The Potential for Combined Heat and Power in Massachusetts

Lauren Mattison and Dragoljub Kosanovic, University of Massachusetts Amherst

ABSTRACT

Use of combined heat and power (CHP) can benefit both the user and society by providing benefits to the economy, the environment and energy security. This study investigated the potential for use of CHP in Massachusetts. Research identified 120 existing CHP systems in the commercial/institutional, industrial and multifamily residential sectors in the state, with total electrical capacity of 375 MW and average system size of 3.1 MW. Technical potential for new CHP installations was determined using current average energy consumption and hours of operation for each facility type, and was based on existing CHP technologies. The remaining technical potential for CHP in Massachusetts was found to be more than 4,700 MW at 18,500 sites, with an average system size of 256 kW. The majority of the potential is in small systems of 50-500 kW in commercial/institutional buildings. The only area in which there has been significant market penetration to date is large systems of at least 5 MW.

Reducing congestion of the electric grid and lowering the overall cost of energy with increased use of CHP would be particularly beneficial in Massachusetts where electricity rates are among the highest in the country. By reporting the current status of CHP in the state, considering the facility types best suited for CHP and estimating the size of the potential market, this study lays the groundwork for further analysis and development of CHP technology and policy in Massachusetts.

Introduction

Combined heat and power (CHP), or cogeneration, is the joint generation and use of electricity and thermal energy. CHP systems can use a variety of fuels and power generation technologies. The thermal energy from CHP can be used for space heating, water heating, steam or hot water for use in manufacturing processes, cooling and dehumidification. CHP is generally used in distributed generation (DG), in which smaller power sources are located closer to the point of use. To meet their full electrical demand, most facilities with CHP systems continue to purchase some electricity from the grid to supplement electricity generated on-site.

CHP is typically at least twice as efficient as conventional electricity generation. The average efficiency of utility power plants in New England is 37%, with the majority of the fuel's energy being lost as waste heat (ISO New England 2004). Factoring in the losses in the transmission and distribution (T&D) process, overall efficiency is approximately 30%.

Across the United States, there were more than 2,800 CHP systems in 2005 with a total electrical generating capacity of 81,000 MW, mostly in large industrial systems (Hedman 2005). The potential for new CHP installations was estimated to be 70,000-90,000 MW in the industrial sector and 60,000-80,000 MW in the commercial/institutional sector (Hedman 2005).

Benefits of CHP

With system efficiencies generally ranging from 60% to 80%, use of CHP can reduce fuel consumption, pollutant emissions and the overall cost of energy. High energy costs can be an obstacle to industry in the United States, especially in states such as Massachusetts where costs are among the highest in the country. Promotion of CHP could provide economic stimulus by helping to lower the cost of living and doing business in Massachusetts.

Benefits of DG include reduced electric grid congestion, reduced T&D losses and increased power reliability. T&D is a significant factor in the cost and reliability of the electricity supply, particularly in highly populated areas such as the greater Boston area. According to ISO New England, the independent system operator which oversees the operation of New England's electric system, "One of the greatest challenges the electricity industry faces is delivering its product to where it is needed most" (ISO New England 2003). ISO New England uses a market pricing approach called locational marginal pricing (LMP) to manage efficient use of the transmission system and assign the cost of congestion to customers in the areas where the congestion occurs. A goal of this system is to encourage consideration of efficiency and DG by customers in congested areas. Increasing efficient distributed electricity generation with CHP would relieve pressure on the transmission system and eliminate or reduce the necessity for additional investment in T&D infrastructure.

A growing demand for electricity is predicted in many parts of the country, and inabilities to meet this demand could limit economic growth. Installations of distributed CHP systems are smaller, usually require less lead-time than building new power plants, and are not limited by grid transmission capacity. Increased use of CHP provides flexibility in meeting increased electrical demand and could be an important component of plans to increase our power supply.

Energy in Massachusetts

Massachusetts is part of the New England electricity market. The New England electric system had approximately 30,000 MW of installed capacity in 2002, which generated more than 124 million MWh in that year. More than 12,000 MW of that generating capacity is located in Massachusetts, and retail sales of electricity to customers in Massachusetts totaled 52 million MWh.

There are three major investor-owned electric utility companies in Massachusetts: NSTAR, National Grid and Western Massachusetts Electric (a subsidiary of Northeast Utilities).

Most consumers and facilities in Massachusetts have access to natural gas, provided primarily by four major companies: Bay State Gas, Berkshire Gas, Keyspan and NSTAR.

Massachusetts is consistently among the ten states with highest electricity and natural gas rates. According to the U.S. Department of Energy, in 2004, the national average retail price of electricity was 7.6 cents/kWh, while the price in Massachusetts was 41% higher at 10.8 cents/kWh. The average retail price of natural gas was $13.45/MMBtu in Massachusetts, which is 59% higher than the national average of $8.49/MMBtu.

Existing CHP in Massachusetts

As of spring 2006, there were 120 known CHP systems in industrial, commercial/institutional and multifamily residential buildings in Massachusetts, with total electrical capacity of 375 MW. This total is equal to 3% of the electric industry's generating capacity in the state. As shown in Table 1, the majority of these systems are in commercial/institutional buildings, but the total capacity is more closely split between commercial/institutional and industrial systems because of the larger average size of industrial CHP systems. Residential systems make up less than 1% of the current installed capacity.

Table 1. Existing CHP in Massachusetts

Sector	# of Sites	Total Capacity (MW)	Average Size (MW)
Industrial	24	166	6.9
Commercial / Institutional	83	206	2.5
Residential	13	2	0.15
TOTAL	120	375	3.1

The most common prime mover in existing CHP systems is the reciprocating internal combustion engine, followed by boilers with steam turbines. Natural gas is the most common fuel. Figures 1 and 2 detail the prime movers and fuels used in existing CHP systems.

Figure 1. Prime Movers of the 120 Existing CHP Systems in Massachusetts

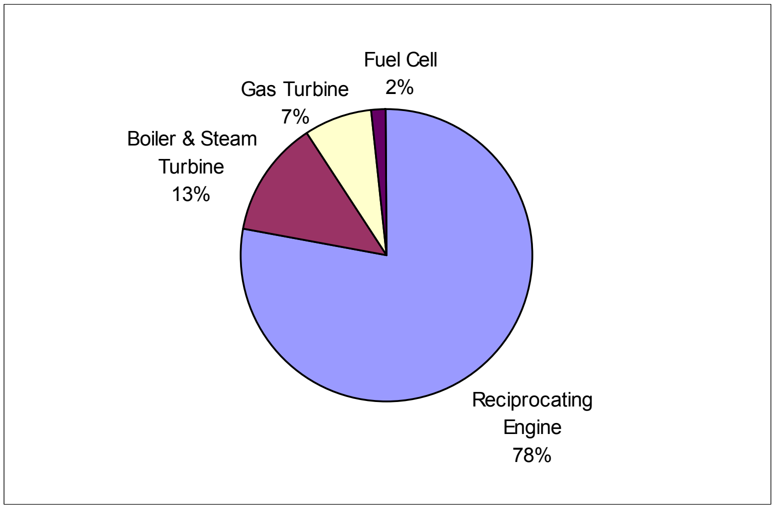
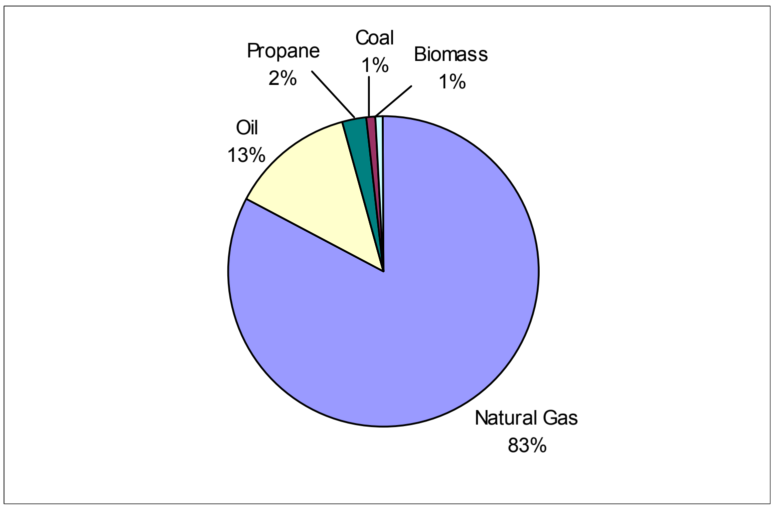


Figure 2. Fuels Used in the 120 Existing CHP Systems in Massachusetts



Industrial Sector

The industrial sector in Massachusetts operates 24 CHP facilities with a total electrical capacity of 166 MW. Most are fairly large systems, with 75% in the 1 to 20 MW range. Half use boilers with steam turbines, followed by reciprocating engines and gas turbines. Natural gas is the primary fuel in 58% of industrial systems, and most other systems use oil.

The paper industry has the most CHP systems, followed by chemicals, food and textiles. The distribution of CHP systems by industry is detailed in Table 2.

Table 2. Industrial CHP Systems in Massachusetts

Industry	NAICS Code	# of Sites	Total Capacity (MW)	Average Size (MW)
Food	311	3	19	6.5
Textiles	313	3	18	6.1
Paper	322	7	28	3.9
Chemicals	325	4	24	6.0
Nonmetallic Mineral Products	327	1	6	6.0
Fabricated Metal Products	332	2	13	6.7
Machinery	333	1	1	0.5
Computer & Electronic Products	334	2	2	1.1
Transportation Equipment	336	1	55	55.0
TOTAL		24	166	6.9

Commercial/Institutional Sector

Of the 83 commercial/institutional CHP systems in Massachusetts, 81% are small systems in the 50-500 kW range. The remaining systems range from 500 kW to over 20 MW. Natural gas-fired reciprocating engines are used in most of the commercial/institutional systems.

As shown in Table 3, many nursing homes and assisted living facilities use CHP, and several colleges and universities have CHP systems which range from 60 kW to over 20 MW.

Table 3. Commercial/Institutional CHP Systems in Massachusetts

Facility Type	# of Sites	Total Capacity (MW)	Average Size (MW)
Nursing Homes & Assisted Living	34	3	0.10
Colleges & Universities	18	48	2.7
Schools	8	2	0.22
Hospitals	6	71	11.8
Health Clubs	4	0.3	0.07
Hotels	4	0.5	0.13
Other	9	82	9.1
TOTAL	83	206	2.5

Residential Sector

There are 13 CHP systems in apartment or condominium buildings in the state. All use reciprocating engines fueled with natural gas, in systems ranging from 60 to 300 kW in size.

Market Potential for CHP in Massachusetts

This study evaluated the technical market potential for CHP in the industrial, commercial/institutional and multifamily residential sectors.

Ongoing development of micro-CHP technology is expanding CHP potential to smaller buildings and single-family homes. CHP also has some applications in the agricultural sector, particularly large dairy farms. Most farms in Massachusetts are relatively small and focus on less energy intensive crop production, so there is not believed to be significant agricultural CHP potential in the state.

Technical potential is limited only by technological feasibility of CHP based on average energy consumption characteristics for a facility type. Facility-specific factors such as interest in CHP, availability of natural gas, economics and ease of integrating CHP with existing systems are not considered. The analysis was based on current business and energy consumption data without consideration of future growth.

In the interest of optimizing the efficiency and economics of grid-connected CHP systems, this analysis bases system sizes primarily on the facility's average electrical demand.

Methodology and Data Sources

The methodology used for evaluating CHP potential in Massachusetts was similar to those used in previous studies from the U.S. Department of Energy (DOE), the New York State Energy Research and Development Authority (NYSERDA) and the California Energy Commission (CEC).[1] The analysis focused on building types previously identified, primarily in the NYSERDA report, to be best for CHP, based on basic criteria including significant year-round electric and thermal energy demand.

Energy consumption data was obtained from the DOE Energy Information Administration's *Manufacturing Energy Consumption Survey*, *Commercial Buildings Energy Consumption Survey* and *Residential Energy Consumption Survey*, with supplemental information from the NYSERDA and CEC reports and DOE's Industrial Assessment Center (IAC) at the University of Massachusetts Amherst. Using these sources, the average energy consumption per employee was calculated for each industrial and commercial/institutional facility type. Industrial facilities were grouped by North American Industry Classification System (NAICS) codes. For most facility types, the number and size of facilities in the state was obtained from the U.S. Census Bureau's 2002 *County Business Patterns*, which provides the number of establishments in each state, broken down by employee size ranges. This analysis resulted in the number of sites in each sector, broken down by CHP system size ranges.

Overall Potential

The original potential for CHP in target facility types in Massachusetts was calculated to be 4,967 MW at 18,665 sites. This is equal to approximately 40% of the electric industry's

[1] *The Market and Technical Potential for Combined Heat and Power in the Industrial Sector* and *The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector* were published by DOE in 2000. *Combined Heat and Power Market Potential for New York State* was published by NYSERDA in 2002. *Assessment of California CHP Market and Policy Options for Increased Penetration* was published by CEC and EPRI in 2005.

generating capacity in the state. Subtracting the existing CHP systems in target facility types gives 18,549 remaining sites with electrical potential of 4,751 MW, as detailed in Table 4.

The commercial/institutional sector has had the least market penetration to date, though as shown in Figure 3 the penetration has been limited in all sectors.

The average size of the potential systems is 256 kW each, with the largest average size in the industrial sector. As shown in Figures 4 and 5, the most potential is in the 50 to 500 kW size range, which has seen the least market penetration to date.

Table 4. CHP Potential in Massachusetts

Sector	# of Sites	Total Capacity (MW)	Average Size (kW)
Industrial	2,254	774	343
Commercial / Institutional	15,857	3,911	247
Residential	438	66	150
TOTAL	18,549	4,751	256

Figure 3. Penetration of Massachusetts CHP Market by Sector

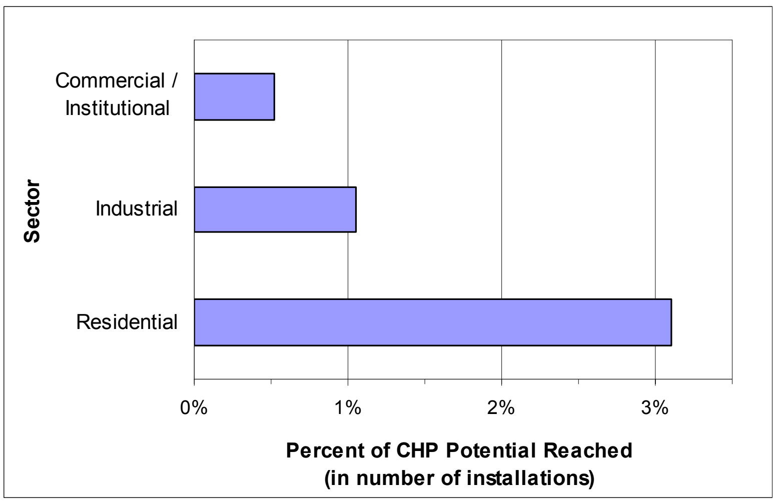


Figure 4. Size of Potential CHP Systems in Massachusetts

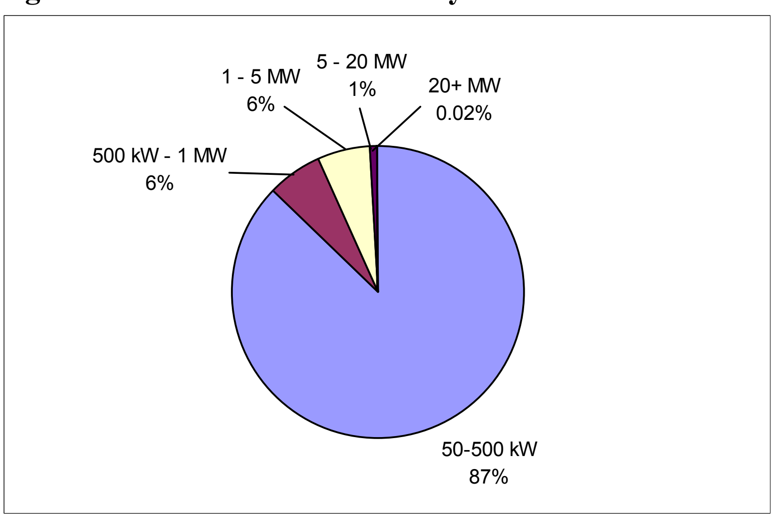
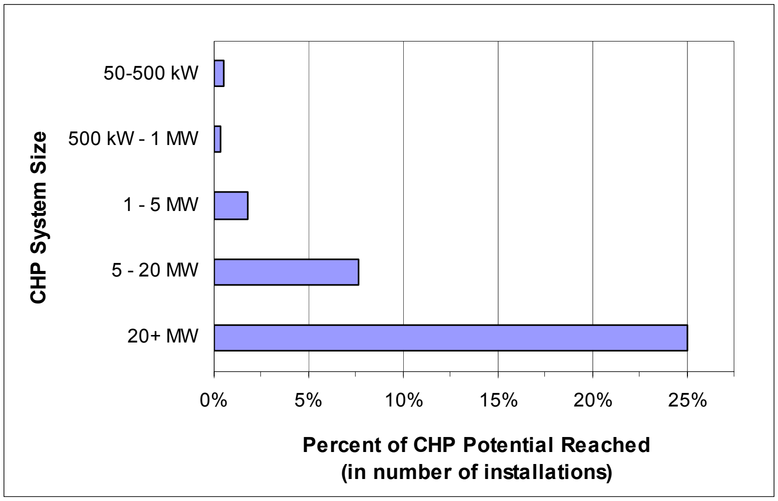


Figure 5. Penetration of Massachusetts CHP Market by System Size



Industrial Sector

This study analyzed 13 manufacturing industries that have been identified to be well suited to CHP. This analysis included only traditional CHP systems using thermal energy in the form of steam or hot water. Additional CHP capacity would be possible with the use of absorption chillers and desiccants for space cooling and dehumidification. The original potential for CHP was calculated to be 877 MW at 2,277 sites. Subtracting the existing CHP systems in these industries gives a remaining potential of 774 MW at 2,254 sites, detailed in Table 5.

Table 5. Industrial CHP Potential in Massachusetts

NAICS Code	Industry Description	# of Sites	Total Capacity (MW)	Average System Size (kW)
311	Food	327	120	368
313	Textiles	88	35	402
321	Wood products	38	5	123
322	Paper	155	141	908
325	Chemicals	131	50	385
326	Plastics & rubber products	99	13	131
331	Primary metals	76	23	302
332	Fabricated metal products	758	199	263
333	Machinery	118	36	305
334	Computer & electronic products	244	102	416
335	Electrical equipment, appliances & components	63	25	402
336	Transportation equipment	21	8	398
337	Furniture	136	16	120
TOTAL		2,254	774	343

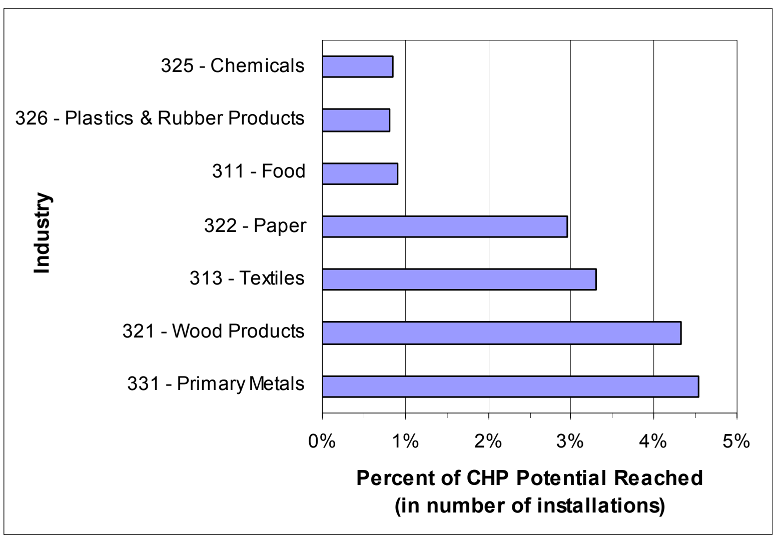
This analysis considers the total energy used for space and process heating in each industry, but the source data does not include specifics such as the form or temperature of heating required. In some applications, such as manufacturing processes that require high temperatures, actual CHP potential is limited because the output from CHP is not able to satisfy the specific thermal loads of the facility. With further analysis of thermal loads, especially at the NAICS sub-industry level, these results could be narrowed down to include only the sub-industries best suited to CHP.

The industries with the greatest potential number of systems are fabricated metal products (NAICS 332), food (NAICS 311) and computer and electronic products (NAICS 334). For the greatest combined potential CHP capacity, fabricated metals is followed by the paper (NAICS 322) and food industries. The fabricated metals industry and computer and electronics industry are among the largest in the state, making up 18% and 12% of Massachusetts industrial facilities, respectively. The food and paper industries in Massachusetts are relatively small, but have great potential because they are energy intensive industries with energy consumption profiles very well suited to CHP.

Figure 6 shows the current market penetration in terms of number of installations in the target industries that have existing CHP systems in Massachusetts. No industry is found to have significant market penetration to date.

At the national level, the industrial market penetration in terms of total installed electrical capacity is more than 40%, far higher than the 19% in Massachusetts (Hedman 2005).

Figure 6. Penetration of Massachusetts Industrial CHP Market



Commercial/Institutional Sector

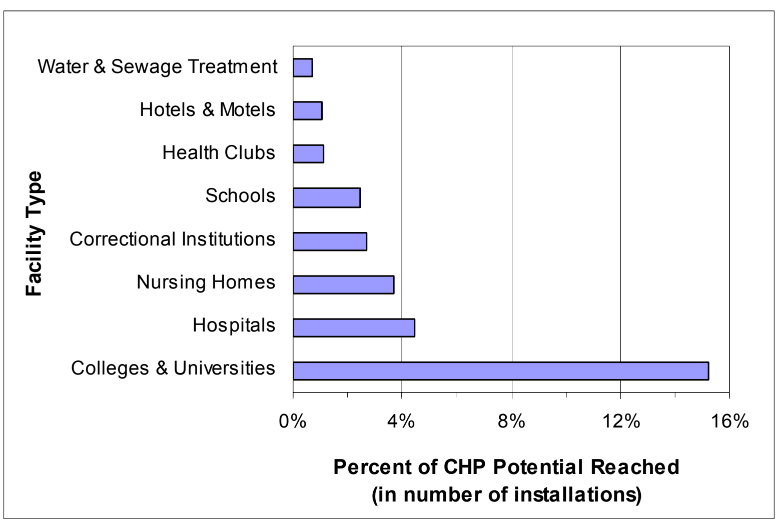
This study analyzed 18 types of commercial/institutional facilities. The original potential for CHP was calculated to be 4,022 MW at 15,937 sites. Subtracting the existing CHP systems in these facilities gave a remaining potential of 3,911 MW at 15,857 sites, detailed in Table 6.

Table 6. Commercial/Institutional CHP Potential in Massachusetts

Facility Type	# of Sites	Total Capacity (MW)	Average System Size (MW)	Primary Thermal Applications				
				Hot water	Space heating	Space cooling	Refrig-eration	Pools
Car washes	67	10	150	X				
Colleges & universities	100	458	4,483	X	X	X		X
Correctional institutions	36	29	807	X	X			
Golf & country clubs	147	34	230	X	X	X		X
Grocery stores	842	307	365	X	X	X	X	
Health clubs	364	82	226	X	X	X		X
Hospitals	128	347	2,707	X	X	X		
Hotels & motels	380	143	376	X	X	X		X
Laundries, commercial/industrial	211	39	184	X				
Movie theaters	59	9	150	X	X	X		
Museums	62	26	416	X	X	X		
Nursing homes & assisted living	881	195	221	X	X	X		
Office buildings	5,651	1,454	257	X	X	X		
Restaurants, excluding fast-food	2,696	220	81	X	X	X	X	
Retail stores	3,759	376	100	X	X	X		
Schools	316	54	170	X	X	X		X
Warehouses, refrigerated	11	2	150	X			X	
Water & sewage treatment plants	147	128	867	Process heating				
TOTAL	15,857	3,911	247	-				

Figure 7 shows the current market penetration in target facility types that have existing CHP systems in Massachusetts. At both the state and national levels, the greatest market commercial/institutional penetration is in colleges and universities (ONSITE SYCOM 2000).

Figure 7. Penetration of Massachusetts Commercial/Institutional CHP Market



Residential Sector

At the time of this study, CHP in the residential sector was most feasible for apartment and condominium buildings with 100 or more units. Thermal output from CHP can be used to provide space heating and cooling or domestic hot water. The original potential for CHP was calculated to be 68 MW in 451 multifamily buildings. Subtracting the existing CHP gave a remaining potential of 66 MW at 438 sites, with an average system size of 150 kW. Current market penetration is 3% in the residential sector.

Economic Feasibility of CHP

The technical potential is based on energy consumption profiles, without taking economic factors into account. Economic analysis is necessary to determine the true viability of each potential CHP system.

Energy costs vary by utility company, location and utility rate class. With several electric utilities and fuel companies across Massachusetts, there is significant variation in rates and therefore in the economics of CHP across the state. The higher the spark spread – the difference between the unit prices (in dollars per million Btu) of electricity and fuel – the more likely that CHP will be financially beneficial. Spark spread, however, does not include other important factors such as the cost of demand or other utility charges. Standby charges, which are imposed by some utilities on some self-generating customers for maintaining the ability to provide power when necessary, can significantly affect the feasibility of potential CHP installations.

Facility-specific considerations include existing equipment and ease of integration with CHP, number of operating hours, financing parameters and payback requirements. While many manufacturing facilities look for investments with a simple payback of two years, the ability to make longer-term investments is likely a reason for the relatively high market penetration of CHP in residential buildings and colleges and universities.

Obstacles to Use of CHP

Despite the benefits of CHP, there are often many obstacles to its use. These can include policy and utility issues such as outdated environmental regulations, the complication of obtaining necessary permitting and high standby rates charged by some electrical utilities. The electric utility company and state policies and regulations can have a significant impact on the likelihood that a CHP system will be installed at a particular site.

Furthermore, for a company in which energy is not part of the core business to take on electricity generation requires awareness, initiative, risk and investment. These efforts can pay for themselves and result in lower net energy costs in the long term, but they require the ability and willingness to take on a capital project with deferred benefits.

Conclusion

This study provides a better understanding of the status of CHP in Massachusetts and the potential for future installations, showing that the current market penetration in this state is well below the national level. Some other states have encouraged use of this efficient technology through measures including limitation of electric standby rates, implementation of output-based emissions standards for power generation that consider full system efficiency by recognizing the thermal output from CHP, inclusion of CHP in renewable portfolio standards and distribution of financial incentives toward CHP projects.

While there is technical potential for nearly 5,000 MW of CHP in Massachusetts industrial, commercial/institutional and residential facilities, the current installed capacity is only 375 MW. This technical potential is based only on general technological feasibility yet there are many factors in the viability of each CHP installation. Full market penetration is therefore not expected, but there is great potential for increased use of CHP, which could provide many benefits in this state with an aging electricity infrastructure and electricity costs 41% above the national average.

References

Beebe, Christopher. 2004. *Investigation into the Systemwide Economic Benefits of Combined Heat and Power Generation in the New England Energy Market*. Amherst, Mass.: University of Massachusetts Amherst, Masters Thesis.

Bourgeois, Thomas and Mackenzie Schoonmaker. 2006. *Current and Potential CHP Use in the NY/New England Agricultural Industry*. White Plains, N.Y.: Pace University Energy Project.

Census Bureau. 2004. *2002 County Business Patterns*. Washington, D.C.: U.S. Department of Commerce.

Census Bureau. 2005. *2003 Annual Survey of Manufactures*. Washington, D.C.: U.S. Department of Commerce.

Center for Energy Efficiency and Renewable Energy, University of Massachusetts Amherst. 1999. *White Paper on Combined Heat and Power Generation in Massachusetts*. Boston, Mass.: Massachusetts Division of Energy Resources.

Department of Agriculture. 2004. *2002 Census of Agriculture*. Washington, D.C.: U.S. Department of Agriculture, National Agricultural Statistics Service.

Department of Energy. 2005. *Annual Energy Outlook 2005*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2005. *Electric Power Annual 2004*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2006. *2003 Commercial Buildings Energy Consumption Survey*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2005. *2002 Manufacturing Energy Consumption Survey*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2005. *Natural Gas Annual 2004*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2004. *2001 Residential Energy Consumption Survey*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Department of Energy. 2004. *State Electricity Profiles 2002*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Environmental Protection Agency. 2004. Output-Based Regulations: A Handbook for Air Regulators. Washington, D.C.: U.S. Environmental Protection Agency.

EPRI & California Energy Commission. 2005. *Assessment of California CHP Market and Policy Options for Increased Penetration*. Sacramento, Calif.: California Energy Commission.

Hedman, Bruce. 2005. "The Potential for Combined Heat and Power." Presentation to Northeast Midwest Institute. Arlington, Va.: Energy and Environmental Analysis, Inc.

ISO New England. 2004. *2003 NEPOOL Marginal Emission Rate Analysis*. Holyoke, Mass: ISO New England.

ISO New England. 2003. *Annual Report 2002*. Holyoke, Mass: ISO New England.

Mattison, Lauren. 2006. *Potential for Combined Heat and Power in Massachusetts*. Amherst, Mass.: University of Massachusetts Amherst, Masters Thesis.

Onsite Energy Corporation & Pace Energy Project. 2002. *Combined Heat and Power Market Potential for New York State*. Albany, N.Y.: New York State Energy Research and Development Authority.

ONSITE SYCOM Energy Corporation. 2000. *The Market and Technical Potential for Combined Heat and Power in the Industrial Sector*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

ONSITE SYCOM Energy Corporation. 2000. *The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector*. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Resource Dynamics Corporation. 2002. *Integrated Energy Systems (IES) for Buildings: A Market Assessment*. Oak Ridge, Tenn.: U.S. Department of Energy, Oak Ridge National Laboratory.

Roth, Ian. 1999. *Life-Cycle Costing of Electric Power Generation Plants in New England: A Complete Fuel Cycle Approach Incorporating Externalities*. Amherst, Mass.: University of Massachusetts Amherst, Masters Thesis.