Boiling the Wort and Cooling the Brew: Combined Heat and Power Opportunities for Small and Regional Brewers

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ABSTRACT

Brewing is an energy-intensive industry, large amounts of energy are needed for the mash and to boil the wort, and then many beers need to be cooled at a very specific and stable temperature throughout the fermentation process. While the larger breweries in the United States and abroad have invested considerably in combined heat and power (CHP) and advanced energy efficiency technologies smaller breweries from brewpubs to regional brewers lag considerably behind, many focusing on the craft and not the operating expenses of the process and its electrical and thermal requirements. This paper examines beer production in the United States, the temperature and residence times for the stages of the brewing process, the opportunities for implementing CHP technology, and the economic feasibility of selected CHP resources. CHP can provide for numerous functions of the brewing process; electrical outputs can offset grid power for refrigeration and air compressors; provide back-up in the event of a power failure, and operate conveyers, grinders and agitators. Thermal outputs can be used for mashing, lauter tuning, sparging, wort holding, wort boiling, sanitation, and even cooling when combined with a thermal chiller. The goal of the paper is to highlight opportunities where CHP can be integrated into small and regional breweries providing energy and cost savings for the facility while maintaining or enhancing beer production rates, quality, and uniqueness.

Brewing as an Art and Science – Different Styles and Needs

What could be better than a nice cold beer on a hot summer afternoon? A cold beer brewed using at a lower energy cost to the brewer! Brewing is an energy-intensive industry. The need for thermal energy provides an excellent opportunity for the implementation of on-site CHP technology.

In its simplest form commercial brewing is an industrial process converting sugars into alcohol by the formula $C_6H_{12}O_6 \Rightarrow 2(CH_3CH_2OH) + 2(CO_2)$. However, when brewing beverages to be enjoyed by the public— factors such as taste, bitterness, sweetness, body, aroma, color and consistency are of utmost importance. The large breweries, with a cadre of energy managers have been able to embrace many of the energy technology advances that other industries have, and implement them on a scale that meets their product output. However small and regional brewers, who may not have access to dedicated energy managers, brew in small batches with quickly changing formulas, and have an emphasis on quality, flavor, and uniqueness. In addition, these brewers may or may not perform their own yeast culturing, malting. Carbonation may be done "in the bottle" and pasteurization may be omitted. Not surprisingly, with smaller volume, more flexible production schedules, and rotating recipes, these brewers are not always a candidate for the one-size fits all or large CHP installations that the large breweries have incorporated.

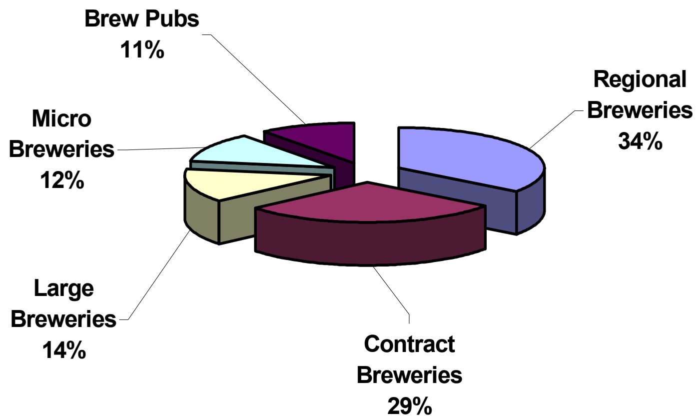
With the diversity of CHP technologies and capacities available including microturbines, fuel cells, and reciprocating engines, the technology is equally as relevant to the small and regional brewer as to the larger companies.

United States Beer Brewing Industry

Commercial Beer Brewing industry in the United States got it start in the 1840s, with the increase in popularity of the lager beer and technological innovations such as refrigeration and pasteurization. Before this point, the majority of beer produced was home-craft or produced by brewpubs. By the early 1900s there were well over 1,000 breweries in the United States. Prohibition was enacted which led to the closure of all but 35 breweries; however within a year after the appeal of the 18^{th} amendment the number of breweries had expanded to over 800. Following World War II the beer industry began consolidating and most of the smaller and regional breweries were forced out of business or merged with larger brewing companies. Resulting in only 100 breweries pumping out over 170 million barrels annually. However, in the 1980s, with a population once again becoming "adventurous" about their beer tastes and craving a variety of specialty beers, the number of breweries increased; by 1997 1,300 breweries were operating. (Goldhammer, 1999). Beer shipments in the United States, both domestic and imported, hit a record high of over 197 million barrels in 2000. Despite a brief drop in beer shipments after the September 11^{th} attacks, leading beer industry associations expect beer shipments to maintain a level over 190 million barrels annually throughout the mid-part of the decade. (Beer Institute). However, in 2004 the craft beer industry comprised of small and regional breweries produced 6,590,763 barrels of beer. (Beertown)

Within the brewing industry there are three primary categories of brewer. These includes the large breweries producing over 15 million barrels of beer annually; regional breweries with between 15 million barrels and 15,000 barrels annually; and small breweries producing less than 15,000 barrels of beer. The large brewery category in the United States is completely dominated by Anheuser Busch Inc, Miller Brewing Company, and Adolph Coors Company. The regional breweries include Stroh Brewing Company, Falstaff Brewing Company, D.G. Yeungling and Sons, and Matt Brewing Company. Small brewing companies are diverse and widespread across the country including brewpubs and craft breweries. (Goldhammer, 1999). Crosscutting categories are the contract breweries, which brew beer to be marketed under other labels. The contract brewing industry may be composed of regional brewers with excess production capacity, specific contract breweries who do not produce their own label but brew to order for other labels, and small breweries and brewpubs that produce small runs of specialty beers to be marketed under house labels. The contract brewing model has been successful, with labels like The Boston Beer Company Inc, operating almost entirely from contract breweries.

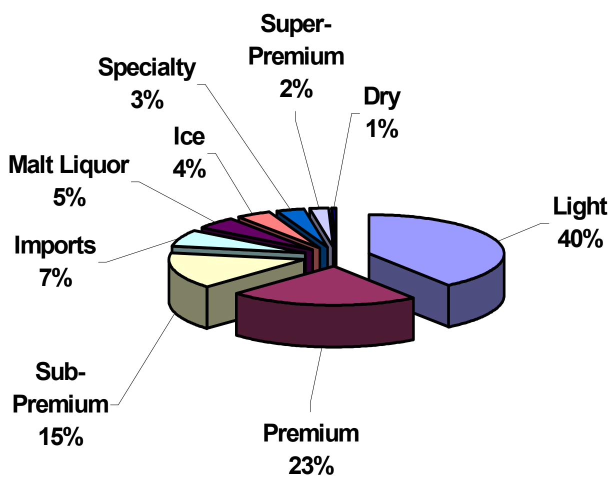
Figure 1. Beer Sales by Brewer Classification (1997)



Source: Goldhammer, 1999

The bulk of beer production was light beer and premium, provided primarily by large breweries and regional breweries, with 3% or 6.5 million barrels classified as specialty (including craft) beer.

Figure 2. Beer Sales by Type (1997)



Source: Goldhammer, 1999

Of the specialty beer segment regional breweries produced 2.3 million barrels, contract breweries[1] produced 1.9 million barrels, large breweries produced 0.9 million barrels, micro breweries produced 0.8 million barrels, and brew pubs produced 0.7 million barrels.

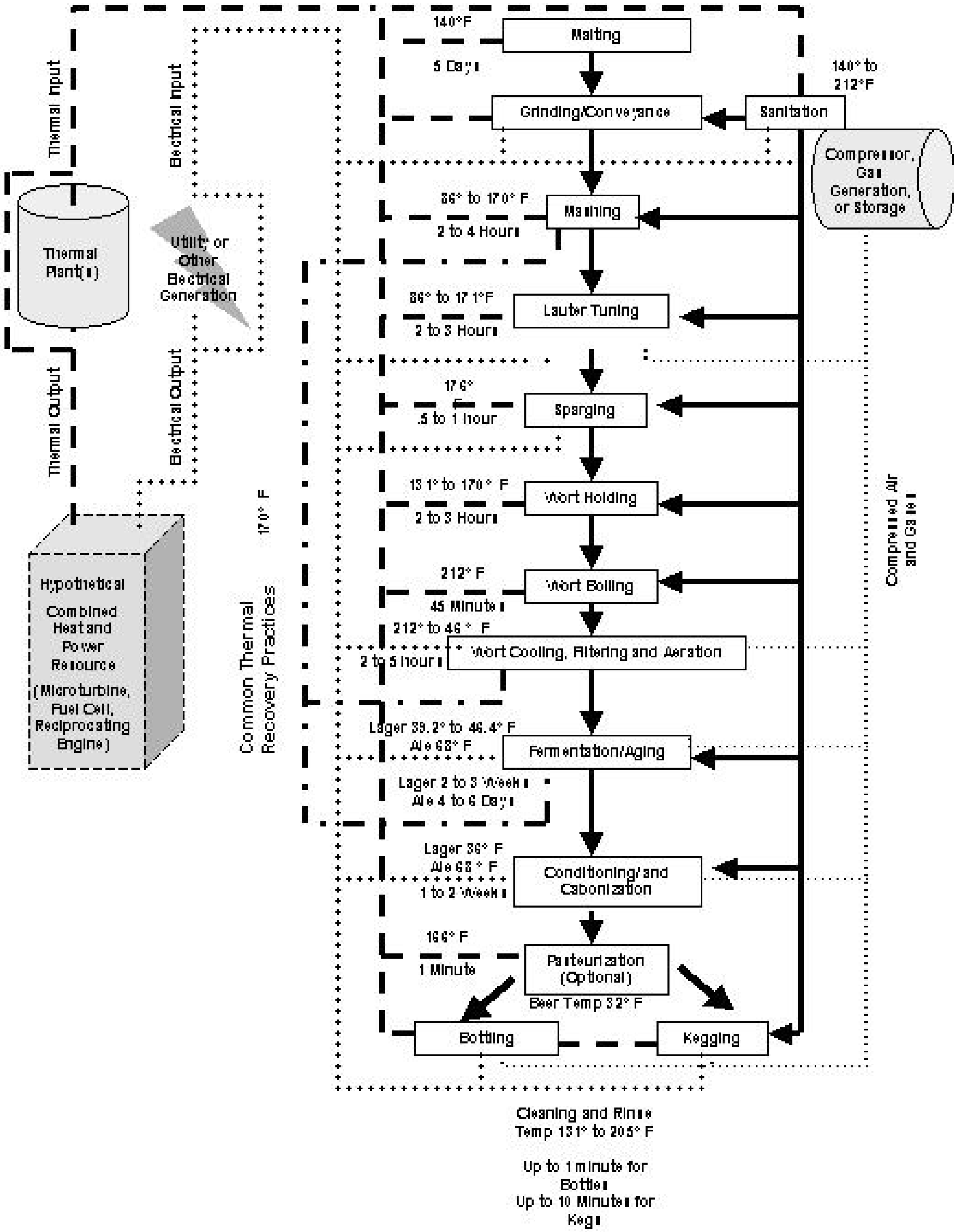
[1] Contract breweries do not brew the majority of their beer at their own facilities, instead they contract other breweries (usually independent and regional breweries) to produce their product.

Thermal and Electrical Loads of the Brewing Process

The brewing process has numerous thermal and electrical loads that require large inputs of heating and cooling. Figure 3. shows the common steps of the brewing process for small and regional brewers along with the typical thermal needs and residence times.

- Malting: The process of germinating barley (and occasionally other grains such as wheat or rye) in water to produce malt which is then ground, roasted, and processed into extract. Most breweries purchase malt extracts, but some craft breweries may insist on their own malting processes.
- Mashing: Is the process of converting starch from milled malt and brewing adjuncts into fermentable and unfermentable sugars for wort production. Mashing involves mixing ingredients with water at a set temperature and volume, and maintaining specific temperatures to foster specific biochemical processes. The thermal needs of mashing vary depending on the mashing method, and beer style. However, one of the most common is infusion mashing that has a peak temperature of 170º F.
- Lauter Tuning: After the mashing process is complete the wort is transferred to the lauter tun, where the wort is further separated from the mash. The later tuning process usually occurs between 86º and 171º F.
- Sparging: Is the addition of water at around 176º F during the drawing off of the wort to maximize wort flow.
- Wort Holding: Is the process of holding the sparged wort, at 131º to 170º F
- Wort Boiling: Kills off any remaining microorganisms from mashing and sparging by boiling the mix, at 212º F for at least 45 minutes.
- Wort Cooling: Cools the wort from boiling to the fermentation temperature, from 212º to 46ºF before transferring the material to fermentation tanks. In most breweries, the water used to cool the wort is circulated to a holding tank at about 170 ºF and used in the mash.
- Fermentation: Fermentation temperatures and durations vary dramatically from beer style to beer style, but as a general role, lagers are fermented at a temperature of 39.2ºF for 1 to 3 weeks, and ales are fermented at 68ºF for 4 to 6 days.
- Conditioning: In the brewing process, lagering is the most common, with the fermented beer being reduced to 39ºF. In addition, bottled beers may be conditioned, in bottle for 10 to 14 days.
- Pasteurization: A common process for eradicating microorganisms, most commonly flash, involves raising the temperature of the beer to 166ºF for approximately 1 minute.
- Keg Cleaning/Preparation: Involves several steps, most commonly pre-rinsing the kegs with water at 131ºF, a caustic and phosphoric acid wash at 131º to 150ºF, a hot water wash at 131º to 150ºF and a steam wash at 205ºF.
- Sanitation: Throughout the brewing process, hot water and steam is needed for cleaning and flushing of equipment. Typically the water is around 140º to 212ºF with a typical contact time of 15 to 20 minutes.

Figure 3. Brewing Process Thermal and Electrical Inputs and Outputs



Source: Compiled from Goldhammer, 1999, and Karim, 2005

As a whole, the industry is an extremely thermal intensive industry, requiring massive amounts of energy to meet the basic requirements of brewing. Fortunately, even among small and regional brewers, equipment suppliers have made strides towards conserving thermal energy within the process through heat recovery. Rejected heat from cooling, is used to preheat water used in other processes.

Breweries are also electricity intensive: refrigeration compressors consume large amounts of electricity to chill water and refrigerate storage areas; compressed air/gas is used in most breweries; a variety of motors power conveyers and grinders; plus breweries also have the usual electric loads of lighting, space heating/cooling; office equipment, and other facility functions.

Combined Heat and Power's Potential for Regional and Small Brewers

Modern CHP options come in a wide variety of forms, sizes, and capacities with different alternatives being suitable for different size and volumes of breweries: For small breweries microturbines, reciprocating engines, and fuel cells; for larger regional breweries a combined-cycle turbine may be a better opportunity, or to a lesser extent a steam take-off turbine from a new or existing central plant. Given the current status of the CHP industry, a technically feasible option can be applied to nearly every brewery, however the economic potential is will be dependent on the cost of electricity, natural gas, production intensity, production volume, and electricity buy-back price.

Many of the large domestic and international brewers including Anheuser Busch Inc, Guinness, and Labbatt/Molson have already embraced CHP (as well as renewable energy technologies) as an option for reducing the costs of brewing and increasing process efficiency.

Table 1. Applicability of Combined Heat and Power Opportunities for Breweries

CHP Opportunity	Cost/kW_e [2]	Hot Water	Steam	Baseload Power	Peak Shaving	Small Brewery 15,000 to 50,000 Barrels/year	Regional Brewery 50,000+ Barrels/year
Central Plant Steam Take-Off	$300 to $2000	•	•	•			•
Combined Cycle	$350 to $1,500	•	•	•			•
Microturbine	$350 to $1,500	•	•	•	•	•	•
Reciprocating Engine[3][4]	$300 to $1,500	•	•	•	•	•	•
Fuel Cell SOFC/PAFC	$2,000 to $5,000+	•	•	•		•	•
Fuel Cell PEM[5]		•		•		•	•

[2] Source: U.S. Combined Heat and Power Association

[3] Includes diesel, gasoline, alcohol, and bottled/natural gas fueled engines. For cost purposes, natural gas fueled engines will usually yield the lowest cost per BTU.

[4] Sufficient temperature can be obtained from a heat exchanger located in the exhaust for steam generation. Lower temperature hot water can be obtained from the water jacket.

[5] PEM fuel cells produce relatively low-thermal outputs and are only marginally suited for combined heat and power for industrial processes. Combined with a reformer, their outputs are considerably higher.

Given that electricity accounts for approximately 30 to 40% of a breweries primary energy requirements, but is highly variable due to facility and process characteristics it is assumed most brewers will size CHP resources to meet thermal needs and that the electrical production for each CHP resource will be less than or equal to 100% of the facility's electrical energy needs. Offsetting utility costs, but not providing any excess electricity generation. This assumption is reasonable, as most small and regional brewers will be deploying relatively small CHP resources and will not be in a position to strongly negotiate buyback with the utility. As typical CHP resources will be fossil fueled (e.g. natural gas), they may not be eligible for net metering programs were excess generation is purchased at the retail rate.

To evaluate the CHP opportunities for small and regional brewers, the researchers collected information to develop a partial process model to determine the economic potential of the installation of microturbines or fuel cells. The model was developed through the following process.

- Collecting data on the thermal needs of the brewing process. Due to data limitations only lauter tuning, sparging, wort boiling, wort cooling, fermenting, pasteurization, and bottling/kegging were considered. These processes make up the majority of the non-building thermal loads. Heat recovery was assumed from wort cooling as is common practice within the industry. Many other thermal loads including sanitation exist in small and regional breweries.
- Data was converted to thousand BTU (kBTU) per barrel of beer (31 gallons) of production and all analysis was done with the barrel of beer as the unit of energy intensity/cost savings.
- Installed electric capacity was determined by the output of a generation resource sized to meet 100% of the identified processes thermal needs.

Table 2. Electricity Production from CHP Resources at Different Brewery Production Levels

Brewery Annual Capacity (Barrels)	15k	50k	200k
	kWh		
Microturbine	16,451	54,837	109,675
Fuel Cell (SOFC)	67,959	226,530	453,061

- Central plant and CHP natural gas consumption was based on assumed thermal conversion efficiencies.
- Electricity and natural gas usage and costs are based on Energy Information Administration industrial rate data for 2003 to 2004 for the identified states. Peak pricing and time of use charges were not considered in this analysis.

Table 3. Natural Gas and Electricity Prices Used in Analysis

Fuel	California	Washington	New York	Massachusetts
Natural Gas ($/Therm)	0.72	2.01	0.74	0.72
Electricity ($/kWh)	0.086	0.039	0.062	0.049

- The cost saving potential was determined by subtracting additional natural gas usage consumed by the CHP over the assumed central plant from the retail value of the electricity generated. Savings were quoted per barrel of production

Table 4. Cost Savings from Selected CHP Resources per Barrel of Beer Production

	California	Washington	New York	Massachusetts
Microturbine	$0.04	$0.01	$0.04	$0.03
Fuel Cell (SOFC)	$0.25	$0.05	$0.17	$0.13

Source: Analysis developed with data from Gatlisky C. Et al 2003; Hamel Et al 1979, U.S. Department of Energy, Energy Information Administration, U.S Combined Heat and Power Association, Plug Power Fuel Cell Systems, and Acumentrics.

As demonstrated by Table 5, the best potential for CHP in small and regional breweries is in the states of New York and California, where substantial populations of breweries exist.

Table 5. Simple Payback (Years) for CHP Installations[6]

	California	Washington	New York	Massachusetts
Microturbine	3.03	6.77	4.19	5.35
FuelCell (SOFC)	10.10	22.55	13.96	17.79

Though not quantified in this analysis, there may be significant opportunities for further cost savings by replacing conventional chillers with absorption chillers using CHP generated and recovered thermal loads.

Recommendations for Small and Regional Breweries

- Generally, if a breweries production is greater than 5,000 barrels per year consider having the facility evaluated for combined heat and power.
- Be sure to request that the party(s) evaluating your facility for CHP include efficiency (both process and building) opportunities in their analysis to minimize the capacity of the CHP resource required.
- Evaluate your facility for specific high efficiency CHP resources including state of the art fuel cells and microturbines.
- Consider absorption chillers to further utilize thermal loads from CHP and minimize electricity usage.
- Over sizing of electrical generation capacity should be considered primarily in states that permit net metering of generated power for CHP in excess of annual consumption.

[6] Based on incremental increases in thermal requirements and CHP capacity costs. Paybacks may be higher due to higher costs for lesser capacities.

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