shell and tube heat exchangers to recover thermal energy from condensate in its bottle washing section and fuel oil heater condensate (CIPEC, 1998).

Burnett and Rolfe (2001), which constructs a majority of the brewing industry's in-line kegging systems, has noted that in-line kegging has advanced and resulted in the use of less energy. Older plants used a steam purge to remove washes two and three. In newer systems, the steam air purging has replaced steam purging for wash 2, thereby resulting in a reduction of steam consumption of 50% from 0.8 kg steam/keg to 0.4 kg steam/keg. Additionally, the 3rd wash water is reused as the first wash medium, and prior to its use, the water is passed through a heat exchanger, where heat is captured to pre-heat incoming wash water. Burnett and Rolfe (2001) estimate the heat exchanger reduces steam consumption by 0.88 to 1.46 kg/keg processed. Additionally, water consumption is reduced from 20 liters/keg to 12 liters/keg (Burnett & Rolfe, 2001). This equates to energy savings of roughly 6 kBtu/barrel and a payback of 3 years or less (Burnett & Rolfe, 2001).

Cleaning efficiency improvements

An efficient bottle cleaning was installed by Brand Brewery (Wijlre, the Netherlands). In the Netherlands, bottles are returned to the brewery for cleaning and reuse. The brewery developed a new cleaning and label removal process that incorporates several caustic bath cycles and heat recovery. In order to reduce heat demand in the later stages of the cleaning, the bottles are pre-heated in a recuperation bath using heat from the bottles leaving the cleaner. In the new situation, the caustic liquid is cleaned continuously by circulating it through a Rehman filter, which regenerates it and removes label remnants. Because of the continuous cleaning, the liquid only has to be replaced once a year. The bottles are sterilized by steam, which also drives out the air, saving the energy required for the vacuum stage. Net energy savings, after accounting for increased steam demand from the cleaning process, are 11,250 GJ/year (CADDET, 2000b). Total production at the facility was 550,000 hectoliters/year, estimating a net specific savings of 25 kBtu/barrel (21 MJ/hl). The project had a payback of 3.4 years (CADDET, 2000b).

7. Cross-cutting Measures

Utilities are vital in enabling the operation of the production process for breweries (Benson et al., 1997). Specifically, they provide fuel and electricity for heating, steam, refrigeration, lighting, motors, pumps, compressors, fans and conveyor systems. Cross-cutting utility energy efficiency measures that do not interfere with the brewing process may have immediate potential for cost-effective energy savings. Below we discuss cross-cutting energy efficiency improvement measures that can reduce energy consumption in hot water and steam distribution, hot water and steam generation, motors and motor systems, refrigeration and cooling and other utilities such as lighting. Savings of individual measures can be relatively small; however, the cumulative effect of these measures can potentially be large.

7.1 Boilers and Steam Distribution

Boiler maintenance

A simple maintenance program to ensure that all components of the boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, the burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 20-30% of initial efficiency over 2-3 years (OIT, 1998). Lom and Associates (1998) note that a chemical treatment program to reduce scaling and fouling can have a significant improvement in efficiency since reduction of a scale layer by 1mm can reduce fuel usage by 2%.

Improved process control

Using flue gas monitors to analyze the composition of exhaust from boiler combustion makes it possible to maintain optimum flame temperature and monitor CO, oxygen and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete the fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and low emissions. Lom and Associates (1998) note that a 10% reduction in excess oxygen will increase boiler efficiency by 1.5%. This measure may be too costly to implement in small boiler systems (IAC, 1999). Miller's Milwaukee, Wisconsin plant's conversion from pneumatic to electronic boiler controls resulted in savings of 2.1 kBtu/barrel (Miller Brewing Co., 2000).

Flue gas heat recovery

Heat from boiler flue gasses can be used to preheat boiler feed water in an economizer or to preheat boiler air intake. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids in the flue gas, such as sulfuric acid in sulfur-containing fossil fuels. As a rule of

thumb, one percent of fuel use is saved for every 20-25°C reduction in exhaust gas temperature (Ganapathy, 1994; Lom and Associates, 1998). Capital costs for such systems are likely to have a payback greater than 3 years (Lom and Associates, 1998). Miller's Milwaukee, Wisconsin plant was able to increase heat recovery from the flue gas by installing an economizer and reduced energy use by 1.0 kBtu/barrel (Miller Brewing Co., 2000).

Blowdown steam recovery

Water is periodically blown from the boiler to remove accumulated impurities. When the water is blown from the high-pressure boiler tank to remove impurities, the pressure reduction often produces substantial amounts of steam. This steam is low grade, but can be used for space heating and feed water preheating or other applications in the brewery. We assume that this measure can save 1.3% of boiler fuel use across small boilers.¹¹ Operating expenses may increase slightly with this system. We estimate an overall payback of 2.7 years for this measure (Einstein et al., 2001).

Steam trap maintenance

Steam traps have the function of removing condensed steam and non-condensable gases without losing any live steam. As these traps can vent significant amounts of steam if not properly monitored, a simple inspection and maintenance program can save significant amounts of energy for very little money. If the steam traps are not regularly monitored, 15-20% of the traps can be malfunctioning. Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% (OIT, 1998; Jones 1997). Miller's Milwaukee, Wisconsin plant was able to reduce energy losses of 3.5 kBtu/barrel by implementing a steam trap management program for 1500 traps (Miller Brewing Co., 2000). We estimate a payback of less than one year for this measure (Einstein et al. 2001).

Automatic steam trap monitoring

Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy, without significant added cost. This system is an improvement over steam trap maintenance alone, because it gives faster notice of steam trap failure, and can detect when a steam trap is not performing at peak efficiency. Using automatic monitoring is conservatively estimated to save an additional 5% on energy use over steam trap maintenance alone with a payback of less than one year (Johnston, 1995; Jones, 1997; Martin et al., 2000a). There are some small additional O&M costs to maintain the monitors.

Leak repair

As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. In addition to saving 3% of energy costs, having such a program can reduce the likelihood of having to repair major leaks (OIT, 1998; Martin et al., 2000a). Even a small leak that emits a weak hissing sound

¹¹ Based on the following assumptions: 10% of boiler water is blown down (OIT, 1998) and 13% of the energy can be recovered from this (Johnston, 1995).

and hardly a visible cloud of steam can result in a loss of 1 kg of steam per hour, or energy requirements comparable to producing 200 hl (170 barrels) of beer (UNEP, 1996).

Condensate return

Reusing the hot condensate in the boiler saves energy and reduces the need for treated boiler feed water. Usually fresh water must be treated to remove solids that might accumulate in the boiler, and returning condensate can substantially reduce the amount of purchased chemical required to accomplish this treatment. A good target for condensate return in breweries is at least 75% (Kidger, 2001). The fact that this measure can save substantial energy costs and purchased chemicals costs makes building a return piping system attractive. In some cases it may be more effective to install steam powered condensate return pumps (instead of electric) at the brewery (Lom and Associates, 1998). We assume a 10% energy savings (OIT, 1998). For condensate that is unfit to recirculate it is still possible to recover thermal energy using heat exchangers, as is being done at Moosehead's brewery (Canada) (CIPEC, 1998).

Improved insulation of steam distribution systems

Careful analysis of the use of existing insulation materials can often yield energy savings. Factors in the choice of materials include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption and resistance to combustion. According to data from the U.S. Department of Energy's Steam Challenge Program, improving insulation of the existing stock of heat distribution systems would save an average of 3-13% with an average payback of 1.1 years (Einstein et al., 2001).

Process integration or pinch analysis

Process integration or pinch analysis refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of process integration techniques can significantly improve efficiencies.

Developed in the early 1970's process integration is now an established methodology for continuous processes (Linnhoff, 1992; CADDET, 1993c). The methodology involves the linking of hot and cold streams in a process in the thermodynamic optimal way (i.e. not over the so-called 'pinch'). Process integration is the art of ensuring that the components are well suited and matched in terms of size, function and capability. Pinch analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process (Kumana, 2000a). It was developed originally in the late 1970s at the University of Manchester in England and other places (Linnhoff, 1993) in response to the energy crisis of the 1970s, and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water or a specific chemical compound, such as hydrogen.

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

The analytical approach to this analysis has been well documented in the literature (Kumana, 2000b; Smith, 1995; Shenoy, 1994). Energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation and steam trap management. Kumana (2000b) has reviewed pinch analyses in almost 60 U.S. plants and found cost savings potentials varying between 3 and 50%, and payback periods ranging from 0.6 to 4.7 years.

A process energy analysis of the Valaisanne brewery (Switzerland) using pinch analysis techniques achieved a primary energy savings of 25% (Helbing, 2000). Ontario Hydro (Canada) noted that the use of pinch technology to reduce the refrigeration load in a brewery was able to cut peak load by 35%, saving nearly \$600,000 annually (Singleton, 2000). A detailed model of four brewhouses in an industrial brewery identified significant opportunities to downsize equipment and reduce steam consumption peaks with a potential peak reduction of 20% (Mignon, 1995).

7.2 Motors and Systems that Use Motors

Motors and systems that use motors include compressed air, pumps and the motor itself. Using a “systems approach” to optimize supply and demand of energy services can often yield increased savings. For example, in pumping, a systems approach analyzes both the supply and demand sides and how they interact, shifting the focus of the analysis from individual components to total system performance. The measures we identify below reflect aspects of this system approach including matching speed and load (variable speed drives), sizing the system correctly, as well as upgrading system components.

Variable speed drives (VSDs) or adjustable speed drives (ASDs)

Variable speed drives better match load requirements to motor operations, thereby improving overall motor operating efficiencies. Pump systems and compressor systems are particularly attractive in breweries for the use of variable speed drive technology. In many cases, the annual energy cost required to operate compressed air systems is often greater than their initial cost. Variable speed drives working with differential pressure control have shown very good savings when demand is reduced (e.g. when the brewery is not operating at full capacity). According to inventory data collected by Xenergy (1998), 82% of pumps have no load modulation feature (or VSD). Similar to being able to adjust load in motor systems, including pumps with modulation features are estimated to save

between 15 and 45% of pump energy consumption, at relatively short payback periods, depending on motor size, load and load variation (Xenergy, 1998).

A brewery in Romford (UK) installed an electronic variable speed drive on a circulating pump in their secondary refrigeration circuit. The VSD was installed to regulate the supply of refrigerant to match demand. A dramatic reduction in average motor power of approximately 45% was achieved by introduction of the VSD (CADDET, 1993a). The project had a payback of less than two years (CADDET, 1993a). The Suntory brewery in Musashino (Japan) installed variable speed drives on five motors. They were able to reduce electricity use of these motors between 32-65%, with payback periods of less than 2 years (CADDET, 1992). Total annual savings for the plant were 709,000 kWh (CADDET, 1992).

Size reduction for motors, pumps, and compressors

When motors and pumps are sized inappropriately, unnecessary loss results. At times, peak loads can be reduced which can lead to a reduction in motor size. Xenergy (1998) estimates that correcting for motor oversizing can save 1.2% of electricity consumption (with even larger savings for smaller motors), while matching pump size to load can save 4% of pump energy consumption in the U.S. manufacturing industry. For pumping systems, measures to reduce pump load include considering alternative pump configurations and improved O&M practices. Stroh's Heileman Brewery (U.S.) undertook a systems analysis of pump loads and was able to reduce the size of their pump motor from 150 hp to 75 hp through trimming the impeller (ECW, 1998). Energy savings were estimated to be 508,000 kWh annually and the return on the investment was over 200% (ECW, 1998).

The U.S. Department of Energy (2001) notes that leaks can sometimes waste 20-30% of a compressor's output. Lom and Associates (1998) note several basic housekeeping and maintenance approaches to reduce compressed air loads, hence leading to reducing the size of compressors. These measures include the use of leak detectors, maintaining appropriate pressures that are not too high, enclosing compressors, using intake air from the coolest location and minimizing the air dryer regeneration cycle. Paybacks for this can be less than a year (Lom and Associates, 1998). A leak reduction project by Ford Monroe (U.S.) resulted in a 50% reduction in compressed air use from 17 million cubic feet (mcf) per day to 9 mcf/day and a \$2,000/day savings (U.S. DOE, 2001). The City of Milford (U.S.) decided to replace one 75-hp pump with a 35-hp pump. Since the smaller pump generates less flow, the pump has to run more often; however, since the average flow velocity is reduced, the system experiences less friction loss, increasing the average efficiency. The energy and maintenance savings from the new pump configuration provided a 1.7-year payback (U.S. DOE, 2001).

Use of high efficiency motors, pumps, and system components

Energy-efficient electric motors reduce energy losses through improved design, better materials and improved manufacturing techniques. The use of improved pump components can save 0.5% of pump energy consumption in U.S. manufacturing industry (Xenergy, 1998). With proper installation, energy-efficient motors run cooler and

consequently have higher service factors, longer bearing and insulation life and less vibration. To be considered energy efficient, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). Most manufacturers offer lines of motors that significantly exceed the NEMA-defined criteria (U.S. DOE, 2001). Currently NEMA and other organizations are sponsoring a “Motor Decisions Matter” campaign to market NEMA approved premium efficient motors to industry (NEMA, 2001). According to data from the Copper Development Association, the upgrade to high efficiency motors as compared to motors that achieve the minimum efficiency as specified by the Energy Policy Act have paybacks of less than 15 months for 50 hp motors (CDA, 2001).

7.3 Refrigeration and Cooling

Optimally running refrigeration systems work with minimized differences between condenser conditions and evaporator conditions. For the condenser, the goal is to obtain the lowest possible condensing temperature and pressure of the refrigerant. This reduces the power input while increasing the refrigeration output. For the evaporator, an increase in temperature and pressure increases the power input of the compressor, but can dramatically increase the refrigeration output of the system. Increasing evaporator temperature by one degree can reduce electricity consumption of the compressor by roughly 3% (Hackensellner, 2001; Lom & Associates, 1998). In addition, wet cooling systems are generally more efficient than dry systems, since the wet bulb temperature is open to the atmosphere and is 9°F (5°C) below the dry bulb temperature.

Better matching of cooling capacity and cooling loads

In order to provide better cooling for the different processes, the Grolsch brewery in Groenlo (the Netherlands) installed a new compressor system with a single screw-type compressor providing the base load, aided by five compressors from the original system. The new system is capable of providing cold at all desired temperature levels without compromising the COP's of the coolers. Savings are 324,000 kWh/year, or roughly 0.35 kWh/barrel (0.3 kWh/hl) (CADDET, 1999b). The payback period is about 3.6 years with an investment of \$283,000 (NLG 577,000) (CADDET, 1999b). The Bavaria Brewery (the Netherlands) installed a similar system, reducing power consumption by 0.49 kWh/barrel (0.42 kWh/hl) (NOVEM, 1996).

Improved operation of ammonia cooling system

One of the Heineken Brewery facilities in the Netherlands uses a central cooling system with ammonia as the coolant. Due to the large number of hours operating at full load, the system uses screw-type compressors. At present, a recently developed gas scrubber has been installed at the pressure side of the compressors. Using this new technology, the oil concentration in the gas leaving the compressor has been reduced to less than 1 ppm. The annual energy savings are in the order of 840,000 kWh. Additional to the energy savings, non-energy benefits add up to \$16,000 (NLG 28,500), so the \$360,000 investment (NLG 640,000) is paid back in 5.5 years. The new technology increased the lifetime of the cooling system and reduced operation and maintenance costs (CADDET, 1993b; NOVEM, 1993c). However, there may be an increase in construction costs and safety considerations with a direct ammonia system since the fermenting vessel jackets need to

be designed to handle the additional system pressures associated with ammonia, and a potential for leakage directly into the product (Kidger, 2001; Anheuser Busch, 2001). The Grolsch brewery (the Netherlands), in 1995 installed an oil separator for its ammonia cooling system as well as replacing five of its smaller compressors with a larger screw-type compressor. Electricity savings were estimated at 2% of electricity consumption for the brewery, or 0.07 kWh/barrel (0.06 kWh/hl) (NOVEM, 1995; CADDET, 1999b).

Improve operations and maintenance for cooling systems

Often it is possible to achieve energy savings at very low investment costs with attention to improved operations and maintenance (Caffal, 1995). Such improvements can include shutting doors, setting correct head pressure, maintaining correct levels of refrigerant, effectively maintaining cooling towers; and selecting and running appropriate compressors for part load. Energy saving can also be achieved by cleaning the condensers and evaporators. Scale on condensers increases power input and decreases refrigeration output. Three millimeters of scale can increase power input by 30% and reduce output by 20% (Kidger, 2001). Water treatment and blowdown or magnetic water treatment may eliminate scales. In ammonia system evaporators, oil tends to accumulate and needs to be drained to avoid reduction of heat transfer. The New Belgium Brewery in Colorado takes advantage of outside cooling air during the winter months, thereby reducing cooling energy loads (Farrell, 1998). The Miller brewing company reduced seasonal system pressures on its system saving 1.1 kWh/barrel (1.0 kWh/hl) in its Milwaukee, Wisconsin brewing operations (Miller Brewing Co. 2000).

System modifications and improved design of cooling systems

The use of a closed loop system for compressors and condensers can improve overall cooling efficiency by simplifying the cooling cycle (Lom and Associates, 1998). The payback period is estimated to be three years or less for this measure. The Heineken Brewery in Zoeterwoude (the Netherlands) separated its cooling water streams from the carbon dioxide and air compressors, thereby reducing energy and water use for cooling by 20%. Overall energy savings are 0.13 kWh/barrel (0.11 kWh/hl) (NOVEM, 1999b). The New Belgium Brewing Company in Colorado installed an evaporative condenser cooling system that simplified system operations, eliminated one heat exchange step in the cooling process, and increased efficiency (New Belgium Brewing Co., 2001). A Grolsch brewery in the Netherlands installed an automatic deaerator that improves the heat transfer capabilities in the condensers. Electricity savings are estimated at 4% of brewery electricity use or 0.14 kWh/barrel (0.12 kWh/hl) (NOVEM, 1995).

Insulate cooling lines and jackets

It often can be cost-effective to insulate cooling lines if the lines are uninsulated and there is a significant average temperature difference between the cooling lines and the surroundings (e.g. more than 15°F). If lines are already insulated, upgrading may not be cost-effective. Insulated jacket tanks use less refrigeration than tanks in an insulated enclosure (cold room) due to reduced losses (Kidger, 2001).

Absorption cooling

Absorption cooling needs a low-cost heat source to drive the cooling. Therefore, absorption cooling is most beneficial with installation of combined heat and power production (CHP). See the example given below in combined heat and power.

7.4 Other Utilities

Lighting

Several opportunities exist to reduce lighting energy consumption, which accounts for 7% of electricity use in U.S. breweries. In a brewery in Romford (UK), faulty, dilapidated, obsolete or oversized luminaries were replaced or upgraded by using slimmer and more efficient fluorescent tubes, compact fluorescent lamps (instead of tungsten lamps), fluorescent fittings or high pressure sodium lamps (instead of mercury discharge lamps), and electronic starters in all fluorescent luminaries. With these measures, the overall installed load was reduced by 50%. With the addition of lighting controls, electricity consumption for lighting was reduced by 66%. Estimated annual savings amount to almost 650,000 kWh, with a payback period of 2.5 years (CADDET, 1994). New Belgium Brewing Company in Colorado has also drastically reduced its lighting load by designing for maximum use of natural light, including light pipes, and by installing high efficiency fluorescent lighting along with motion sensors (Farrell, 1998). Miller's Milwaukee, Wisconsin plant relamped the brewery with high efficiency lighting and controls, reducing energy consumption by 0.6 kWh/barrel (Miller Brewing Co. 2000). Moosehead breweries had a program to replace older T12 fluorescent lamps with higher efficiency T8 lamps (Moosehead, 1999). Lom and Associates (1998) estimate less than a 2 year payback for the replacement of standard fluorescent lighting with energy-efficient tubes. In addition to energy savings, lighting retrofits can increase productivity and the attractiveness of the workplace.

Reduce space heating demand

As we have noted in several measures, there are opportunities to capture low grade heat from the various brewing processes (e.g. wort boiling and cooling, bottle and keg washing) to be used for space heating. Another example is using discharge air from air-cooled compressors to provide space heating during the winter, and recovering heat from water-cooled compressors (Lom and Associates, 1998). A project to recover heat from the refrigeration plant in a brewery in Canada saved an estimated 7.6 kBtu/barrel in heating energy (Singleton, 2000).

Anaerobic wastewater treatment

Industrial wastewater is typically treated by aerobic systems that remove contaminants prior to discharging the water. Use of aerobic systems can be disadvantageous because of their relatively high electricity use. Some breweries spend significant costs on sewer charges. Anaerobic wastewater treatment is an alternative method for cleaning industrial wastewater that converts organic compounds in the wastewater into a biogas that can be used on site. These systems are feasible if the influent concentration is approximately 1 kg of BOD/m³ (UNEP, 1996). Loading of anaerobic treatment plants is normally in the

range of 5-10 kg COD/m³ or 8-15 kg BOD/m³ (UNEP, 1996)¹². Before being injected into the reactor, the wastewater is fed to an equalizing or hydrolyzing tank with a retention time of 4-8 hours in order to filter out suspended material (UNEP, 1996).

The Grolsch brewery at Enschede (the Netherlands) uses an anaerobic pre-purifying system. The system reduced annual purchased natural gas consumption by 730,000 Nm³ while increasing electricity consumption by 150,000 kWh. The net savings was 20.4 billion Btu (21.5 TJ), equivalent to 11.9 kBtu/barrel (10.2 kBtu/hl) (CADDET, 1997; NOVEM, 1993b; Anonymous, 1998). In their analysis of anaerobic systems, Heyse et al. (1996) estimate an energy production range of 2.3-6.8 kBtu/barrel depending on the actual level of COD loading and wastewater volume. Anheuser-Busch has installed bio-energy recovery systems at 8 of its 12 breweries in the U.S. realizing energy savings of 10-15% on purchased fuel consumption and payback of less than two years (Anheuser-Busch, 2000). When the reduced sludge production and disposal are included, paybacks can drop to less than one year (Martin et al., 2000a). Additional benefits include less capital requirements for the expansion of existing facilities and a significant reduction in wastewater and solid waste. An in-house wastewater treatment system installed in an Austrian brewery (with energy recovery) realized an electricity savings of 0.3 kWh/barrel (0.3 kWh/hl) and a thermal savings of 1.4 kBtu/barrel (1.2 MJ/hl) (EC, 1998). In a more recent development, Ince et al. (2001) report on piloting the use of a crossflow ultrafiltration membrane in anaerobic digester systems, also known as the anaerobic digestion ultrafiltration process (ADUF). This system may have several advantages to traditional anaerobic systems including the reduction in equipment (no sedimentation tank), minimizing required reactor volume and improved control. However, only pilot data are currently available (Ince et al., 2001).

Membrane filtration for waste water treatment

Companies that face increasing costs for wastewater disposal with high levels of biological contaminants may find the use of membrane technologies economically attractive. Membrane technologies focus on separating the water from the contaminants using semi-permeable membranes and applied pressure differentials. Cross flow microfiltration membranes can be used to remove particles from 0.05 to 2 microns in size (CERF, 1997). The average brewery effluent is composed of 1500 to 2500 mg/l of COD and 1000 to 1500 mg/l of BOD⁵ (Heyse et al. 1996). It has been demonstrated that the use of membranes can be cost-effective, reduce electricity demand and occupy less space than traditional settling and filtration systems (Pearce, 1996; CERF, 1997). System costs range from \$900-\$1,300 per m² and the costs of filtration range from 0.5 to 10 cents per gallon of filtrate (NFPA, 1996). Problems with membrane applications include biofouling of the membrane and the fragility of the membrane surface (CERF, 1997). We currently estimate a payback of up to five years for this technology, although this depends on the application (Martin et al., 2000b).

¹² Chemical oxygen demand (COD) is a way of measuring the concentration of organic material in the discharge. Normally breweries operate at a ratio of 1.5-1.7 COD/BOD.

Control and monitoring systems

As in many industries, the use of process control systems can play an important role in reducing energy use. Control systems reduce the time required to perform complex tasks, often can improve product quality and consistency and optimize process operations. Specific examples of control systems include refrigeration and manufacturing controls for brewery utilities. This includes the use of metering equipment (e.g. on compressors) and the use of automation in process operations. Monitoring and target setting systems require the establishment of dynamic information feedback loops so that operations can continually be adjusted and optimized (Macdonald, 1996).

Savings can typically run from 2-5% or more for many industrial applications. The Tui Brewery was able to reduce its energy costs by 12.5% at its Mangatainoka plant (New Zealand) through the installation of automatic monitoring and control systems, and the payback was nearly immediate (EECA, 2000). In the United Kingdom, the use of monitoring and targeting systems has identified average savings of over \$300,000 per brewery for 19 breweries with payback periods ranging from 2-5 years (McDonald, 1996). In Lieshout (the Netherlands), the Bavaria brewery installed an automatic refrigeration control system for its ammonia cooling system. The system reduced annual electricity use by 450,000 kWh, or 0.15 kWh/barrel (0.13 kWh/hl) (NOVEM, 1996). Similarly, the El Aguila Heineken brewery (Spain) installed a monitoring and control system for their cooling installation, reducing electricity consumption by 0.67 kWh/barrel (0.57 kWh/hl) (NOVEM, 1991b). The payback period for this last project was about 2 years. The Carlsberg-Tetley brewery (UK) installed a refrigeration fault diagnostics system to evaluate and advise on problems in the refrigeration system. Savings during the 9 month monitoring period of the expert system were 524,000 kWh (30% of electricity use) with a payback of 8 months (CADDET, 1996b). Labatt Breweries (Canada) implemented a monitoring and tracking program beginning in 1992, which resulted in energy savings of 23% (CIPEC, 1998). In their study of a Bulgarian Brewery, Askounis and Psarras (1998) estimated a potential savings of 11-13% through the installation of an information management and monitoring system. Finally, Miller's Milwaukee, Wisconsin plant installed compressor controls and achieved savings of 0.24 kWh/barrel (0.2 kWh/hl) (Miller Brewing Co. 2000).

Combined Heat and Power (CHP) or cogeneration

For industries such as breweries that have process heat/steam or cooling and electricity requirements, the use of combined heat and power systems can be an important energy efficiency measure as well as reduce pollution. A thermal to electric ratio of 2:1 is typically a good candidate for CHP (Batts, 1998). CHP is most likely to be economically viable when a unit can run at full load for at least 5,000 hours annually (Sorrell, 2000). Reciprocating engines are two to two and a half times cheaper than gas turbines, but cannot produce the same quantity of steam and do not achieve the same efficiencies as combined cycle systems (Kidger, 2001).

Innovative gas turbine technologies can make CHP more attractive for sites with large variations in heat demand. Steam-injected gas turbines (STIG, or Cheng cycle) can absorb excess steam, e.g. due to seasonal reduced heating needs, to boost power

production by injecting the steam in the turbine. The size of typical STIGs starts around 5 MWe. STIGs are found in various industries and applications, especially in Japan and Europe, as well as in the U.S. International Power Technology (California) installed STIGs at different food industries in the U.S. (e.g. Sunkist Ontario, California). Energy savings and payback period will depend on the local circumstances (e.g. energy patterns, power sales conditions). Heineken installed a STIG-based CHP unit at their brewery in 's Hertogenbosch (the Netherlands).

In the U.S., Coors Brewing Company has a large CHP system (40 MW). In 1995, Coors outsourced its CHP operations to Trigen Energy Corporation. Coors has realized significant energy savings and energy use per barrel has dropped by 20% since the start of the CHP project (Trigen Energy Corporation, 2000). Labatt's brewery in Ontario (Canada) installed a high-efficiency 5 MW Allison gas turbine-driven cogeneration system in 1993. Heineken (Holland) has three Allison gas turbine units producing about 11 MW of power while recovering steam for onsite use at their Zoeterwoude brewery (Brezonick, 1994; Kidger, 2001). Scotland's third largest brewery, the Belhaven Brewery Group, significantly cut energy costs by installing a small CHP unit (60 kW), resulting in a reduction in primary energy use of over 30% and a payback of 3.5 years (CHPA, 1998; Energy Advantage Co. 2000; Kidger, 2001).

CHP combined with absorption cooling

Waste heat exhaust from CHP systems can be used to operate cooling systems. Depending on the number of effects in the chiller steam, requirements of cooling can range from 4.5 kg/kW to 8.3 kg/kW (Moné et al. 2001). A brewery in Suita (Japan) installed a combination gas turbine CHP system and two refrigeration machines (a 4MW turbine generating 1.5 MPa steam (high pressure)) running a back pressure steam driven refrigerating machine. The system reduced fuel demand by 14% and electrical demand by 40% (CADDET, 2000a). Medium pressure steam drives refrigeration equipment at the Coors brewing facility in Colorado (Island Press, 1999). A study of the application of a CHP absorption cooling system to cooling spaces found a payback of 4.5 years (Maidment and Prosser, 2000).

Engine driven chiller systems

The Kirin Brewery Co. in Tokyo (Japan) installed a 596 kW gas engine with a cooling system using boiling water (for steam recovery) in a cogeneration system with a 560 kW generator. The exhaust gas from the engine is used to generate medium pressure steam at 8 bar with a waste heat boiler, and to preheat boiler feedwater with an economizer. The investment costs can be paid back within four years (CADDET, 1994). The company achieved electricity savings of 10% (CADDET, 1994). The Gas Research Institute in the U.S. joined in a combined partnership with Tecogen that markets gas engine-driven chillers. These chiller systems have been installed in several breweries in the U.S., and while the incremental investment cost is roughly double that of electric chillers, the payback is 2-4 years in areas with high electricity rates (Glick, 2001).

8. Material Efficiency Opportunities

Improving the efficiency of raw material use or reduction of product losses results in the indirect reduction of energy use (material efficiency). For example, the reduction of beer wastes can reduce the need for processing an equivalent amount of raw materials, resulting in energy savings in the brewhouse and other process steps. Materials use reduction also results in lowered production costs due to fewer charges for solid and liquid waste disposal. The following section identifies some of the main material reduction measures we have found in our literature survey.

Use of hop extract instead of hops

While hop extract may modify the flavor of beer, its use saves space, reduces boiling time and eliminates the hops separation process (UNIDO, 2000).

Dry milling of malted barley

A minimum four barrels of water are required to make one barrel of beer (UNEP, 2001). One approach to minimize water use is to dry mill malted barley. Savings in the U.S. are limited however, since most malt milling is already done with dry mills (Hardwick, 1994).

Water reuse and conservation measures

Effluent charges in a brewery can typically run \$1 to 2 million annually (Bland, 1993). Many opportunities exist in the brewery to reduce water consumption or recycle water. Water use of four to five barrels input per barrel beer output is considered good practice (Anonymous, 1998; UNEP, 1996). Like heat recovery and reuse, water conservation and reuse approaches seek to best match and reuse high quality, medium quality, and low quality water in various applications (Bland, 1993). Reduced water use will not only reduce effluent charges, but will also reduce water purchases, water treatment costs, as well as energy for water treatment and pumping.

- In the brewhouse area, it is possible to store lauter tun drainage for use as make up water for the subsequent brew. These liquids must be pre-treated by sedimentation, centrifugation, or activated carbon, but their use results in a reduction in water costs, elimination of effluent charges, and a reduction in energy use (Watson, 1993; UNIDO, 2000).
- Reverse osmosis filters can be used to purify vapor condensate and recover clean process water. Filter investment costs for a brewery producing about 8.3 million gallons (31,500 m³) of vapor condensate are estimated at about \$80,000. Depending on water costs, the payback for the investment can be less than two years (Hackensellner, 2000).
- The hot liquor tank overflow can be used to preheat cold water entering the pasteurizer. Implementation of this measure is dependent on the configuration of the particular brewery (Watson, 1993).
- In the fermentation area, one option is to reuse the final rinse of the gauging, fermentation, and storage tanks for the next cleaning in place wash (Watson, 1993).
- For the packaging area it is possible to use the water flowing out of the pasteurizer as an initial rinse in the bottle washer section, or it is possible to collect and reuse

pasteurizer overflow water for make up water back to the pasteurizers (Watson, 1993; Bland, 1993). Raising beer-out temperature limits on pasteurizers can also reduce pasteurizer water losses. Bottle rinse water can also be reclaimed and used for pasteurizers or as dilution water for conveyor lubrication systems. When combined with a water reclamation system in pasteurizers, the use of bottle/rinse water has resulted in a decrease of 90% of water make up to some pasteurizer systems (Bland, 1993).

- Bottle rinse water can also be used as a source for virtually any cleaning-in-place rinse in the brewery (Bland, 1993).
- Throughout the plant, systems that are water-cooled using open cooling systems, can be modified to cool with closed loop systems. These may include tunnel pasteurizers, refrigeration compressors and condensers, air compressors, and carbon dioxide compressors (UNEP, 1996; Bland, 1993). An Asian brewery (0.4 million barrel capacity) switched its tunnel pasteurizer to a closed loop system. The investment for the equipment was \$45,000 while the payback was approximately one year (UNEP, 1996). A study noted that increasing cycles of concentration in the cooling tower and boiler systems results in reduced blowdown (i.e. water and energy losses) (Bland, 1993). Another reuse opportunity is reclaiming the cooling water for the deaerator pump seals (Bland, 1993).
- Other opportunities include the installation of recirculation tanks with vacuum pump bottle filler installations, optimizing bottle washing installations, cleaning in place plants (CIP), the reduction of rinse water after CIP, and cascading of water for various uses (e.g. blowdown for cooling towers). One cascading system saved a brewery over 400,000 gallons/day in total combined effluent.

Recovery of weak wort

After the wort has been strained off, the grains contain large quantities of extract that can be recovered to reduce loss. The wort remaining in the lauter tun that has a low content of extract is called weak wort. Weak wort is generally 2-6% of wort volume, of which 1-1.5% is extract (UNEP, 1996). Recovery of this wort will reduce the load of biological contaminants in the wastewater and increase yield. Weak wort can be collected in a tank equipped with heating jackets and a slow-speed agitator and used for mashing in the next brew. Other approaches include mechanical separation such as a vibrating screen or a centrifuge (O'Rourke, 1999a).

Recycling of spent hop liquid

After being filtered from the boiling wort, hops are sparged with water and pressed to recover wort. The liquid from the sparge can be reused in the wort boiling process. This measure reduces material use with small energy savings (UNIDO, 2000).

Recovery of Trub in fermentation

Trub refers to insoluble protein precipitate obtained during wort cooling. The amount of trub from an effective whirlpool is 0.2-0.4% of the wort volume, or 150-300 mg/ml (UNEP, 1996; O'Rourke, 1999a). Trub can be returned to the mash kettle or lauter tun. A small part of the extract can be recovered and the rest can be utilized as animal fodder

(UNEP, 1996). A centrifuge or decanter can be installed to separate the remaining wort from the hot trub.

Collection of spent yeast and recovery of beer

Leftover and deposited yeast can be collected for sale as animal feed (cattle or pigs) or sold to other breweries. The yield comprises about 15 liters from leftovers and 3-4 liters from deposits per cubic meter of beer, or roughly 2-3% of total beer production (UNIDO, 2000; Bock and Oechsle, 1999). UNEP (1996) notes a production of 5-11 lbs. of spent yeast slurry per barrel of beer.

In the fermentation process, the beer is cooled and stored in storage tanks. Yeast can be recovered from the rinse from the fermentation tanks, if pressed, reducing the pollution load. Yeast can be recovered and reused or sold as animal feed. Any liquor containing yeast could be filtered and yeast or beer recovered. A European brewery with a capacity of 0.8 million barrel/year (1 Million hl/year) estimated the investment costs for installing a beer recovery system from yeast. The system comprised two 40 barrel tanks for yeast after centrifugation, one centrifuge at 17 barrels/hour (20 hl), two 40 barrel tanks for recovered beer, and piping and pumps. The estimated cost was \$500,000-\$700,000 with a payback of 3-4 years based on a recovery of 17,000 barrels (20,000 hl) annually (UNEP, 1996).

Another approach is to use membrane technology to recover beer and spent yeast, with more than 50% of the yeast sediment recovered as beer (Bock and Oechsle, 1999). This technology can be configured in a batch, semi-batch and continuous process. In the continuous and most common process, the retentate and filtrate are continuously removed. The payback for this system varies from 1-4 years depending on the size (Bock and Oechsle, 1999). The PallSep vibrating membrane filter technology may be an improvement from the traditional cross-flow membrane techniques with recovered yeast concentration in excess of 20% dry weight and beer recovery of 3%. Operating costs for the PallSep system are estimated at \$0.50/barrel (\$0.43/hl) (Snyder and Haughney, 1999).

The recovery of yeast also has the effect of reducing contaminant load. One estimate is that the use of a press reduces COD load from the fermentation tanks by 75% and would also reduce loads from the storage tanks (Watson, 1993).

Kieselguhr Recovery after filtration

After filtration, kieselguhr can be recovered and sold as animal feed. Other applications are as a feedstock for cement production and for brick making (UNEP, 1996; Anonymous, 1998). Typically, 0.3-0.8 lbs/barrel ((100 to 300 g/hl) of kieselguhr is used depending on initial clarity, yeast cell count and beer type. The use of centrifugation can reduce the amount of kieselguhr used at the brewery. However, installation of a centrifuge needs to be balanced with the increased electricity requirement. The foam is recovered using spiral or screw pumps.

Recovery of Beer Wastage

Residual beer is lost during various production stages including in the emptying of process tanks, in the Kieselguhr filter, in pipes, in rejects in the packaging area, returns, and exploding bottles (UNEP, 1996). Wasted beer can run between 1-6% of total production (UNEP, 1996; UNIDO, 2000). Much of this beer can be collected and reused in the process, thereby improving yields. In the filling area, metal sheets can be installed to collect spilt beer (UNIDO, 2000).

Reduce glue and loss of labels.

Use strip or point glue rather than global gumming to reduce glue materials. The use of liquid proof labels can also reduce glue requirements.

Use of refillable bottles or PET bottles

The use of refillable glass bottles or of bottles made of polyethylene (PET) generates less waste than their single use counterparts if the bottles are reused enough times (Saphire and Azimi, 1991). Today, only about 6% of beer and soft drinks are sold in refillable containers. Beer and soft drink containers comprised about 8 million tons of waste in 1990 (about 4% of total solid waste). According to David Saphire, today's refillable bottles of glass or PET are capable of 25 refills (Saphire and Azimi, 1991). Energy savings can be significant in terms of the reduced need for glass manufacture or lower energy use for PET manufacture, as well as reduced air and water pollution in this sector (Saphire and Azimi, 1991). A 1985 survey of New York State brewing companies found that some companies that switched from one-way containers to refillable bottles saved between \$4 and \$15 a barrel (between \$3 and 13 a hl) (Saphire and Azimi, 1991). The shipment of PET bottles can reduce transport costs by allowing for the packing of a larger number of partially formed bottles per truck that can be fully formed using blow molding equipment on site (New Belgium Brewing Co., 2001). These systems do require additional investment in bottling equipment and for PET bottles there is concern about the diffusion of oxygen into the bottle and therefore lead to a shorter shelf life. Miller Beer is selling some of its beers in plastic containers, primarily for consumption at stadiums and arenas. Currently these containers are slated only for one-time use. Some of the containers are now being collected, flaked, recycled, and included as one of five layers in the manufacture of the new bottle (Phillip Morris, 2000; Beer News, 2000; BEERWeek, 2000). Anheuser-Busch decided to cancel its plans for bottling in plastic last year after test-marketing the products in selected areas (BEERWeek, 2000).

Caustic savings measures

Caustic is often used as a cleaning agent in breweries. A caustic sediment tank can be installed in connection with the bottle washer. When the brewery is not operating, the contents of the bottle washer can be pumped to the sediment tank where impurities and sediment are removed. After sedimentation, the caustic is returned to the bottle washer (UNEP, 1996).

9. Future Technologies

We include description of technologies that may hold promise for the future but are still currently in the research and development phase.

Continuous wort boiling

Continuous wort boiling is carried out under pressure where the wort is passed through a series of heat exchanges and the pressure is reduced to atmospheric through a series of flash off vessels. Wort residence can be reduced to a few minutes and the system can be run at any evaporation rate (O'Rourke, 1999a). The advantages of this process are consistent good quality wort, reduced energy requirements, easier integration of the system, full use of energy to preheat the wort, variable evaporation rates and high energy savings (UNIDO, 2000). The disadvantages are possible negative changes in product quality (especially if the wort is stored hot), and possible microbial infection if the wort is stored cold (O'Rourke, 1999a). There is no system currently operating with a continuous wort boiler, as all systems are currently batch processes.

Hydrocyclones and ultrasonic separation

Other technologies that are still emerging but have potential applications for the industry include hydrocyclones and ultrasonic separation. Hydrocyclones have been established as compact separators of dense, solid particles from liquids and research is underway to extend their use in fermented beverage applications such as trub removal (UNIDO, 2000). Green beer yeast removal, and preclarification ahead of powder filters (O'Shaughnessy and McKechnie, 2000). This technology is known for its reliability and low maintenance, ease of installation, and modularity. No energy savings data are yet available. Also, preliminary studies have shown that high frequency ultrasonic stationary wave forms can be used to aggregate and separate suspended solids from a process stream. It is possible to allow for continuous separation using this technology (O'Shaughnessy and McKechnie, 2000).

Use of ultra high pressure for sterilizing beer

The Institut Francais des Boissons in France has developed a technique using high pressures to sterilize beer at room temperature. The technology does not currently work well with cans and bottles. Costs are estimated at \$0.08 U.S./liter (Anonymous, 1998). No energy savings were given for this technology.

10. Summary & Conclusions

Breweries in the United States spend over \$200 million on energy annually. Energy consumption is equal to 3 – 8% of the production costs of beer, making energy efficiency improvement an important way to reduce and control production costs. We found energy efficiency improvement opportunities in the brewery industry, both for utilities and for various processes. Cross-cutting utility energy efficiency measures that do not interfere directly with the brewing process show immediate and significant potential for cost-effective energy savings. For process-specific measures, interesting new technologies both reduce energy and improve product quality (either in quality or yield). Specific primary energy savings are provided for each energy efficiency measure based on case studies that described implementation of the measures as well as references to technical literature. If available, typical payback periods are also listed. Tables 8 and 9 summarize the energy efficiency opportunities, typical energy savings and payback periods.

We also provide information on other opportunities for materials efficiency and waste prevention, as well as emerging technologies. Our findings suggest that given available technology, there are still opportunities to reduce energy consumption cost-effectively in the brewing industry. Many of the evaluated energy efficiency measures not only save energy, but they do so within a short payback period, and accrue other benefits as well, such as reducing carbon dioxide emissions, reducing waste, or saving water. Further research on the economics of the measures, as well as their applicability to different brewing practices, is needed to assess implementation of selected technologies at individual breweries.

Table 8. Specific primary energy savings and estimated paybacks for process specific efficiency measures

Process specific		
Measure	Payback (Years)	Primary Energy Savings^A (kBtu/barrel)
Mashing and Lauter Tun		
Waste heat recovery	n/a	limited data
Use of compression filter	2	19
Wort boiling and cooling		
Vapor condensers	<2 to 5	<1 - 22
Thermal vapor recompression	>2	16-18
Mechanical vapor recompression	^D	23
Steineker Merlin system	2	31
High gravity brewing	<1	13-22
Low pressure wort boiling	n/a	32-40
Wort stripping	n/a	20-42
Wort cooling	3	17
Fermentation		
Immobilized yeast fermenter	n/a	limited data
Heat recovery	>2	limited data
New CO ₂ recovery systems	>2	limited data
Processing		
Microfiltration	2 to 4	limited data
Membranes (alcohol-free)	4	19
Heat recovery-pasteurization	n/a	1
Flash pasteurization	n/a	6-14
Packaging		
Heat recovery washing	≤3	6
Cleaning improvements	3.4	23

^A Primary energy savings account for savings in fuel use, electricity use and electricity transmission and distribution losses. We use a conversion factor of 3.08 from final to primary electricity use based on average U.S. power plant heat rates. Energy savings are primarily taken from data from case studies in the literature. To convert kBtu/barrel to kWh/hl use the conversion factor 0.25 kWh/hl/kBtu/barrel. To convert kBtu/barrel to GJ/hl, use the conversion factor 0.0009 GJ/hl/kBtu/barrel

^B Based on data from two sources (EIA, 1997; Beer Institute, 2000), we assume an average U.S. brewery fuel usage of 212 kBtu/barrel (53 kWh/hl), 90 to 100% of the fuel is used in the boilers, and an average boiler conversion efficiency of 85%. We estimate a total plant electricity consumption of 122 kBtu/barrel (30.5 kWh/hl) (EIA, 1997).

^C We assume motors and systems using them make up 46% and process cooling make up 32% brewery electricity use (EIA, 1997).

^D Results vary widely depending on plant configuration and size of the brewery
n/a Paybacks for this measure could not be estimated from available data

Table 9. Specific primary energy savings and estimated paybacks for efficiency measures for utilities

Utilities		
Measure	Payback (Years)	Primary Energy Savings^A (kBtu/barrel)
Boilers and Steam distribution^B		
Maintenance	<1	4
Improved process control	<1	3
Flue gas heat recovery	>3	2
Blowdown steam recovery	2.7	2-3
Steam trap maintenance	<1	3.4
Automatic steam trap monitoring	<1	<1
Leak repair	<1	6
Condensate return	>1	19-21
Insulation of steam pipes	1	6-28
Process integration	^D	47-84
Motors and Systems Using Motors^C		
Variable speed drives	2 to 3	6-25
Downsizing	2	1-2
High efficiency	1 to 2	1-2
Refrigeration and cooling^C		
Better matching of cooling capacity and cooling loads	3.6	1-2
Improved operation of ammonia cooling system	5.5	<1 - 2
Improved operations and maintenance	<1	4
System modifications and improved design	≤3	5-8
Insulation of cooling lines	n/a	Limited data
Other utilities		
Lighting	<2 to 3	2-6
Reduce space heating demand	n/a	8
Anaerobic waste water treatment	>2	5-9
Membrane filtration wastewater	≤5	limited data
Control & monitoring systems	<1 - 5	<1 - 37
Combined heat and power	3.5	67-100
CHP with absorption cooling	4.5	79
Engine driven chiller systems	2 to 4	12

A Primary energy savings account for savings in fuel use, electricity use and electricity transmission and distribution losses. We use a conversion factor of 3.08 from final to primary electricity use based on average U.S. power plant heat rates. Energy savings are primarily taken from data from case studies in the literature. To convert kBtu/barrel to kWh/hl use the conversion factor 0.25 kWh/hl/kBtu/barrel. To convert kBtu/barrel to GJ/hl, use the conversion factor 0.0009 GJ/hl/kBtu/barrel

B Based on data from two sources (EIA, 1997; Beer Institute, 2000), we assume an average U.S. brewery fuel usage of 212 kBtu/barrel (53 kWh/hl), 90 to 100% of the fuel is used in the boilers, and an average boiler conversion efficiency of 85%. We estimate a total plant electricity consumption of 122 kBtu/barrel (30.5 kWh/hl) (EIA, 1997).

C We assume motors and systems using them make up 46% and process cooling make up 32% brewery electricity use (EIA, 1997).

D Results vary widely depending on plant configuration and size of the brewery
n/a Paybacks for this measure could not be estimated from available data

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Appendix I. Locations and capacity of large breweries

Company	Location (City)	Location (State)	Year began operation	Capacity (million barrel)
Anheuser-Busch	Fairfield	CA	1976	3.8
Anheuser-Busch	Los Angeles	CA	1954	12.0
Anheuser-Busch	Ft. Collins	CO	1988	6.1
Anheuser-Busch	Houston	TX	1966	10.0
Anheuser-Busch	St. Louis	MO	1879	14.4
Anheuser-Busch	Columbus	OH	1968	7.1
Anheuser-Busch	Merrimack	NH	1970	3.0
Anheuser-Busch	Baldensville	NY	1983	7.7
Anheuser-Busch	Newark	NJ	1951	10.0
Anheuser-Busch	Williamsburg	VA	1972	10.0
Anheuser-Busch	Cartersville	GA	1993	6.6
Anheuser-Busch	Jacksonville	FL	1969	7.9
Miller	Albany	GA	1980	10.3
Miller	Eden	NC	1977	9.7
Miller	Ft. Worth	TX	1969	8.8
Miller	Orinda (Irwindale)	CA	1980	6.8
Miller	Milwaukee	WI	1855	9.2
Miller	Trenton	OH	1991	10.5
Miller	Tumwater	WA	1896	3.5
Coors	Golden	CO	1873	20.0
Coors	Memphis	TN	1990	5.0
Latrobe Brewing/Labatt	Latrobe	PA	1933	1.5
Minnesota Brewing Co.	St. Paul	MI		2.0
Boston Beer Co.	Boston	MA	1984	1.2
Highfalls Brewing	Rochester	NY	1933	3.0
Pittsburgh Brewing	Pittsburgh	PA	1861	1.0
Yuengling	Tampa	FL	1831	0.6
Pabst (closed 2001)	Lehigh Valley	PA	1971	3.5
Rainer Brewing (closed)	Seattle	WA	1916	7.9
Total				

Sources: <http://www.beerexpedition.com/northamerica.shtml>, company telephone correspondence with Anheuser Busch, Miller, Coors, Pittsburgh Brewing and Boston Beer Company

Appendix II. Employee tasks for energy efficiency

One of the key steps to a successful energy management program is the involvement of all personnel. Staff may be trained in both skills and the general approach to energy efficiency in daily practices. Personnel at all levels should be aware of energy use and objectives for efficiency. By passing information to everyone, each employee may be able to save energy every day. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high performers. Examples of some simple tasks employees can do include the following (Caffal, 1995):

- Switch off motors, fans and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.
- Switch off unnecessary lights and rely on daylighting whenever possible.
- Use weekend and night setbacks on HVAC in offices or conditioned buildings.
- Report leaks of water (both process water and dripping taps), steam and compressed air and ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.
- Look for unoccupied, heated or cooled areas, and switch off heating or cooling.
- Check that heating controls are not set too high or cooling controls are not set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.
- Check to make sure the pressure and temperature of equipment is not set too high.
- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.
- Carry out regular maintenance of energy-consuming equipment.
- Ensure that the insulation on process heating equipment is effective.

Appendix III: Energy management system assessment for best practices in energy efficiency

ORGANIZATION		SYSTEMS MONITORING		TECHNOLOGY		O & M	
Accountability	Organization	Monitoring & Targeting	Utilities Management	Reviews	Plans	Operation & Maintenance	
0	No awareness of responsibility for energy usage. Energy not specifically discussed in meetings.	No energy manager or "energy champion."	Energy efficiency of processes on site not determined. Few process parameters monitored regularly.	No utilities consumption monitoring.	No specific reviews held.	No energy improvement plans published.	No written procedures for practices affecting energy efficiency.
1	Operations staff aware of the energy efficiency performance objective of the site.	Energy manager is combined with other tasks and roles such that less than 10% of one person's time is given to specific energy activities.	Energy efficiency of site determined monthly or yearly. Site annual energy efficiency target set. Some significant process parameters are monitored.	Utilities (like power and fuel consumption) monitored on overall site basis.	Energy only reviewed as part of other type reviews	Energy improvement plans published but based on an arbitrary assessment of opportunities.	No procedures available to operating staff.
2	Energy efficiency performance indicators are produced and available to operations staff. Periodic energy campaigns. Intermittent energy review meetings.	Energy manager appointed giving greater than 10% of time to task. Occasional training in energy related issues.	Weekly trend monitoring of energy efficiency of processes and of site, monitored against targets. Process parameters monitored against target.	Weekly monitoring of steam/power balance.	Infrequent energy review.	Energy performance plan published based on estimate of opportunities.	Procedures available to operators but not recently reviewed.
3	Energy efficiency performance parameter determined for all energy consuming areas. Operations staff advised of performance. All employees aware of energy policy. Performance review meetings held once/month.	Energy manager in place greater than 30% of time given to task. Adhoc training arranged. Energy performance reported to management.	Daily trend monitoring of energy efficiency of processes and of site, monitored against target. Process parameters monitored against targets.	Daily monitoring of steam/power. Steam & fuel balances adjusted daily.	Regular plant/site energy reviews carried out.	A five-year energy improvement plan is published based on identified opportunities from energy review.	Procedures available to operators and reviewed in the last three years.

ORGANIZATION		SYSTEMS MONITORING		TECHNOLOGY		O & M	
Accountability	Organization	Monitoring & Targeting	Utilities Management	Reviews	Plans	Operation & Maintenance	
4	Energy efficiency performance parameter included in personal performance appraisals. All staff involved in site energy targets and improvement plans. Regular weekly meeting to review performance.	An energy manager is in place giving greater than 50% time to task. Energy training to take place regularly. Energy performance reported to management and actions followed up.	Same as 3, with additional participation in energy efficiency target setting. Process parameters trended.	Real time monitoring of fuel, steam and steam/power balance. Optimum balances maintained.	Site wide energy studies carried out at least every five years with follow up actions progressed to completion	A ten year energy improvement plan based on review is published and integrated into the Business Plan.	Procedures are reviewed regularly and updated to incorporate the best practices. Used regularly by operators and supervisors.

Appendix IV. Support programs for industrial energy efficiency improvement

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

Tools for Self-Assessment

Steam System Assessment Tool

Description: Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group: Any industry operating a steam system
Format: Downloadable software package (13.6 MB)
Contact: U.S. Department of Energy, Office of Industrial Technologies
URL: <http://www.oit.doe.gov/bestpractices/steam/ssat.html>

Steam System Scoping Tool

Description: Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group: Any industrial steam system operator
Format: Downloadable software (Excel)
Contact: U.S. Department of Energy, Office of Industrial Technologies
URL: <http://www.oit.doe.gov/bestpractices/steam/docs/steamtool.xls>

MotorMaster+

Description: Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting and environmental reporting capabilities.
Target Group: Any industry
Format: Downloadable Software (can also be ordered on CD)
Contact: U.S. Department of Energy, Office of Industrial Technologies
URL: <http://mm3.energy.wsu.edu/mmplus/default.stm>

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

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

AirMaster:+ Compressed Air System Assessment and Analysis Software

Description: Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices
Target Group: Any industry operating a compressed air system

Format: Downloadable software
Contact: U.S. Department of Energy, Office of Industrial Technologies
URL: <http://www.compressedairchallenge.org/>

Pump System Assessment Tool (PSAT)

Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.

Target Group: Any industrial pump user

Format: Downloadable software

Contact: U.S. Department of Energy, Office of Industrial Technologies

URL: <http://public.ornl.gov/psat/>

ENERGY STAR Portfolio Manager

Description: Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.

Target Group: Any building user or owner

Format: Online software tool

Contact: U.S. Environmental Protection Agency,

URL: http://www.energystar.gov/index.cfm?c=business.bus_index

Optimization of the insulation of boiler steam lines – 3E Plus

Description: Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.

Target Group: Energy and plant managers

Format: Downloadable software

Contact: Office of Industrial Technologies, U.S. Department of Energy

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

Assessment and Technical Assistance

Industrial Assessment Centers

Description: Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. who assesses the plant's performance and recommends ways to improve efficiency.

Target Group: Small- to medium-sized manufacturing facilities with gross annual sales below \$75 million and fewer than 500 employees at the plant site.

Format: A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.

Contact: U.S. Department of Energy, Office of Industrial Technologies

URL: <http://www.oit.doe.gov/iac/>

Plant-Wide Audits

Description: An industry-defined team conducts an on-site analysis of total energy use and identifies opportunities to save energy in operations and in motor, steam, compressed air and process heating systems. The program covers 50% of the audit costs.

Target Group: Large plants

Format: Solicitation (put out regularly by DOE)

Contact: U.S. Department of Energy, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/plant_wide_assessments.shtml

Manufacturing Extension Partnership (MEP)

Description: MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.

Target Group: Small- and medium-sized plants

Format: Direct contact with local MEP Office

Contact: National Institute of Standards and Technology, (301) 975-5020

URL: <http://www.mep.nist.gov/>

Small Business Development Center (SBDC)

Description: The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.

Target Group: Small businesses

Format: Direct contact with local SBDC

Contact: Small Business Administration, (800) 8-ASK-SBA

URL: <http://www.sba.gov/sbdc/>

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

Description: ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.

Target Group: Any user of labeled equipment.

Format: Website

Contact: U.S. Environmental Protection Agency

URL: http://www.energystar.gov/index.cfm?c=business.bus_index

Training

Best Practices Program

Description: The Best Practices Program of the Office for Industrial Technologies of U.S. DOE provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences. A clearinghouse provides answers to technical questions and on available opportunities: 202-586-2090 or <http://www.oit.doe.gov/clearinghouse/>

Target Group: Technical support staff, energy and plant managers

Format: Various training workshops (one day and multi-day workshops)

Contact: Office of Industrial Technologies, U.S. Department of Energy

URL: <http://www.oit.doe.gov/bestpractices/training/>

ENERGY STAR

Description: As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.

Target Group: Corporate and plant energy managers

Format: Web-based teleconference

Contact: Climate Protection Partnerships Division, U.S. Environmental Protection Agency

URL: <http://www.energystar.gov/>

Financial Assistance

Below we summarize the major federal programs that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs).

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

Description: Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.

Target Group: Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.

Format: Solicitations (by sector or technology)

Contact: U.S. Department of Energy – Office of Industrial Technologies

URL: <http://www.oit.doe.gov/industries.shtml>

Inventions & Innovations (I&I)

Description: The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to \$75,000) and 2) prototype development or commercialization of a technology (up to \$250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.

Target Group: Any industry (with a focus on energy-intensive industries)

Format: Solicitation

Contact: U.S. Department of Energy – Office of Industrial Technologies

URL: <http://www.oit.doe.gov/inventions/>

National Industrial Competitiveness through Energy, Environment and Economics (NICE³)

Description: Cost-sharing program to promote energy efficiency, clean production and economic competitiveness in industry through state and industry partnerships (large and small business) for projects that develop and demonstrate advances in energy efficiency and clean production technologies. Applicants must submit project proposals through a state energy, pollution prevention or business development office. Non-federal cost share must be at least 50% of the total cost of the project.

Target Group: Any industry

Format: Solicitation

Contact: U.S. Department of Energy – Office of Industrial Technologies

URL: <http://www.oit.doe.gov/nice3/>

Small Business Administration (SBA)

Description: The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.

Target Group: Small businesses

Format: Direct contact with SBA

Contact: Small Business Administration

URL: <http://www.sba.gov/>

State and Local Programs

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. Below we summarize selected programs earmarked specifically for support of energy efficiency activities.

California – Public Interest Energy Research (PIER)

Description: PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.

Target Group: Targeted industries (e.g. food industries) located in California

Format: Solicitation

Contact: California Energy Commission, (916) 654-4637

URL: <http://www.energy.ca.gov/pier/funding.html>

California – Energy Innovations Small Grant Program (EISG)

Description: EISG provides small grants for development of innovative energy technologies in California. Grants are limited to \$75,000.

Target Group: All businesses in California

Format: Solicitation

Contact: California Energy Commission, (619) 594-1049

URL: <http://www.energy.ca.gov/research/innovations/index.html>

Indiana – Industrial Programs

Description: The Energy Policy Division of the Indiana Department of Commerce operates two industrial programs. The Industrial Energy Efficiency Fund (IEEF) is a zero-interest loan program (up to \$250,000) to help Indiana manufacturers increase the energy efficiency of manufacturing processes. The fund is used to replace or convert existing equipment, or to purchase new equipment as part of a process/plant expansion that will lower energy use. The Distributed Generation Grant Program (DGGP) offers grants of up to \$30,000 or up to 30% of eligible costs for distributed generation with an efficiency over 50% to install and study distributed generation technologies such as fuel cells, micro turbines, cogeneration, combined heat & power and renewable energy sources. Other programs support can support companies in the use of biomass for energy, research or building efficiency.

Target Group: Any industry located in Indiana

Format: Application year-round for IEEF and in direct contact for DGGP

Contact: Energy Policy Division, (317) 232-8970.

URL: http://www.in.gov/doc/businesses/EP_industrial.html

Iowa – Alternate Energy Revolving Loan Program

Description: The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.

Target Group: Any potential user of renewable energy

Format: Proposals under \$50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.

Contact: Iowa Energy Center, (515) 294-3832

URL: <http://www.energy.iastate.edu/funding/aerlp-index.html>

New York – Industry Research and Development Programs

Description: The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.

Target Group: Industries located in New York

Format: Solicitation

Contact: NYSERDA, (866) NYSERDA

URL: <http://www.nysesda.org/industry/industrialprograms.html>

Wisconsin – Focus on Energy

Description: Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.

Target Group: Industries in Wisconsin

Format: Open year round

Contact: Wisconsin Department of Administration, (800) 762-7077

URL: <http://focusonenergy.com/page.jsp?pageId=4>