POTENTIAL FOR
COMBINED HEAT AND POWER
IN MASSACHUSETTS

A Thesis Presented

by

LAUREN R. MATTISON

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

May 2006

Mechanical and Industrial Engineering

© Copyright by Lauren R. Mattison 2006

All Rights Reserved

ABSTRACT

POTENTIAL FOR COMBINED HEAT AND POWER IN MASSACHUSETTS

MAY 2006

LAUREN R. MATTISON,

B.S., UNIVERSITY OF MASSACHUSETTS AMHERST

M.S.M.E., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Lawrence Ambs

This thesis investigates the potential market for combined heat and power (CHP) installations in Massachusetts. CHP, also referred to as cogeneration, is the joint generation of electricity and useful thermal energy. The total efficiency of CHP systems is generally between 60% and 80%, while the average efficiency of conventional power plants is approximately 30%. This highly efficient method of energy generation has potential to alleviate many of the concerns associated with energy use, including use of limited fuel resources, energy costs, electrical grid congestion and pollutant emissions. Its current usage is limited, however, due to obstacles including electric utility policies, environmental regulations and the initial investment required for CHP equipment.

There are currently more than 2,800 commercial/institutional, industrial and residential CHP systems in the United States with a total electrical capacity of 81,000 MW. It has been estimated that the remaining potential is approximately 150,000 MW.

In Massachusetts, there are 121 known CHP systems with total electrical capacity of 375 MW. The basic criteria that determine if a facility is a good candidate for CHP include its energy consumption profile and hours of operation. The remaining technical potential for CHP was determined, using these criteria and energy consumption data collected by the U.S. Department of Energy, to be more than 4,700 MW at 18,000 sites. This technical potential is

technological feasibility based on average energy consumption for a facility type and does not consider facility-specific factors such as economics, interest in CHP, or ease of integrating CHP with existing systems.

An economic analysis then evaluated the viability of several sample facilities with technical potential for CHP. This showed that significant savings is possible with CHP, but that the economics of each system is highly dependent on many variables including local electricity and fuel prices and other electric utility charges.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

Btu	British thermal unit
CBECS	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CHP	Combined heat and power
CMR	Code of Massachusetts Regulations
CO_2	Carbon dioxide
CO	Carbon monoxide
DEP	Massachusetts Department of Environmental Protection
DG	Distributed generation
DOE	United States Department of Energy
DOER	Massachusetts Division of Energy Resources
DTE	Massachusetts Department of Telecommunications and Energy
EIA	United States Department of Energy's Energy Information Administration
EPA	United States Environmental Protection Agency
E/T	Ratio of electric to thermal energy demand
ESCO	Energy service company
GIS	Geographic Information System
HHV	Higher heating value
HUD	United States Department of Housing and Urban Development
IEEE	Institute of Electrical and Electronics Engineers
IAC	Industrial Assessment Center
ISO	Independent System Operator
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pound
LMP	Locational marginal pricing
MECS	Manufacturing Energy Consumption Survey
MMBtu	Million British thermal units
MW	Megawatt
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NEPOOL	New England Power Pool
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NYSERDA	New York State Energy Research and Development Authority
O_3	Ozone
PBA	CBECS Principal Building Activity
PM	Particulate matter
RECS	Residential Energy Consumption Survey
SO_2	Sulfur dioxide
SIC	Standard Industrial Classification
T&D	Transmission and distribution
USDA	United States Department of Agriculture

CHAPTER 1
INTRODUCTION

This thesis investigates the technical market potential for combined heat and power (CHP) installations in Massachusetts. This highly efficient method of energy generation has great potential to reduce fuel consumption, energy costs, electrical grid congestion and pollutant emissions, but its usage is currently limited. By analyzing the facility types optimal for CHP installations and estimating the size of this potential market, this thesis lays the groundwork and serves as a reference for further analysis and development of CHP technology and policy.

1.1 Background

CHP is the joint generation of electricity and useful thermal energy. *Waste heat* is created as a byproduct of conventional electricity generation at power plants, while many of the electric utility's customers also operate a boiler or furnace to generate necessary thermal energy on-site. Alternatively, a CHP system can be installed at a facility for on-site energy needs, with an electrical generator producing electricity and the waste heat being used to meet the thermal load. Average efficiencies for CHP systems are about twice the average power plant efficiency of 30%.

Benefits of CHP compared to conventional generation include reduced fuel consumption, reduced emissions, reduced congestion of the electricity transmission and distribution (T&D) grid, increased power reliability, and lower overall cost of energy. These benefits are particularly valuable in Massachusetts, where air quality and grid congestion are important issues and electricity rates are among the highest in the country.

There are many obstacles to using CHP, however. This is largely because current energy policy has been geared toward large, centralized power plants, and the distributed generation (DG) of electricity is a change from that model. Some regulatory agencies and electric utilities impose requirements and charges that make self-generation with CHP difficult and costly for customers. Additionally, taking on the responsibility and investment for electricity generation is a concern for many facility owners who are not in the electricity business.

More than 2,800 sites across the United States currently have CHP systems with a total electrical generating capacity of 81,000 MW. Much of this capacity is in large systems installed in industrial facilities. The technical potential for new CHP installations is believed to be 70,000-90,000 MW in the industrial sector and 60,000-80,000 MW in the commercial and institutional sector.[1]

1.2 Objectives

This thesis explains the benefits of CHP and obstacles to its use, studies the current status of CHP policy and usage in Massachusetts, determines the potential market for additional CHP installations in the state, and considers the economic viability of potential CHP projects.

This provides information that can serve as a reference for many groups with an interest in energy generation and CHP. Policy makers can use this study to better understand this method of energy generation and its potential impact, and to evaluate potential benefits to the state such as reduced emissions and economic stimulus. Information on the size of the market can be used to evaluate the costs and benefits of potential changes to regulations, charges, or laws relating to CHP. Technical development can be directed toward the applications showing the greatest potential. Advocates for CHP can use information on the market to focus their attention on areas with the greatest potential to maximize the effect of their education and outreach.

---

[1] Bruce Hedman, The Potential for Combined Heat and Power, pages 10-15.

CHAPTER 2
COMBINED HEAT AND POWER

2.1 Description

In conventional electricity generation, electricity is generated at large, centralized power plants and distributed to consumers through the transmission grid. 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.[2] Factoring in the losses in the T&D process, the total power plant efficiency is approximately 30%. In addition to the electricity generally obtained from the utility grid, many buildings have equipment on-site that generates thermal energy to meet a demand such as space conditioning, water heating, or heating or cooling for manufacturing processes.

Combined heat and power, also referred to as cogeneration, is the joint generation and use of electricity and thermal energy. Rather than disposing of the heat produced in electricity generation, it is used to satisfy a thermal load by providing necessary thermal energy. To make use of this heat, electrical generation must occur close to a thermal load, so CHP is generally used in distributed generation, in which smaller power sources provide electricity closer to the point of use, rather than centralized power plants.

Figure 2.1 demonstrates the increased efficiency of CHP over the conventional separate generation of electricity and thermal energy. In this example, the engine-driven CHP system has a total efficiency of 69%, while conventional generation from a power plant and on-site boiler has a total efficiency of 45%, so the conventional system uses 55% more fuel to generate the same quantity of electricity and heat.

---

[2] ISO New England, <u>2003 NEPOOL Marginal Emission Rate Analysis</u>, page 19.

Figure 2.1: Efficiency Comparison for Conventional Generation and CHP

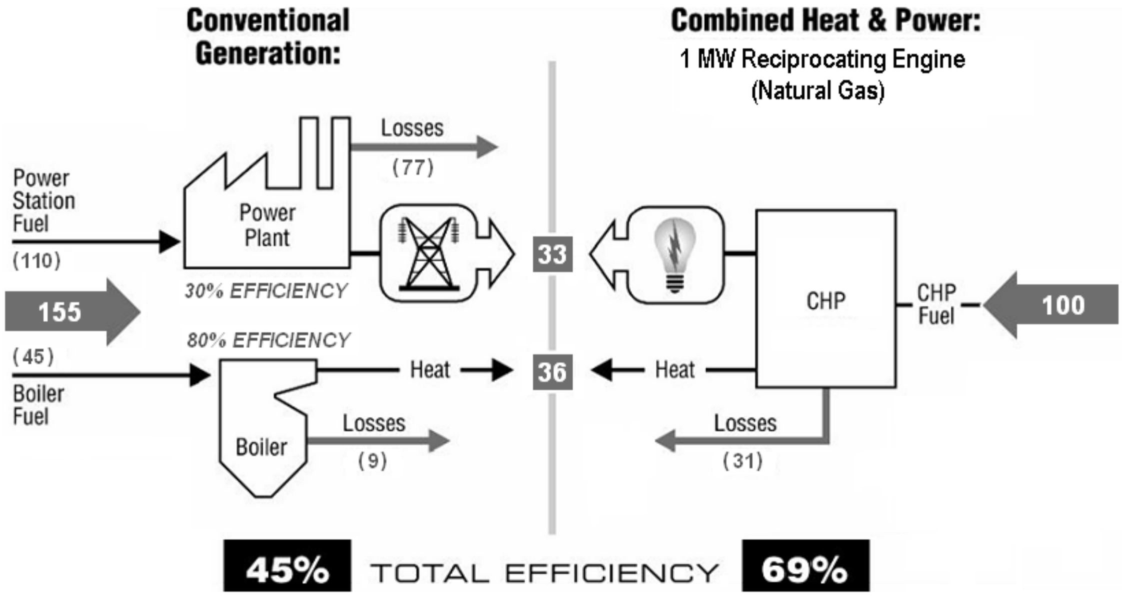


Table 2.1 shows a comparison of the emissions from these two systems, and Table 2.2 compares emissions for a turbine-driven CHP system. Both show that significant emissions reductions can be obtained with CHP, due largely to the increase in efficiency.

Table 2.1: Emissions Comparison for Conventional Generation and Engine-Driven CHP

		Conventional Generation: Electric Power Plant & Boiler (natural gas)	CHP: 1 MW Engine (natural gas)	
Total Efficiency		45%	69%	
Annual Electricity Output		4,800 MWh		
Annual Thermal Output		17,872 MMBtu		
Annual Emissions (tons)	NO_x	6.3	0.7	
	CO_2	4,418	2,730	
	SO_2	13	0.01	
Annual CHP Emissions Reduction	NO_x	-	5.6 tons*	88%
	CO_2		1,688 tons	38%
	SO_2		13 tons	100%

* This new CHP system is assumed to have additional NO_x emissions controls. Without aftertreatment, annual NO_x emissions would increase by 1.1 tons or 17%.

Table 2.2: Emissions Comparison for Conventional Generation and Turbine-Driven CHP

		Conventional Generation: Electric Power Plant & Boiler (natural gas)	CHP: 1 MW Turbine (natural gas)	
Total Efficiency		51%	65%	
Annual Electricity Output		4,800 MWh		
Annual Thermal Output		32,020 MMBtu		
Annual Emissions (tons)	NO_x	7.6	5.3	
	CO_2	5,459	4,096	
	SO_2	13	0.1	
Annual CHP Emissions Reduction	NO_x	-	2.3 tons	30%
	CO_2		1,363 tons	25%
	SO_2		13 tons	99%

2.2 Criteria for CHP Installations

Because of the variety of equipment and other parameters that can be used for CHP, a system can be sized and designed to best fit the needs of a particular facility. There are, however, several basic criteria that can be used to determine if a facility is a good candidate for CHP. First the facility must require both electric and thermal energy throughout the year. It is recommended that the electrical to thermal demand ratio be at least 0.5 for CHP to be economically feasible. If excess electricity is produced in a CHP system it can sometimes be sold to the utility grid for use by other customers, but it is generally most economical to primarily use the electricity on-site. CHP is most cost effective in locations with high electricity rates and relatively low fuel costs. The more operating hours a facility has, the faster the electricity savings can pay back the investment required for CHP. A minimum of 3,000 annual operating hours is generally recommended.

2.3 Technology

CHP facilities may use a variety of generation technologies and fuels, depending on many factors including size of electrical and thermal loads, types of fuel available, allowable emissions, local regulations and finances.

2.3.1 Fuels

Most CHP technologies can operate with a variety of fuels, but natural gas is most commonly used. As in conventional electricity generation, natural gas has the advantage of producing lower emissions, and economics and availability also generally support use of natural gas. The descriptions below of CHP equipment will provide more information on the types of fuels that can be used with different CHP systems.

2.3.2 Thermal Applications

CHP provides thermal energy in the form of steam, hot water, hot gas, or chilled water. In many systems, heat is recovered from the exhaust gas from a turbine or engine, and in others the steam or hot water is a direct byproduct of the electricity generation process. The following section on prime movers provides more information on the thermal output for each type of CHP equipment.

The thermal energy can be used for a variety of applications. The most common applications are space heating, water heating, and steam or hot water for use in manufacturing processes, which can be provided through conventional systems using the steam or hot water generated in CHP. Newer technology has increased the thermal applications for CHP to include cooling and dehumidification. While most chillers are driven by mechanical energy, absorption chillers use thermal energy in the form of steam, hot water, or exhaust gas to provide space or process cooling. Desiccant dehumidifiers can use thermal output from electricity generation to remove moisture from the air.

2.3.3 Prime Movers

The *prime mover* in a CHP system is the power generation device. Following are descriptions of the available prime mover technologies.

2.3.3.1 Reciprocating Internal Combustion Engines

Reciprocating internal combustion engines are the most common prime movers for CHP, primarily used in systems of 1 MW or less. These engines have a long history of use in numerous applications including electricity generation. Sizes range from small portable generators with 5 kW capacity to large 10 MW engines. Recovery of heat, mainly from engine exhaust and jacket water coolant, can create useful thermal output in the form of hot water or low-pressure steam. These engines can be operated with a variety of fuels including diesel, gasoline, natural gas and dual-fuel configurations. Advantages include short start-up time, proven reliability, flexibility in fuel choice, and the ability to follow loads well. Disadvantages include relatively high noise and emissions. The standard electrical efficiency, based on higher heating value (HHV), for a reciprocating engine is typically 30-37%, and total CHP efficiency is in the range of 69-78%.[3]

2.3.3.2 Gas Turbines

Gas turbines, or combustion turbines, were developed nearly 75 years ago and today are commonly used in CHP systems with capacity of 1 MW to 10 MW. Industrial gas turbines range in size from 500 kW to 50 MW. Fuel is burned with air to create high-temperature and high-pressure gas that drives the turbine to generate electricity. The high quality exhaust created by gas turbines can be used for additional electricity generation in a combined cycle system, as well as to provide high-pressure steam or hot water. Gas turbines can be operated

---

[3] Brendan O'Connor, Combined Heat and Power Feasibility Study Characterization Utilizing Applicable Software Programs, page 7.

with natural gas, fuel oil, propane, landfill gas and dual-fuel configurations. Advantages of gas turbines include low emissions and low maintenance cost. The HHV electrical efficiency for a simple gas turbine is 22-37%, and the CHP efficiency is 65-72%. For a combined-cycle turbine the electrical efficiency is more than 40%. [4]

2.3.3.3 Microturbines

Microturbines, small gas turbines ranging from 25 kW to 500 kW in size, have become commercially available in the past few years. In CHP systems, the thermal output is hot water or low-pressure steam. Natural gas is the primary fuel used for microturbines. Key advantages are low emissions, a compact and lightweight design with few moving parts, relatively simple installation and maintenance requirements, and less noisy operation. At 23-26%, the HHV electrical efficiency of microturbines is lower than reciprocating engines of comparable size, but with CHP the efficiency reaches 61-67%.[5]

2.3.3.4 Steam Turbines with Boilers

Steam turbines use steam as input, rather than generating electricity directly from fuel, and therefore require a boiler or other source of steam. Electrical capacities for this mature technology range from 20 kW up. Large volumes of steam can be extracted from the turbine to provide thermal output, which also reduces electrical output. The boiler can operate with a wide variety of fuels, including natural gas, fuel oil, coal and wood. Steam turbines have relatively low installed cost and long equipment life, but operation is noisy and requires a long

---

[4] Combined Heat and Power Feasibility Study Characterization Utilizing Applicable Software Programs, page 7.

[5] Combined Heat and Power Feasibility Study Characterization Utilizing Applicable Software Programs, page 7.

start-up time (from one hour up to one day). The HHV electrical efficiency is approximately 5-15%, and CHP significantly increases the efficiency to approximately 80%.[6]

2.3.3.5 Fuel Cells

Fuel cells, while not yet widely available, have potential for use in CHP. In a fuel cell, hydrogen or natural gas fuel is used to generate electricity along with hot water, through an electrochemical reaction rather than combustion. Very low emissions and noise are advantages of fuel cells, and current disadvantages include limited availability and high cost.

---

[6] Combined Heat and Power Feasibility Study Characterization Utilizing Applicable Software Programs, page 7.

CHAPTER 3
BENEFITS & OBSTACLES TO CHP

3.1 Benefits

CHP can benefit both the user and society by providing gains in areas from the environment to the economy to energy security. The national impact of CHP in 1999 included more than $5 billion in energy cost savings, a reduction of nearly 1.3 trillion Btu of energy consumption and a 35 million ton reduction in carbon dioxide equivalent greenhouse gas emissions.[7]

3.1.1 Efficiency

Fossil fuels, such as coal, oil and natural gas, commonly used to generate electricity and thermal energy are limited resources. More efficient use of these fuels for energy generation is important to sustaining our fuel supply.

In the Annual Energy Outlook 2005, the United States Department of Energy's (DOE) Energy Information Administration (EIA) projects that national electricity consumption will increase from 3,657 billion kWh in 2003 to 5,467 billion kWh in 2025, or an average annual rate of 1.8%. Over the same period, use of natural gas for electricity generation is projected to increase significantly, contributing to an average annual increase of 1.5% in total demand for natural gas. In about ten years, the rate of increase will slow when increases in the price of natural gas are expected to contribute to the construction of more coal-fired power plants.[8] Because increases in domestic fuel supply are not expected to keep up with total national energy consumption, imported fuel will be increasingly important in meeting demand, with

[7] Center for Energy Efficiency and Renewable Energy, White Paper on Combined Heat and Power Generation in Massachusetts, page 5.
[8] U.S. Department of Energy, Annual Energy Outlook 2005, page 4.

imports projected to be 38% of national consumption in 2025 compared to 27% in 2003.[9] Efficient generation methods such as CHP could be valuable in meeting this increasing demand for energy.

In addition to the significant increase in generation efficiency, CHP has an efficiency advantage in transmission. Energy is lost in the standard transmission and distribution of electricity, due to resistance in the utility grid lines through which electricity must travel from the power plant to the end user. These line losses are estimated to range from 5% to 20% of electricity generated, with the average at approximately 7%. Because this is not an issue for systems located at the point of use, distributed CHP provides a further improvement in efficiency over traditional power plants.

3.1.2 Environment & Health

Generation of energy by burning fossil fuels causes damage to the environment and human health. Greenhouse gas emissions cause climate change, and the specific impact of climate change in Massachusetts is expected to include greater weather extremes, droughts, losing beachfront land, detriment to important industries such as agriculture and fishing and tourism, and declining outdoor air quality.

Power plants emit numerous other pollutants in addition to greenhouse gases. High ozone (O_3) levels are associated with environmental and health problems. Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) contribute to smog and acid rain, and they are linked to respiratory damage and lung disease such as asthma. Mercury emissions from coal-fired power plants contaminate waterways then enter humans through consumption of fish, and exposure to mercury can cause numerous health problems including neurological damage to fetuses and

---

[9] Annual Energy Outlook 2005, page 7.

children. Emissions of small particulate matter, which enter the human respiratory system and bloodstream, are linked to respiratory and cardiovascular problems as well as premature death.

There are also environmental and political issues with obtaining and distributing fossil fuels. Both mining for coal and drilling for oil or natural gas have a significant impact on the environment. Accidents in transporting oil, such as the large oil spill in Buzzards Bay off Cape Cod in April 2003, affect the surrounding environment, wildlife and human health. More efficient use of fuel can curtail the environmental and societal costs associated with its extraction and consumption.

3.1.3 Distributed Generation

As a form of distributed generation, CHP offers benefits in energy reliability and security. With distributed generation, the issues associated with T&D are avoided. Generation at smaller, dispersed facilities is also beneficial because it is less susceptible than centralized power plants to disruption from failure or attack.

According to ISO New England, the independent system operator which oversees the operation of New England's electric generation and transmission system, "One of the greatest challenges the electricity industry faces is delivering its product to where it is needed most." [10]

The electric utility industry is split into two major components: supply and delivery. Delivery further breaks down into transmission of electricity from the generator over high voltage lines and distribution from the transmission system to the customer. 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.

Meeting increasing electric demand with centralized power plants also requires increases to electrical transmission capacity. Meeting this capacity can be complicated by

---

[10] ISO New England, 2002 Annual Report, page 8.

difficulty in siting transmission lines. Overhead lines sometimes face opposition due to their visual impact, but construction of transmission lines underground comes at increased cost and disruption.

In a recent issue of Power Magazine, Tom Casten, chairman and CEO of Private Energy Holdings LLC, was quoted as saying that 9,500 miles of high-voltage transmission lines were constructed in the United States in the 1990s, but this 7% increase was far short of actual demand. According to Casten, "'most recent U.S. power problems were caused by lack of adequate T&D, but nobody close to the industry believes enough new transmission can be built.'"[11]

Because electricity generated through distributed generation is not subject to T&D, increased use of CHP would relieve pressure on the transmission system. This would provide greater reliability and flexibility and would eliminate or reduce the necessity for more transmission infrastructure.

3.1.4 Economics

CHP can provide numerous economic benefits for customers and society. 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, so CHP could be an important component of a plan to increase our power supply.

Meeting future demand with CHP could provide significant cost savings by avoiding the need for investment in T&D. Tom Casten estimated that meeting increased electrical

---

[11] Power Magazine, November/December 2004.

demand in this decade would require approximately 45% less in capital investments with CHP and distributed generation than with new power plants and T&D infrastructure, therefore significantly reducing the cost of new electricity.[12]

CHP can be particularly beneficial for facilities located in a congested area where a premium must be paid to the electric utility for T&D. 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 distributed generation and CHP by customers in congested areas. According to ISO, LMP "helps relieve congestion by promoting efficient investment decisions. Because LMP creates price signals that reflect the locational value of electricity, participants can readily determine areas of congestion and will see the value of investing in generation, transmission and demand response programs."[13]

The cost of energy contributes to high operating costs which are an obstacle to American industry, particularly in Massachusetts where costs are among the highest in the country. See Chapter 4 for more information on energy costs. With its potential to reduce the cost of electricity and thermal energy generation, CHP can lower the cost of living and doing business. Promotion of CHP in energy intensive manufacturing facilities could provide economic stimulus by helping to keep industry and jobs in Massachusetts.

3.2 Obstacles

Despite the benefits of CHP, there are many obstacles to its use. These include difficulty of obtaining necessary permitting, high standby rates and charges from electrical utilities, outdated or inequitable environmental regulations, and financial hurdles. Advocates

---

[12] Power Magazine.
[13] ISO New England, www.iso-ne.com/nwsiss/grid_mkts/how_mkts_wrk/faq/.

of CHP, including organizations such as the United States Combined Heat and Power Association and the Northeast Combined Heat and Power Initiative, CHP manufacturers and energy efficiency supporters, are working to promote policy changes to remove these barriers and to create incentives encouraging expansion of CHP. By determining areas with technical potential for CHP, this thesis aims to support those efforts by directing them to the areas of most relevance. More detail on the specific issues of importance in Massachusetts is provided in Chapter 4.

3.2.1 Utility Relationships

There are a variety of arrangements a CHP system owner may make with their electric utility. Most facilities using CHP continue to purchase some electricity from the grid to supplement electricity generated on-site in meeting the facility's full electrical demand. Some facilities are able to meet all of their regular demand through self-generation, but most of these still maintain connection to the utility for a backup power supply when the CHP equipment goes down or requires maintenance. Some interconnected CHP systems generate more electricity than needed on-site and sell excess electricity to the utility. The policy around these relationships varies by location and utility and can act as a major obstacle to new CHP installations.

3.2.1.1 Interconnection

To ensure safety and reliability of self-generators, electric utilities need to grant approval for new generation systems, such as CHP and renewable energy, before they can be interconnected with the grid. Earning this approval can be complicated, time-consuming, and costly, especially because of inconsistent standards for interconnection between different utilities and state and local governments. Some standards require the same type of studies for installation of a small CHP system as for construction of a new power plant. While compliance with interconnection standards is important, the approval process should not be so difficult as to obstruct new projects. The Institute for Electrical and Electronics Engineers (IEEE) is currently working with DOE to develop a comprehensive series of national interconnection standards. The first in the series, IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems, was released in 2003. Development of an interconnection standard is also underway in Massachusetts. In February 2004, the Massachusetts Department of Telecommunications and Energy (DTE) issued Order 02-38-B with a Model Interconnection Standard Tariff. The Order directed the Distributed Generation Collaborative previously established by DTE to continue to meet for two years to further assess and refine the model standard. In 2006 the Collaborative will report its findings to DTE and a final interconnection standard will be issued for distributed generation systems in Massachusetts. Updated standards should streamline the approval process, facilitate mass production of CHP equipment, allow faster approval for small systems, and support expansion of distributed generation while addressing safety and reliability.

3.2.1.2 Standby Rates & Exit Fees

When a facility generates its own electricity, there is still a cost for the utility to maintain the ability to provide power when necessary, so some utilities bill a standby charge to self-generators to cover this cost. Self-generating customers that leave the grid may be charged an exit fee to cover future revenue that will be lost by the utility. Standby rates and exit fees currently vary by utility and state. The inconsistency in how these fees are determined is an obstacle, and in some cases the charges are prohibitively high for those considering CHP installations. High standby rates are an issue in Massachusetts. Standardization and negotiation of reasonable fees would support increased use of CHP while preventing an unfair burden on the utilities and electric consumers. More information on standby rates in Massachusetts is provided in Chapters 6 and 7.

3.2.2 Emissions Regulations

CHP facilities must meet environmental standards set by the United States Environmental Protection Agency (EPA) and the state level environmental agencies. Despite the significant environmental advantage usually offered by CHP, including the reduction of pollutant emissions, new installations often face difficulty obtaining air emissions permitting.

Emissions standards often do not evaluate the total emissions associated with energy use at a facility. Standards generally consider on-site emissions but do not include emissions produced in off-site generation of energy for a facility. Overall emissions are reduced through the most efficient energy generation methods, but use of distributed generation and CHP, even in highly efficient systems, does increase on-site emissions. Taking total emissions, including those from centralized power plants, into account can provide a different perspective on emissions levels and would more equitably evaluate CHP in comparison to traditional energy generation.

3.2.2.1 Output-Based Standards

Regulations for power generation have traditionally used *input-based* standards; for example a system would be evaluated on pounds of pollutant emissions per unit of fuel input, or lb/MMBtu. This method does not account for the amount of energy generated, so an efficient system would appear equivalent to an inefficient system that uses the same amount of fuel input but outputs less useful energy.

Output-based standards consider emissions in terms of energy output rather than fuel input, for example pounds of pollutant emission per unit of energy generated, lb/MWh electricity or lb/MMBtu steam. This method awards efficiency and pollution prevention, and there has been a recent effort by many agencies to modify their regulations to use output-based standards. An output-based standard will benefit CHP systems with high electrical efficiency, but does not necessarily fully account for the high efficiency of CHP. Some output-based standards evaluate any system that generates electricity solely on the electrical energy output, ignoring the thermal energy that is also generated with CHP. Emission standards like this do not recognize the increase in efficiency and reduction in overall emissions that CHP systems provide over electricity generators with comparable electric efficiency. As explained further in Chapter 6, some states allow credit for thermal output, but Massachusetts currently does not.

3.2.2.2 RAP Model Rule

Many environmental policies are set at the state level, allowing for considerable variation across the country. To assist states in establishing regulations and encourage consistency, DOE funded the development of a national model for regulation of emissions from distributed generation. This effort was led by the Regulatory Assistance Project, based in Montpelier, Vermont and Gardiner, Maine. Published in October 2002, the Model Regulations For the Output Of Specified Air Emissions From Smaller Scale Electric Generation Resources is commonly referred to as the RAP Model Rule. It was developed by consensus amongst a working group of state environmental regulators, state energy officials, state utility regulators, DOE and EPA representatives, environmental advocates and energy industry representatives. The model can be adopted in its entirety or adapted by states.

The RAP Model Rule establishes standards for pollutant emissions and can help to standardize the permitting process for new distributed generation. It establishes emission levels for five air pollutants: carbon monoxide, carbon dioxide, nitrogen oxides, particulate matter and sulfur dioxide. Measurements are based on an output-based approach. CHP systems can receive credit for thermal output if they meet criteria such as a design system efficiency of at least 55%. Thermal credit is based on the emissions that would have resulted from a conventional system used to generate thermal energy separately, then subtracted from the actual emissions of the CHP system.

3.2.3 Ownership & Investment

For most potential CHP customers, energy generation is not part of their core business. Taking on the self-generation of electricity requires initiative, investment, and training.

In the centralized model of electricity generation, each customer pays the utility on a periodic basis for the energy used during that cycle. Distributed generation moves the burden of ownership to the consumer. This is often a worthwhile investment which pays for itself and results in lower net energy cost in the longer term, but it requires the ability and willingness to take on a capital project with deferred benefits. Many potential CHP installations have a simple payback period of several years; even if this would result in lower energy costs over the system life, many businesses will not take on this type of investment, particularly in an area, such as energy generation, that is not core to their business.

Some energy service companies (ESCOs) provide an option for customers to use CHP without needing to make this investment. The ESCO makes the investment itself by building and operating the CHP facility, and the customer enters into a long-term energy purchase agreement then buys the energy from the ESCO as they use it.

The issues of ownership and investment are key to the use of all forms of distributed generation. Society could see more benefits from the many advantages of CHP and distributed generation if these barriers could be lowered. Modification of tax and economic policy could support new installations by providing incentives or reducing the investment required for ownership of CHP systems. Streamlining of permitting requirements and regulations affecting CHP would reduce the administrative burdens associated with ownership and facilitate the installation of new systems.

CHAPTER 4
ENERGY IN MASSACHUSETTS

4.1 The Electricity Market

Massachusetts is part of the New England electricity market, made up of the six New England states. ISO New England is responsible for the day-to-day operation of New England's generation and transmission system, as well as oversight of the region's wholesale electricity markets and power system planning. Most of New England's electric utilities are associated through the New England Power Pool (NEPOOL), which works with ISO to develop market rules and procedures. Interconnection between the New England electrical grid and the systems in New York and Canada allow the import and export of electricity between the regions.

4.2 Utility Companies

There are three major investor-owned electric utility companies in Massachusetts: NSTAR, National Grid (formerly Massachusetts Electric) and Western Massachusetts Electric (WMECO, a subsidiary of Northeast Utilities). Figure 4.1 shows the service territory for each utility. The electric utility company serving a potential CHP location can have a significant affect on the likelihood that CHP will be installed, as the utilities control electricity rates and must approve connection of new CHP systems to the electrical grid.

As discussed in Chapter 2, natural gas is the fuel most commonly used for CHP. Figure 4.2 shows the four major companies that provide natural gas in Massachusetts: Bay State Gas, Berkshire Gas, Keyspan and NSTAR. Most consumers in the state have access to natural gas, but there is not yet natural gas service in many smaller towns in central and western Massachusetts and on Cape Cod and the islands.

Figure 4.1: Massachusetts Electric Utility Service Areas

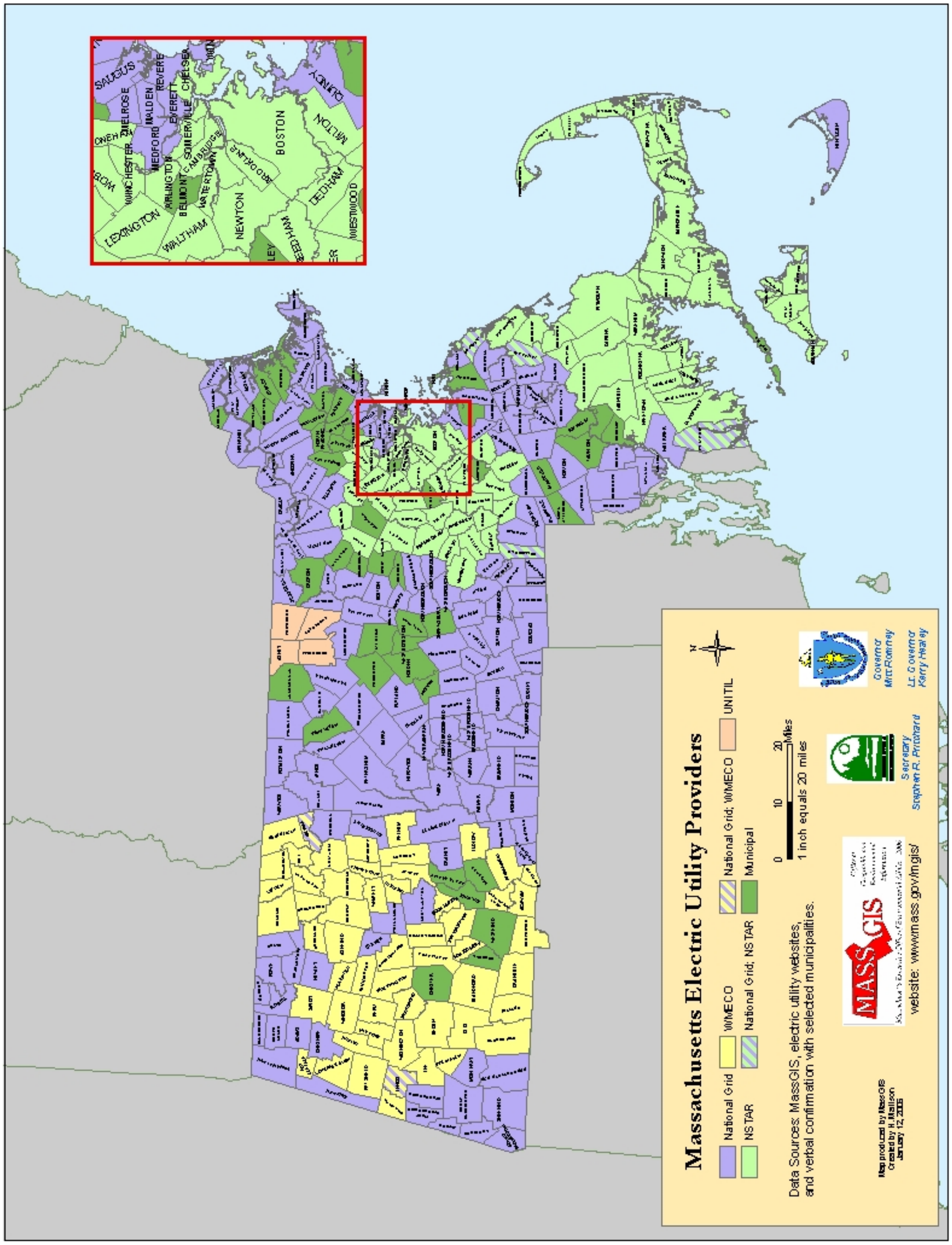
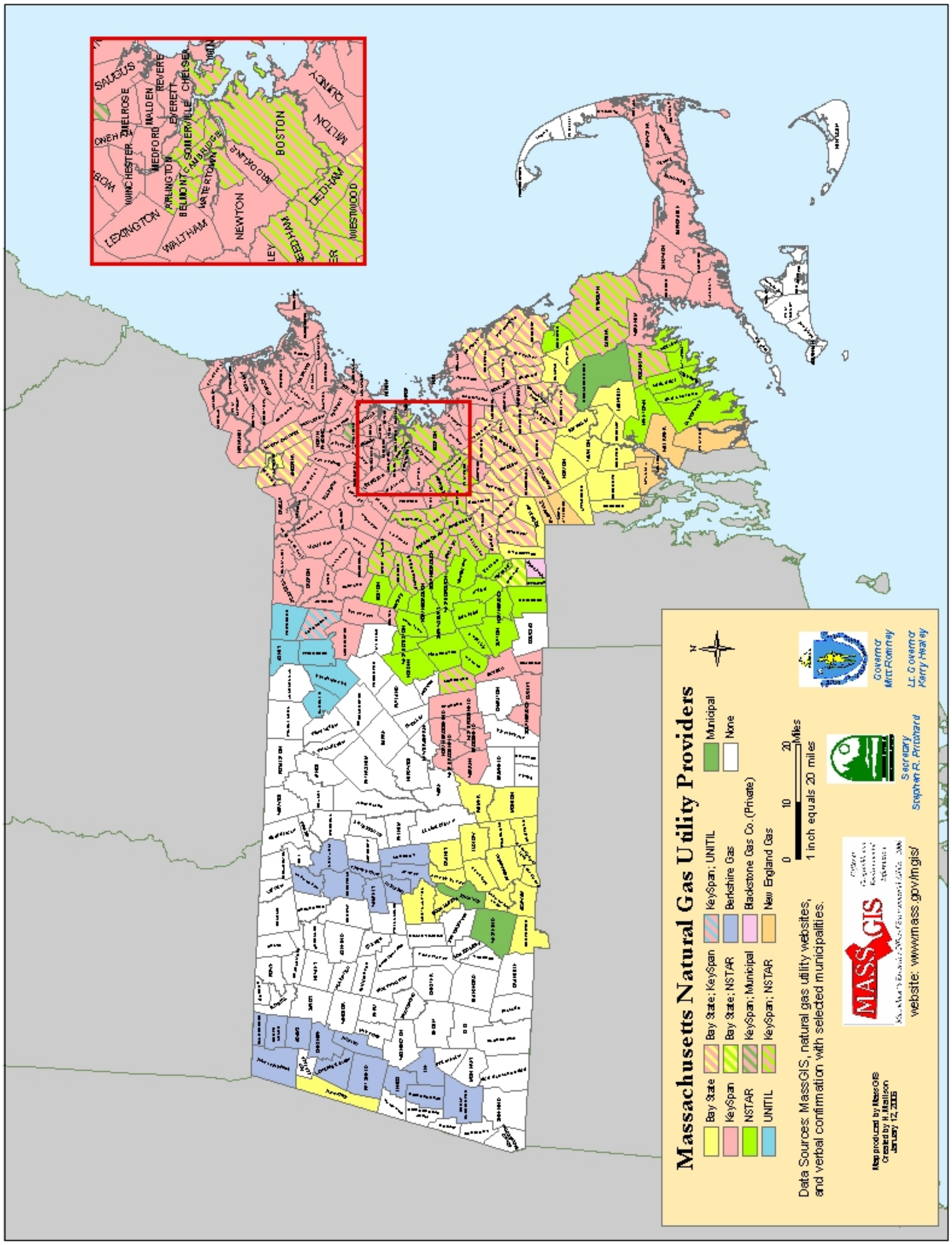


Figure 4.2: Massachusetts Natural Gas Utility Service Areas

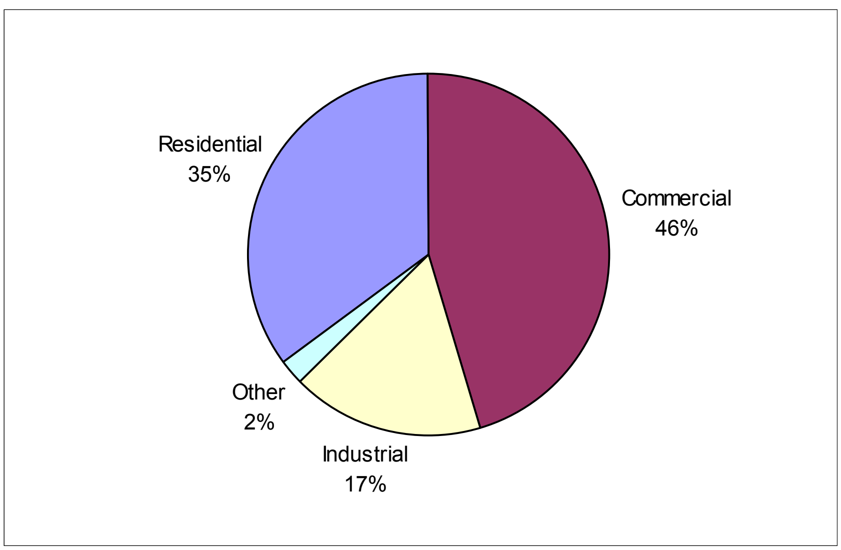


4.3 Current Electrical Capacity & Consumption

The New England electric industry 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.[14]

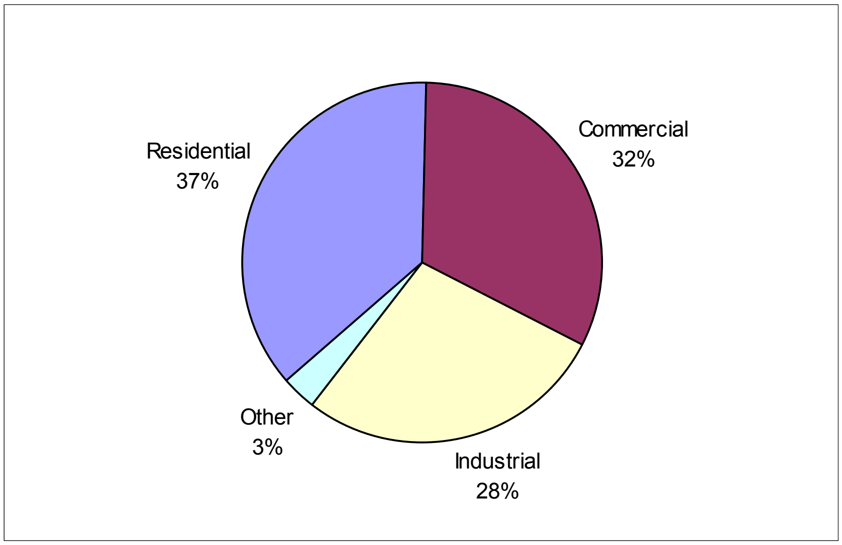
The breakdown of electricity usage by sector in Massachusetts is shown in Figure 4.3. The largest user of electricity is the commercial sector, which accounts for 46% of electricity consumption in the state.[15] At the national level, however, electricity consumption is split more evenly between the commercial, industrial, and residential sectors, as shown in Figure 4.4.[16] Industry is a relatively low consumer of electricity in Massachusetts compared to the country as a whole. One explanation for this difference is that Massachusetts has less energy-intensive manufacturing industries than many other states.

Figure 4.3: Massachusetts Retail Electricity Sales by Sector, 2002



[14] U.S. Department of Energy, State Electricity Profiles 2002, pages 29, 87, 96, 132, 177, 205.
[15] State Electricity Profiles 2002, page 98.
[16] State Electricity Profiles 2002, page 235.

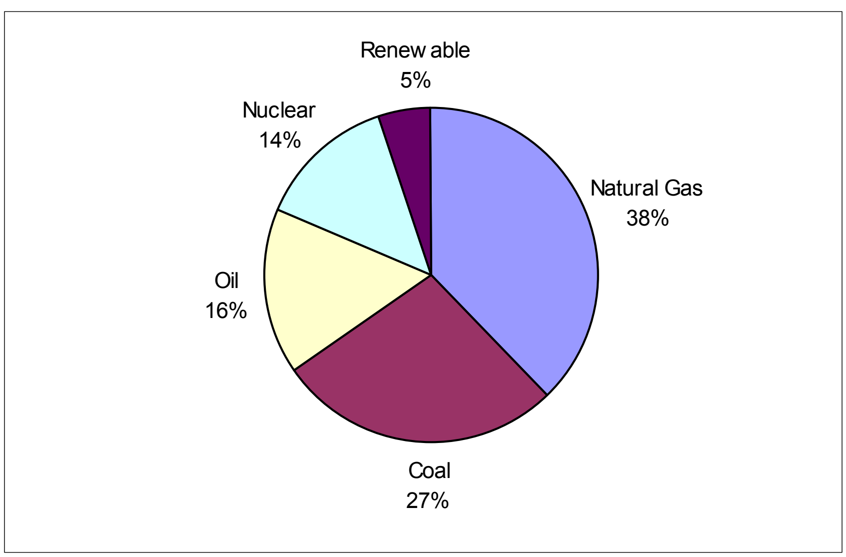
Figure 4.4: National Retail Electricity Sales by Sector, 2002



4.4 Fuel Usage

Use of natural gas for electricity generation is rapidly increasing in New England. As shown in Figure 4.5, it was used in 2002 for 38% of the generation by the electric power industry in Massachusetts, followed by coal, oil and nuclear.[17]

Figure 4.5: Massachusetts Electric Industry Generation by Fuel Type, 2002



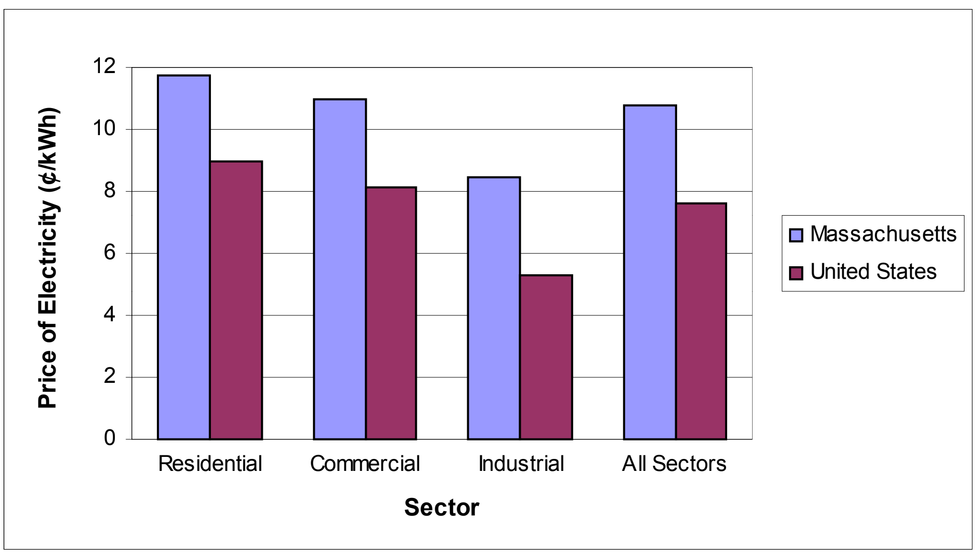
[17] State Electricity Profiles 2002, page 97.

Thermal energy is generated in Massachusetts with a variety of fuels including natural gas, coal, oil and wood, as well as using electricity.

4.5 Energy Costs

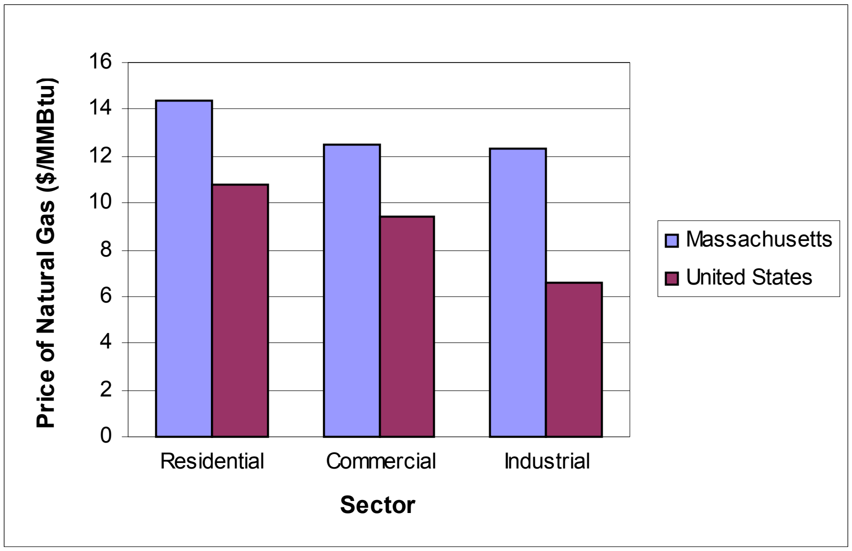
Data compiled by EIA shows Massachusetts to be consistently among the ten states with highest electricity and natural gas rates, as shown in Figures 4.6 and 4.7. At the regional level, energy rates in the northeast are also among the most expensive in the United States. In 2004, the national average retail price of electricity was 7.6 cents/kWh, while the price in Massachusetts was 41% higher at 10.8 cents/kWh.[18] 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.[19] Factors in these differences may include the lack of local fuel resources and the cost of adhering to stricter environmental regulations.

Figure 4.6: Average Electricity Prices, 2004



[18] U.S. Department of Energy, Electric Power Annual 2004, pages 45-48.
[19] U.S. Department of Energy, Natural Gas Annual 2004, pages 1, 47, 96.

Figure 4.7: Average Natural Gas Prices, 2004



4.6 Emissions

Emissions from energy generation in Massachusetts have an impact on the environment and human health. Increased atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gas emissions are causing climate change. This means increasing average temperatures, a rise in sea level, unstable weather patterns, and increased storms and natural disasters. As part of the Massachusetts Climate Protection Plan in support of the Regional Climate Plan of the New England Governors and Eastern Canadian Premiers, the Commonwealth of Massachusetts has committed to reduce statewide greenhouse gas emissions to 10% below the 1990 levels by the year 2010, but emissions have increased in recent years. More than 123 million tons of carbon dioxide equivalent (which includes carbon dioxide, methane, and nitrous oxide) were released in Massachusetts in 2001. This is approximately 2% of the national emissions and a 7% increase over the 1990 level.[20]

For several years, ozone levels have been high in Massachusetts and much of the northeast. Ground-level ozone is associated with damage to vegetation and health problems

[20] Commonwealth of Massachusetts, Climate Protection Plan, page 13.

such as reduced lung function and reduced resistance to infection. Power plants are a source of ozone precursors such as nitrogen oxides. The 2004 Air Quality Report by the Massachusetts Department of Environmental Protection (DEP) reports that over the period from 2002 to 2004, six out of fourteen measurement sites across the state violated the Clean Air Act's National Ambient Air Quality Standards (NAAQS) for ozone. The EPA has therefore designated Massachusetts as an *ozone nonattainment area*. Massachusetts is currently in attainment of the NAAQS for the other five criteria pollutants: carbon monoxide (CO), lead, nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and small particulate matter (PM).[21]

[21] Commonwealth of Massachusetts, Air Quality Report 2004, pages 11, 14.

CHAPTER 5
CHP USAGE & POTENTIAL

5.1 Past Studies

DOE has sponsored several studies on the national usage of and potential for CHP, including The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector and The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, both published in January 2000 by EIA and Onsite Energy Corporation. A few state-specific studies on CHP potential have also been published, such as Combined Heat and Power Market Potential for New York State, a 2002 study from the New York State Energy Research and Development Authority (NYSERDA) and Assessment of California CHP Market and Policy Options for Increased Penetration, a 2005 study from the California Energy Commission (CEC).

5.2 Technical Market Potential

The technical market potential for CHP is considered to be an estimate of the potential capacity for CHP in existing facilities based on their current energy consumption. 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. Most past studies of market potential have been based on current data without consideration of future growth predictions and have evaluated groups of facilities categorized by type and size rather than individual buildings.

5.3 Methodology

This section describes the general methodology used in these EIA and NYSERDA studies on CHP technical potential. The analyses included only traditional CHP systems using thermal energy in the form of steam or hot water, not systems that would use absorption chillers or desiccant dehumidification.

First, information on existing CHP installations was compiled and analyzed. Then the types of buildings were identified for which CHP is compatible with the energy consumption profile. Energy characteristics for different buildings were obtained from sources including the EIA Commercial Buildings Energy Consumption Survey (CBECS) and Manufacturing Energy Consumption Survey (MECS) and compared to the criteria for CHP such as relatively coincident electric and thermal (steam or hot water) loads, electrical to thermal demand ratios in the 0.5-2.5 range, and moderate to high operating hours (at least 3,000 hours per year).

The number of target facilities was then quantified by using Dun and Bradstreet's industry data to identify appropriate facilities by building type or SIC code. Facilities were grouped into categories by potential CHP system size. Then, the total potential CHP capacity was estimated, assuming that CHP systems would be sized to meet the average site electrical demand. The number of existing CHP systems was subtracted to determine the remaining technical potential for CHP.

5.4 National Results

This section details the two studies EIA published in 2000, both prepared by Onsite Energy Corporation under the leadership of Bruce Hedman. At that time, there were approximately 2,000 CHP facilities in the United States with a total capacity of more than 50,000 MW. The number of installations was divided almost evenly between commercial/institutional buildings and industrial buildings, as shown in Figure 5.1, but the studies showed that industrial CHP facilities tend to have much larger capacity as shown in Figure 5.2.[22, 23]

Figure 5.1: Distribution of the 1,996 Existing CHP Systems in the U.S., 2000

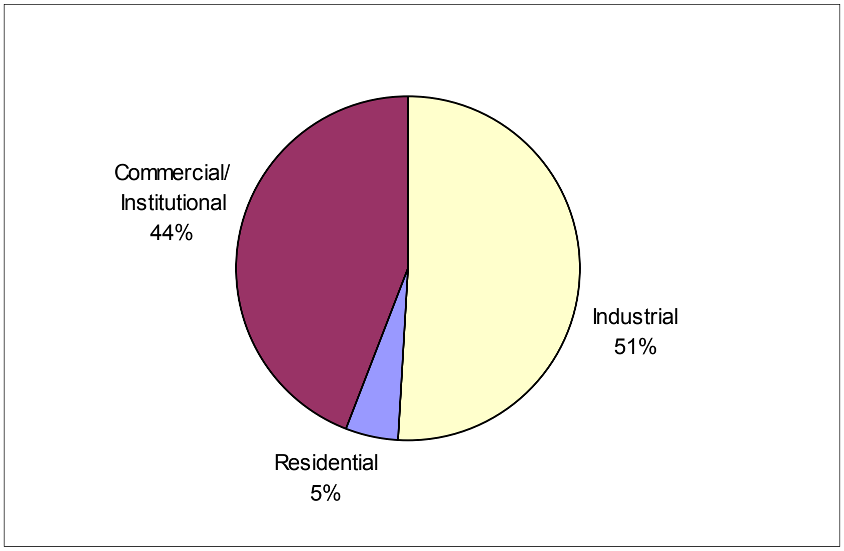
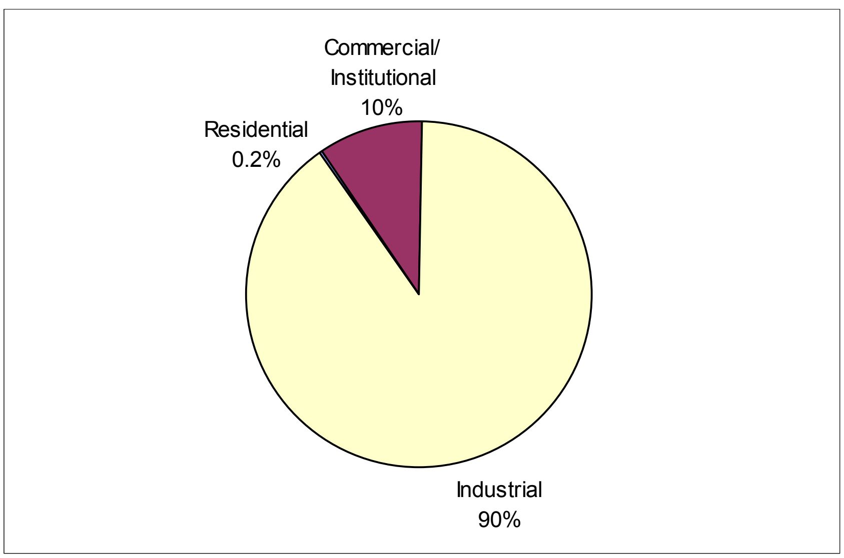


Figure 5.2: Distribution of the 50,392 MW of Existing CHP Capacity in the U.S., 2000



---

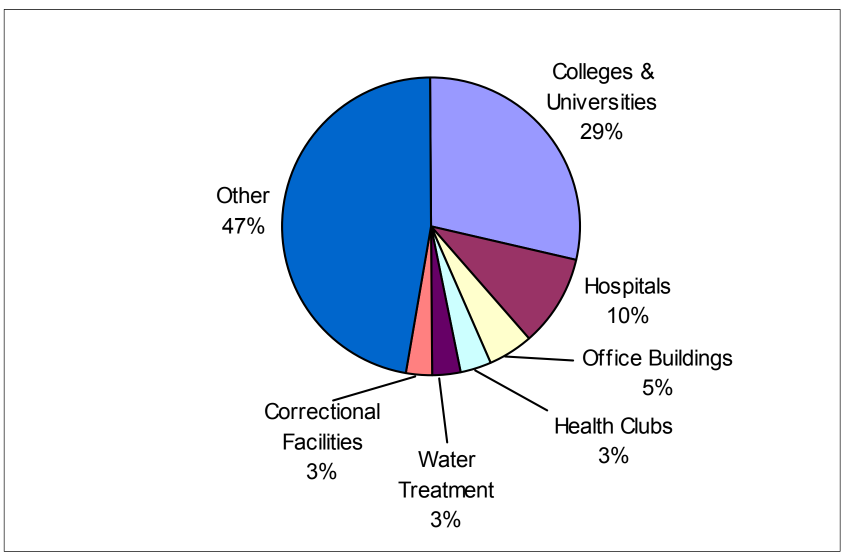
[22] ONSITE SYCOM Energy Corporation, The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, page 3.
[23] ONSITE SYCOM Energy Corporation, The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, page 17.

The national potential for CHP was calculated to be nearly 163,000 MW, with 54% in the industrial sector and 46% in the commercial/institutional sector.[24, 25]

5.4.1 Commercial & Institutional Sector

The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector reported that the commercial/institutional sector was operating more than 980 existing CHP facilities in the United States with an electrical capacity of 4,926 MW. The 29 billion kWh of electricity and 1.5 trillion Btu of thermal energy produced by these CHP facilities made up 3.8% of the sector's total energy consumption. The many types of buildings that use CHP are shown in Figure 5.3, with the largest users, in terms of total electrical capacity, of CHP being colleges and universities, followed by hospitals.[26]

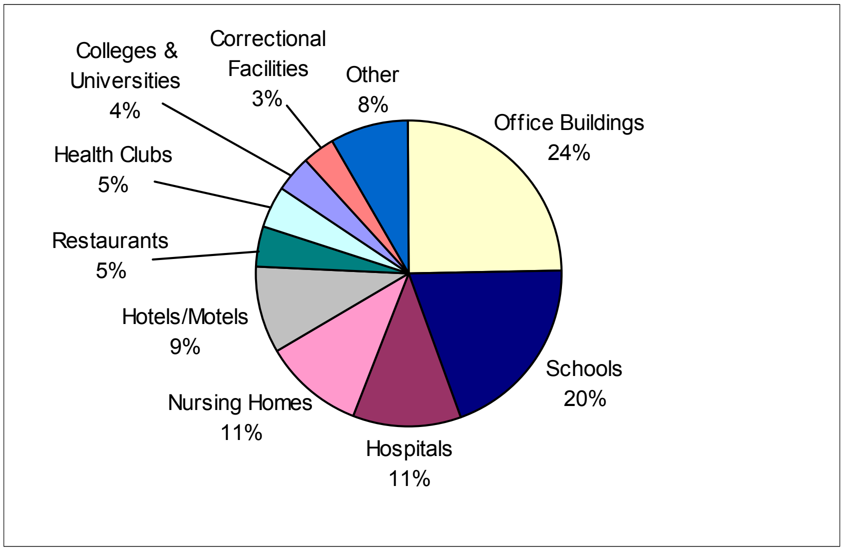
Figure 5.3: Existing Commercial and Institutional CHP Capacity in the U.S., 2000



[24] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, page 14.
[25] The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, page 34.
[26] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, pages 38-39.

The remaining technical potential was calculated to be 74,638 MW, with the greatest potential in office buildings, schools and hospitals, as shown in Figure 5.4.[27]

Figure 5.4: Potential Commercial and Institutional CHP Capacity in the U.S., 2000



This report included limited state-level information. It stated that in Massachusetts there were 30 commercial/institutional CHP facilities with a total electrical capacity of 97 MW. The remaining potential for Massachusetts was calculated to be 1,960 MW.[28]

5.4.2 Industrial Sector

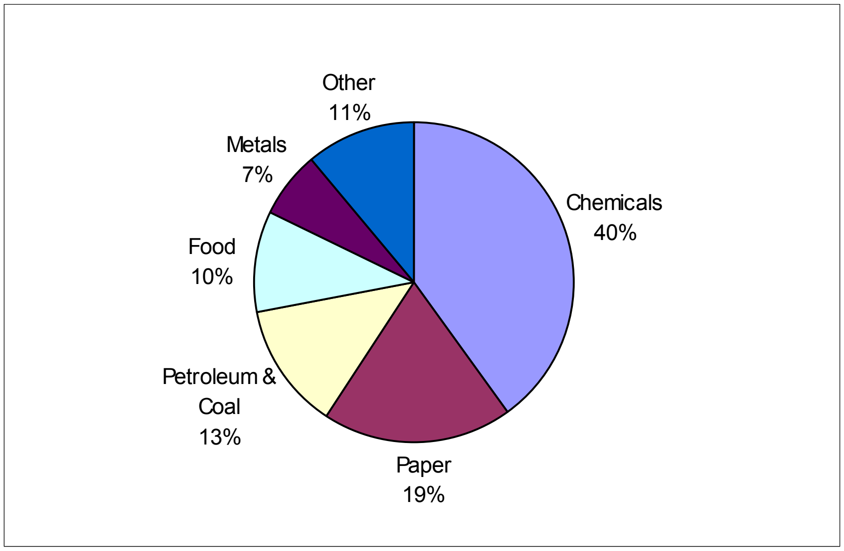
The Market and Technical Potential for Combined Heat and Power in the Industrial Sector reported 1,016 CHP facilities with electrical capacity of more than 44,000 MW and steam capacity of approximately 225,000 million Btu/hour. More than 90% of these were large systems with capacity of 20 MW or more. The distribution of electrical CHP capacity by industry is shown in Figure 5.5. The systems were concentrated in four industries: food

---

[27] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, pages 57-58.
[28] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, pages 44, 59.

processing (SIC group 20), paper (SIC 26), chemicals (SIC 28) and petroleum and coal (SIC 29), which together contained more than 82% of the installed capacity.[29]

Figure 5.5: Existing Industrial CHP Capacity in the U.S., 2000

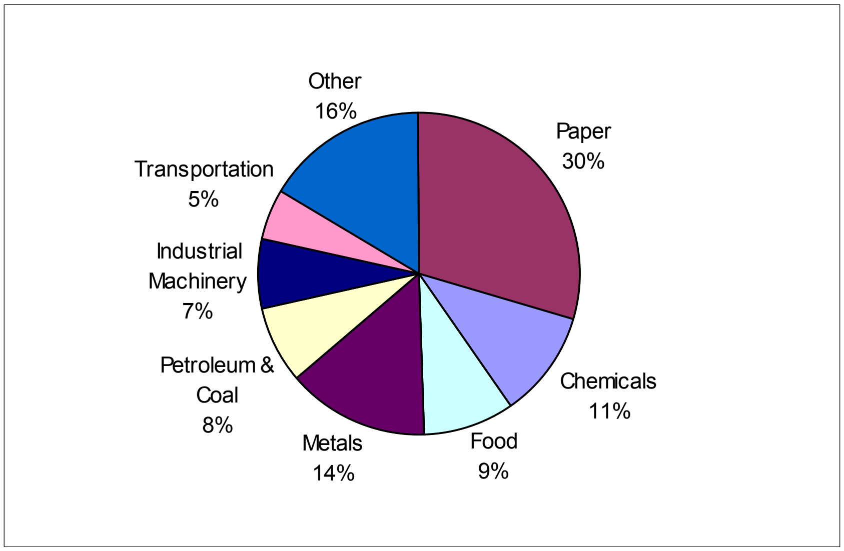


The remaining industrial potential is estimated to be 88,341 MW. As shown in Figure 5.6, more than one fourth of the potential is in paper manufacturing; the other industries with greatest potential are chemicals, petroleum and coal, food processing, metals (SIC groups 33 and 34) and industrial machinery (SIC 35).[30]

---

[29] The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, pages 17, 19, 22.
[30] The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, page 37.

Figure 5.6: Potential Industrial CHP Capacity in the U.S., 2000



In Massachusetts there were 28 industrial CHP systems with a total electrical capacity of 1,053 MW. This report does not provide the potential at the state level.[31]

5.4.3 Residential Sector

The 96 MW of existing CHP in 98 residential buildings was counted as part of the commercial/institutional sector. The report did not provide a value for CHP potential in the residential sector.[32]

5.4.4 National Summary

Nationally, electricity consumption is approximately the same for the industrial and commercial sectors, but these studies showed the potential for CHP to be greater in the industrial sector. Market penetration has been much greater in the industrial sector than in the commercial/institutional sector. The commercial/institutional potential is mainly in the smaller systems with capacity under 1 MW. More than half of the industrial potential is in systems of

---

[31] The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, page 26.
[32] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, page 38.

at least 20 MW, and one third is in systems up to 4 MW where existing market penetration has been limited.

In a 2005 report titled The Potential for Combined Heat and Power, Hedman, now at Energy and Environmental Analysis, Inc., counts 2,866 existing CHP sites with a total capacity of 81,000 MW, a significant increase from the 2000 reports. Existing installations are still concentrated in large facilities, with an average system size of 28 MW and 64% of capacity in systems greater than 100 MW. The largest users continue to be the chemical, paper, petroleum and food processing industries. The remaining potential is 70,000-90,000 MW in the industrial sector and 60,000-80,000 MW in the commercial/institutional sector. Much of this is in areas where there has been little use of CHP to date. In the commercial/institutional sector, there are office buildings, schools, hospitals, lodging and multifamily housing. In the industrial sector much of the potential is in food processing, fabrication and assembly. More than half of the potential is in smaller systems under 5 MW in capacity.[33]

5.5 New York

Combined Heat and Power Market Potential for New York State is a similar study prepared by Onsite Energy Corporation for NYSERDA in 2002. New York's CHP capacity at that time was approximately 5,000 MW at 210 sites. Much of this was in large industrial facilities, with 78% of all capacity in that sector and very little penetration in the commercial market.[34]

The state's remaining technical potential was found to be nearly 8,500 MW at 26,000 sites. The commercial/institutional sector has the most potential, both in terms of total electrical capacity (70% or 5,944 MW) and number of sites (78% or 20,461 sites). The

---

[33] The Potential for Combined Heat and Power, pages 10-15.
[34] Onsite Energy Corporation, Combined Heat and Power Market Potential for New York State, page 3-1.

industrial sector potential is 1,949 MW at 4,828 sites, and the residential sector has 585 MW of potential in 890 buildings. The majority of the potential is in systems under 5 MW in size. In addition to quantifying the potential, this report identified the parts of the state and utility service areas with the most potential.[35]

The New York report then provides an economic analysis, which evaluates the cost of CHP for five size ranges. Considerations include utility charges, both current and advanced CHP technologies, and current and predicted future fuel and power rates. The technical potential was combined with economic analysis, to estimate the future market penetration under two different scenarios: the base case and accelerated case. In the base case scenario, based on current technology and a business-as-usual approach, it was estimated that 764 MW of new CHP would be installed by the year 2012. In the accelerated case, advancing technology would improve CHP cost and performance, standby charges would be reduced and an incentive program would be introduced to facilitate the investment in CHP, which would lead to the installation of 2,200 MW of new CHP in the following ten years. Each scenario was evaluated based on a comparison of potential benefits including user cost savings, annual energy savings, and reduced emissions.[36]

5.6 California

Assessment of California CHP Market and Policy Options for Increased Penetration is a 2005 report prepared for the California Energy Commission (CEC) and the Electric Power Research Institute by Energy and Environmental Analysis, Inc., EPRI Solutions, Inc. and Energy and Environmental Economics, Inc. This analysis is more sophisticated in that it includes CHP with cooling as well as traditional CHP systems in which all thermal energy is

---

[35] Combined Heat and Power Market Potential for New York State, pages 4-6, 4-10, A-1, A-2.
[36] Combined Heat and Power Market Potential for New York State, pages 6-5, 6-6.

used for heating, as well as an evaluation of CHP potential in new buildings constructed in the next fifteen years. It also considers the large CHP export market in which a CHP system provides electricity to the grid and steam to a large industrial facility.

The existing CHP capacity in California is approximately 9,130 MW at 776 sites. As in New York, most of the existing capacity is in large systems, with 90% of capacity in systems of at least 20 MW.[37]

The total remaining technical potential in existing facilities is more than 18,000 MW. The export market potential is more than 5,000 MW. As in New York, the majority of remaining potential in California, both in total capacity and number of sites, is in the commercial/institutional sector. This report also provides a breakdown of potential by region of the state and utility service area.[38]

This report also contains an analysis of likely market penetration in both a base case and high deployment scenario. In the base case, market penetration was predicted to be nearly 2,000 MW, while it was estimated that the high deployment scenario would result in more than 7,300 MW capacity in the year 2020. The economic analysis includes cost-benefit calculations for society, the electric utility and the CHP owner. The impact on CHP of a range of energy policy options and incentive programs is also considered.[39]

---

[37] EPRI & California Energy Commission, Assessment of California CHP Market and Policy Options for Increased Penetration, page 2-1.
[38] Assessment of California CHP Market and Policy Options for Increased Penetration, pages 2-6, 2-7.
[39] Assessment of California CHP Market and Policy Options for Increased Penetration, pages 2-15, 2-24.

CHAPTER 6
CURRENT STATUS OF CHP IN MASSACHUSETTS

6.1 Overview

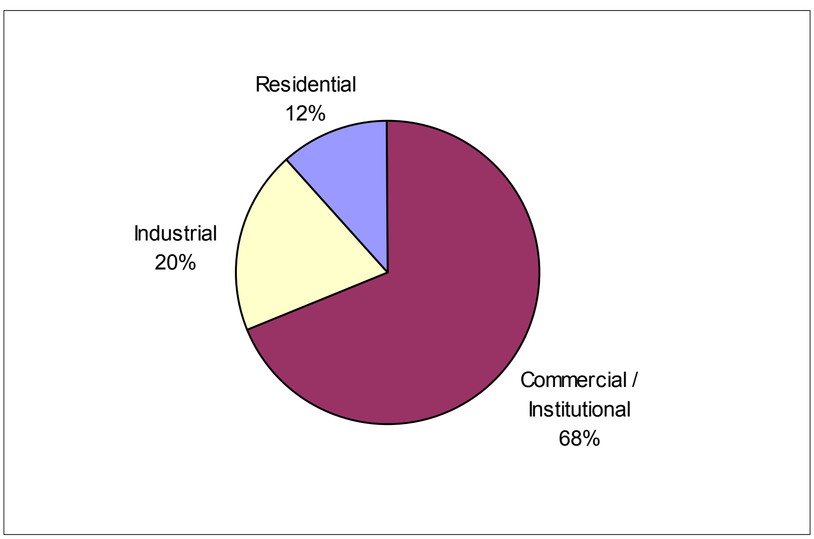
There are currently 121 known CHP industrial, commercial/institutional and residential sites in Massachusetts with total electrical capacity of 375 MW. This total is equal to 3% of the electric industry's generating capacity in the state. The majority of these systems are in commercial/institutional 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.

There are also fourteen utility, landfill and district heating plants with 1,340 MW of CHP, which are not further considered in this analysis. Table 6.1 and Figure 6.1 show the breakdown of existing CHP by sector.

Table 6.1: Existing CHP in Massachusetts

Sector	# of Sites	Total Capacity (MW)	Average Size (MW)
Commercial / Institutional	83	206	2.5
Industrial	24	166	6.9
Residential	14	2	0.13
TOTAL	121	375	3.1

Figure 6.1: Distribution of the 121 Existing CHP Systems in Massachusetts



6.2 Prime Movers & Fuels

Most of the CHP systems use a reciprocating internal combustion engine as the prime mover, followed by boilers with steam turbines. Natural gas is the most common fuel, used in the majority of all system types, except for boiler with steam turbine systems, which are split between natural gas and oil. Figures 6.2 and 6.3 detail the prime movers and fuels used in existing CHP systems. In systems with multiple prime movers or fuels types, the machine with largest capacity and the primary fuel are counted here.

Figure 6.2: Prime Movers of the 121 Existing CHP Systems in Massachusetts

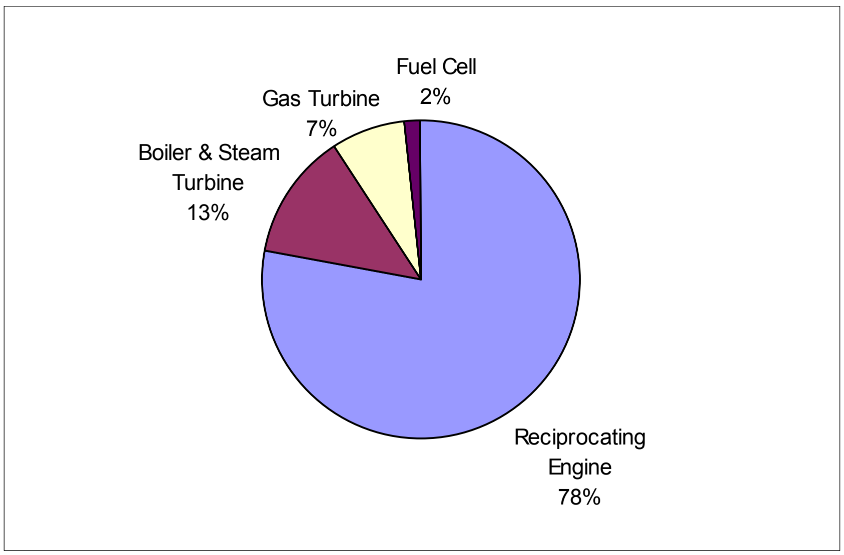
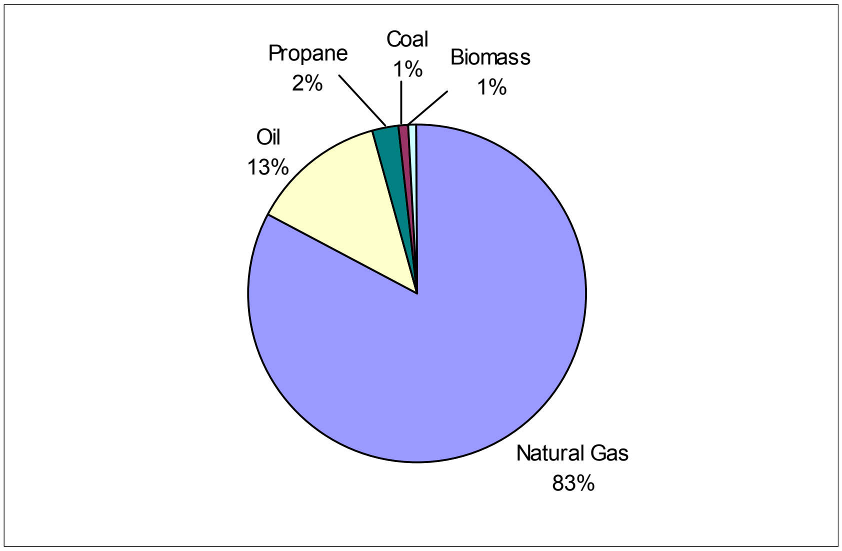


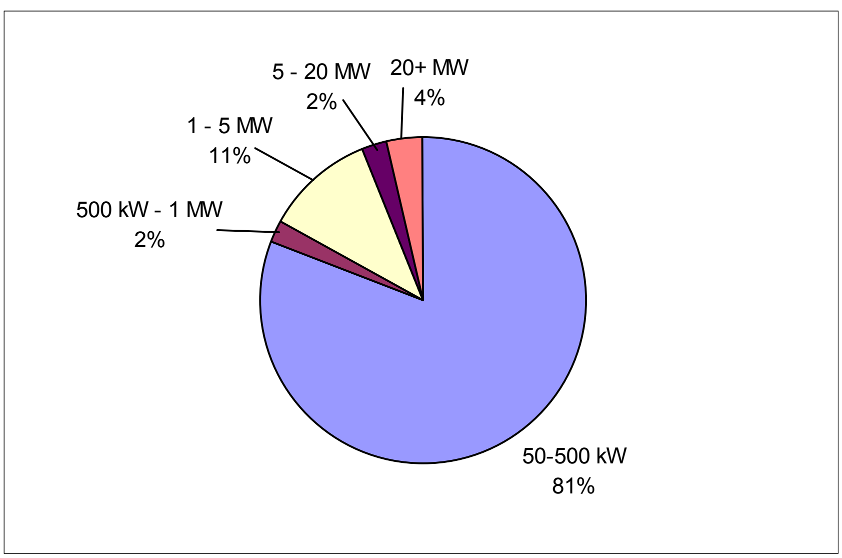
Figure 6.3: Fuels Used in the 121 Existing CHP Systems in Massachusetts



6.3 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 more than 20 MW. The size distribution is detailed in Figure 6.4.

Figure 6.4: Size of Existing Commercial and Institutional CHP Systems in Massachusetts



Natural gas-fired reciprocating engines are used in most of the commercial/institutional CHP systems in Massachusetts. As shown in Figure 6.5, 88% of commercial/institutional systems have reciprocating engines, followed by gas turbines and boilers with steam turbines. Natural gas is the primary fuel in 88% of systems, followed by oil and propane, as shown in Figure 6.6.

Figure 6.5: Prime Movers of Existing Commercial and Institutional CHP Systems in Massachusetts

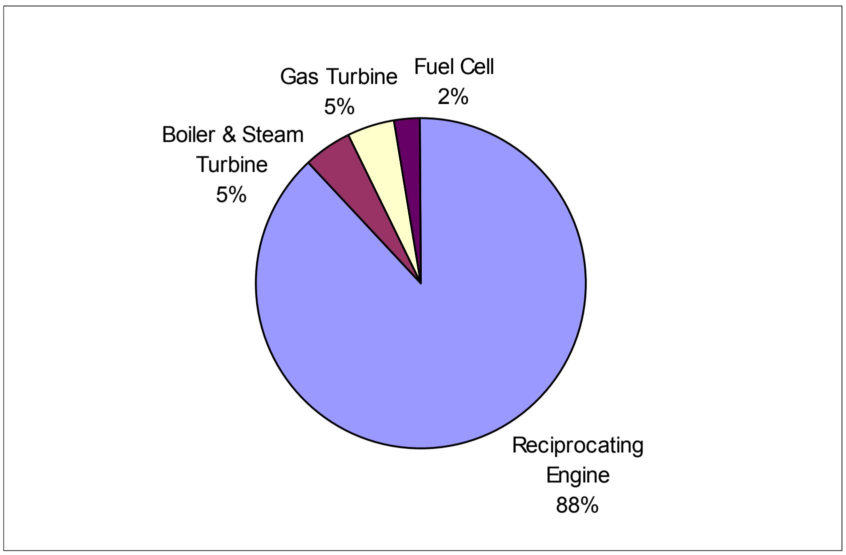
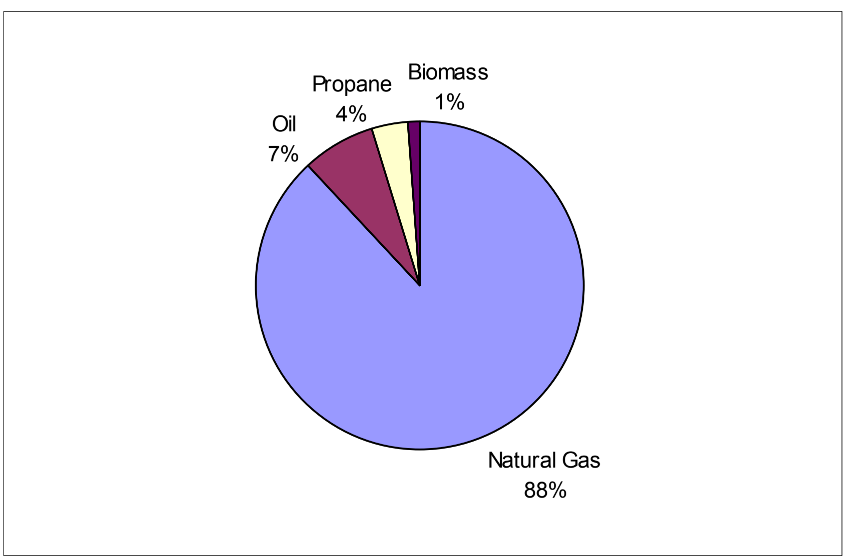


Figure 6.6: Fuels Used in Existing Commercial and Institutional CHP Systems in Massachusetts

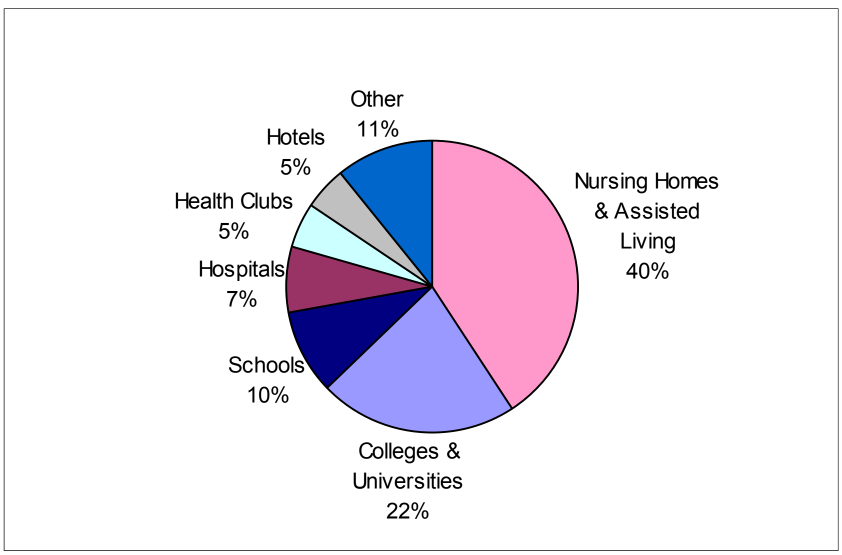


As shown in Table 6.2 and Figure 6.7, there are many nursing homes and assisted living facilities with small CHP systems, ranging from 60 to 300 kW in size. CHP is also used at several colleges and universities throughout Massachusetts, with systems ranging from 60 kW to more than 20 MW.

Table 6.2: Commercial and 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	121	375	3.1

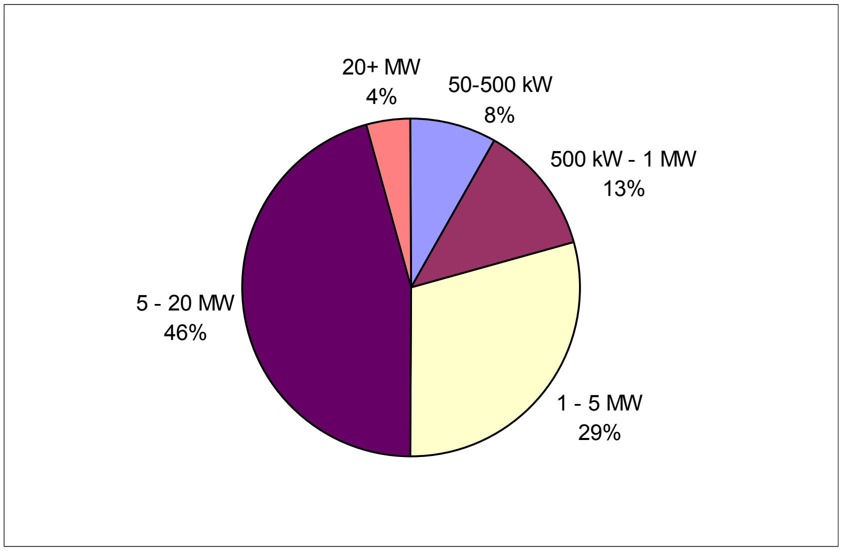
Figure 6.7: Existing Commercial and Institutional CHP Systems in Massachusetts



6.4 Industrial Sector

The industrial sector in Massachusetts operates 24 CHP facilities with a total electrical capacity of 166 MW. The majority of these are mid- to large-sized systems in the 1 to 20 MW range, as shown in Figure 6.8.

Figure 6.8: Size of Existing Industrial CHP Systems in Massachusetts



In the industrial sector, the most common configurations are oil-fired boilers and steam turbines, natural gas-fired reciprocating engines, natural gas-fired boilers and steam turbines and natural gas-fired gas turbines. As shown in Figure 6.9, 50% of industrial CHP systems in Massachusetts use boilers and steam turbines, followed by reciprocating engines and gas turbines. Natural gas is the primary fuel in 58% of industrial systems, followed by oil, as shown in Figure 6.10.

Figure 6.9: Prime Movers of Existing Industrial CHP Systems in Massachusetts

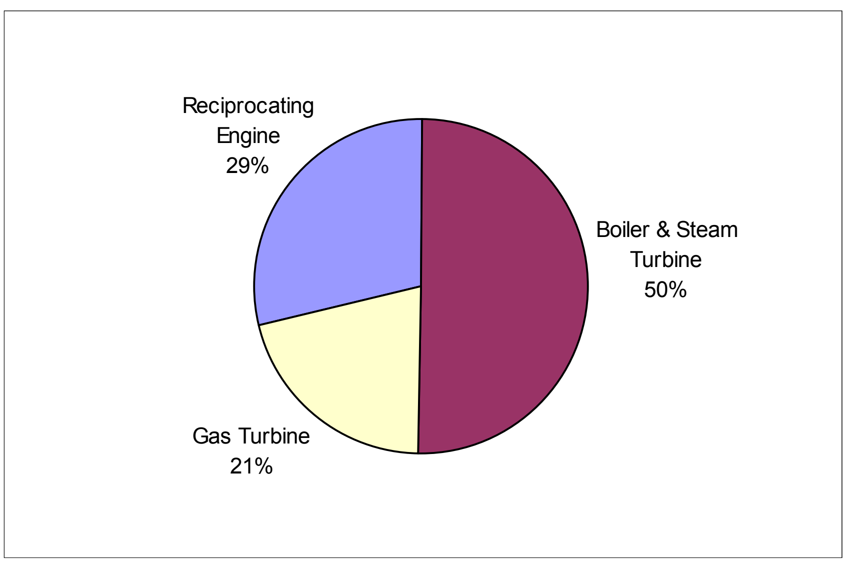
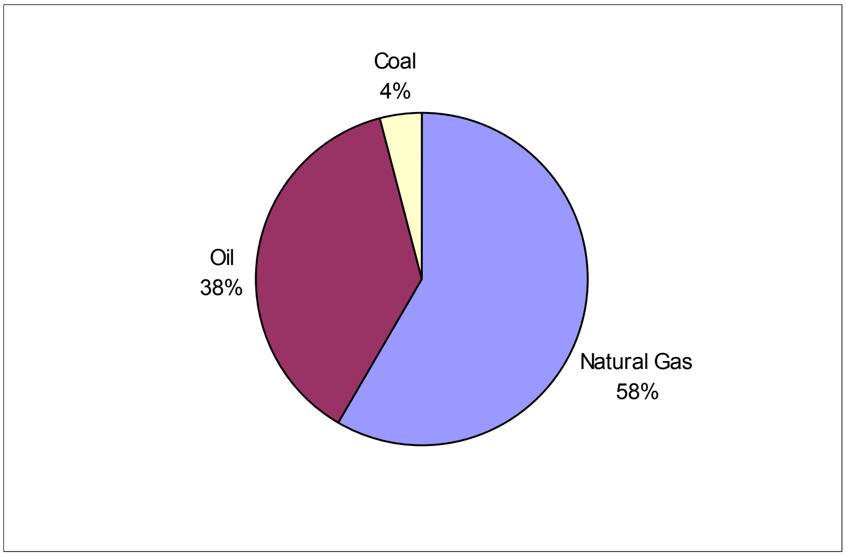


Figure 6.10: Fuels Used in Existing Industrial CHP Systems in Massachusetts

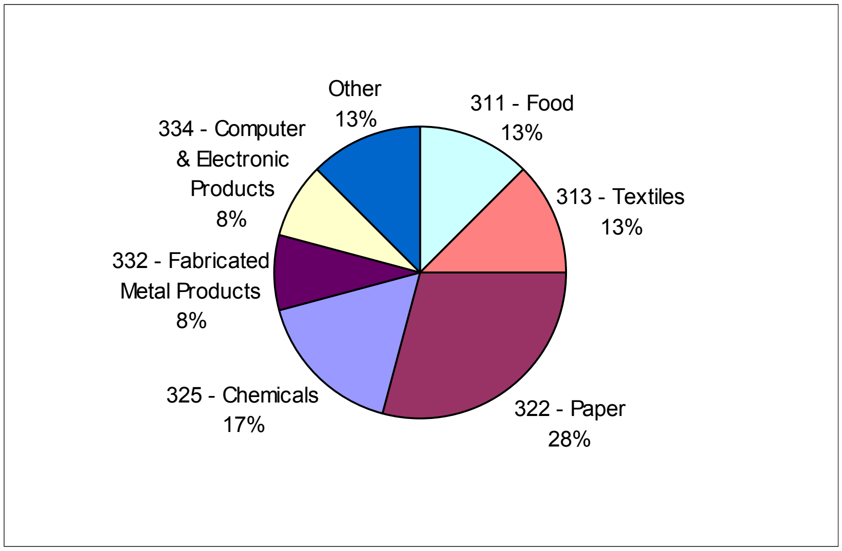


The paper industry has the most systems, followed by chemicals, food and textiles. (Some previous reports have stated a higher value for installed industrial CHP in Massachusetts because some of facilities with CHP have shut down or been converted to utility plants in recent years.) These systems are detailed in Table 6.3 and Figure 6.11.

Table 6.3: 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		121	375	3.1

Figure 6.11: Existing Industrial CHP Systems in Massachusetts



6.5 Residential Sector

There are 14 CHP systems currently installed in residential buildings in Massachusetts. All use reciprocating engines. Thirteen are in apartment or condominium buildings; these are fueled with natural gas and range in size from 60 to 300 kW. The remaining system, which is oil-fueled, is a small 5kW project in a private household. Table 6.4 summarizes these residential CHP systems.

Table 6.4: Residential CHP Systems in Massachusetts

# of Sites	Total Capacity (MW)	Average Size (MW)
14	2	0.13

6.6 Comparison of Massachusetts to National

The distribution of the existing CHP in Massachusetts is fairly different than the national situation described in the EIA reports discussed in Chapter 5. In Massachusetts there are far more commercial/institutional systems, with 68% of existing CHP systems in that sector and only 20% in the industrial sector. At the national level, however, half of existing CHP systems are in industrial facilities. This difference is likely explained by the fact that the commercial/institutional sector makes up a much larger share of total electricity consumption in Massachusetts than in the United States, as explained in Chapter 4.

The distribution of CHP within each sector is more similar at the state and national levels. At both levels, the largest commercial/institutional CHP capacity is in colleges and universities and in hospitals, and three of the four largest industrial users are the food, paper and chemical industries. At the national level, the other industry is petroleum and coal, whereas in Massachusetts it is the textile industry. Industrial systems are generally smaller in Massachusetts though. Nationally, more than 90% of industrial systems are 20 MW or more, but Massachusetts industrial systems are distributed more evenly across the size spectrum with 75% between 1 MW and 20 MW in size.

6.7 Massachusetts CHP Policy

There are many state-specific regulations and policies that affect CHP systems. This section explains three of the issues with the greatest impact on CHP in Massachusetts.

6.7.1 Emissions Regulations

The DEP recently made revisions to their air pollution control regulations, setting new standards for pollutant emissions from small- to mid-sized engines and turbines. This changes the permitting process required of small-scale electric generators, and will impact many potential CHP installations. The new policy is in Sections 40 through 44 of the DEP regulations identified as 310 CMR 7.26, commonly known as the Small Engines and Turbines Rule.

The regulation applies to engines with rated power output of 50 kW or more and turbines rated up to 10 MW. Equipment used only for emergency backup or other limited use situations such as load shaving or peaking power production is addressed separately. The new policy, which went into effect early in 2006, standardizes the permitting requirements for newly installed stationary engines and combustion turbines, replacing the process in which DEP evaluated installations on a case-by-case basis. Emission limits will be phased in over the next several years, becoming more stringent over time.

This introduction of output-based standards in the Massachusetts regulation is based in part on the RAP Model Rule explained in Chapter 3, but it does not address the differences in efficiency measurements for generators that are part of CHP systems. Allowable emissions levels are now stated in terms of pounds of emissions per megawatt-hour of electricity generated, however any useful thermal energy output from the system is not taken into account. This output-based standard provides an incentive for efficiency in electrical generation but in effect it penalizes CHP. For example, an engine that generates electricity with 40% efficiency is allowed the same level of emissions as a CHP system that has the same type of engine but also uses its waste heat to satisfy the facility's thermal load, displacing the need to run a separate boiler and resulting in a total system efficiency of 70%.

While the increased use of CHP would result in an overall increase in efficiency and reduction of emissions, it will be difficult and costly for many new CHP systems to meet these new emission standards to obtain environmental permitting. CHP advocates report that in the past many potential CHP projects, which would have resulted in an overall reduction in emissions and fuel consumption, have not gone forward in Massachusetts because of the obstacles created by outdated standards. These new regulations will continue to discourage Massachusetts businesses from installing CHP systems. In contrast, the states of California, Connecticut, Maine and Texas, have set regulations that consider total useful energy output in evaluating emissions from small CHP systems. DEP officials are reviewing the effect of these new regulations on CHP, with the possibility of proposing revisions in the future. This policy struggle over how to evaluate the environmental impact of energy generation and fairly compare different types of equipment and methods of energy generation is a key issue impacting the growth of CHP.

6.7.2 Standby Rates

As explained in Chapter 3, utilities may charge a standby rate for the utility to maintain the ability to provide the full electrical demand for self-generating customers.

At this time, NSTAR is the only electric utility company in Massachusetts to have implemented a standby charge. Electric utilities in the state must file their proposed rates for approval by the Massachusetts Department of Telecommunications and Energy (DTE). In July 2004, DTE approved the NSTAR standby rate in Order 03-121. This requires that customers using distributed generation pay NSTAR a substantial standby rate, regardless of their current demand for electricity from the utility.

NSTAR's standby charge applies to customers installing new generators with capacity of at least 250 kW that will meet more than 30% of their load and to all generators over 1 MW. Customers may be exempt from this charge if they use renewable fuels or they first implemented distributed generation before 2005. There was also a special exemption for distributed generation systems installed in Boston city schools by the end of 2005.

It is widely expected that National Grid will pursue implementation of a standby charge in the future. In March 2000, DTE issued Order 99-47, a settlement made with Massachusetts Electric (now National Grid), which stated that the utility would be able to charge a standby rate in the future, but that they would not implement the charge until the total on-site generation capacity of their customers exceeds 15 MW. It is expected that this threshold will soon be reached and National Grid will therefore file a proposal to introduce a standby rate.

The NSTAR standby rate adds substantially to the cost of operating a CHP or distributed generation system. An example is provided in Investigation Into the Systemwide

Economic Benefits of Combined Heat and Power Generation In the New England Market by Christopher Beebe. This study quantified the economic costs and benefits associated with the installation of an 800 kW CHP unit in the Boston area. Factors including T&D system upgrades, efficiency, system losses and pollutant emissions were considered. The annual benefit to society of the CHP system was calculated to be $53,028 and annual benefits for the electric and natural gas utility companies were found to be approximately $20,000 each, but the owner of the CHP system would lose $17,844 per year. The annual costs for the CHP owner include standby charges of $77,220. Beebe concluded that there are significant societal benefits associated with CHP but that it is generally not profitable to install CHP systems in the NSTAR service area, in large part because of the high standby rate. Another economic example including standby rates is provided in Chapter 7 of this report.

Many agree that it is reasonable for utilities to charge some standby rate, but there has been considerable disagreement over the magnitude of these charges. Electric utility companies argue that standby rates are necessary to avoid placing an unfair burden on the utility or its other customers. Advocates for CHP oppose high standby rates, contending that they unfairly penalize CHP despite its many benefits to both society and the electric system.

6.7.3 Steam Safety Laws

Massachusetts mandates that facilities with large steam turbines have a licensed operator on-site at all times. According to the Massachusetts Division of Energy Resources (DOER), this requirement from an 1899 law is unique to Massachusetts and is no longer necessary with current technology and computer controls. This adds significant cost to the operation of a CHP system, and this may be enough to prevent some facilities from installing CHP. DOER is working with the Massachusetts Department of Public Safety to update these regulations, which fall in the Massachusetts General Law, Chapter 146 Sections 522 and 527.

CHAPTER 7
CHP POTENTIAL IN MASSACHUSETTS

7.1 Methodology

The general methodology used to quantify the potential for CHP in Massachusetts is described below. More detail on the methodologies, data sources and calculations for each sector are described in Appendices A-C.

Three sectors were studied: commercial/institutional, industrial and residential. The analysis focused on building types previously identified, primarily in the NYSERDA report, to be best for CHP based on the criteria described in Chapter 2: relatively coincident electric and thermal loads, electrical to thermal demand ratios in the 0.5-2.5 range, and moderate to high operating hours (at least 3,000 hours per year). Commercial/institutional facilities were grouped by facility type, and industrial facilities were grouped by the North American Industry Classification System (NAICS) codes.

Energy data for the relevant facility types was obtained from surveys performed by the Department of Energy's Energy Information Administration. The Commercial Buildings Energy Consumption Survey (CBECS), Manufacturing Energy Consumption Survey (MECS) and Residential Energy Consumption Survey (RECS), are each published every four years to provide information about energy consumption in facilities across the country. Supplemental sources were the NYSERDA and CEC reports on CHP potential and data collected in DOE's Industrial Assessment Center (IAC) at the University of Massachusetts Amherst.

Most CHP facilities work in parallel with the electrical grid, so this analysis aims to optimize economics and efficiency rather than to meet full energy loads at the facilities. For grid-connected systems, it is typically most economical to base the size on the facility's average electrical demand. Average annual electricity consumption in kilowatt-hours (kWh) for each facility type was divided by the hours of operation to obtain the average demand in kilowatts (kW).

The number and size of most target facilities in the industrial and commercial/institutional sectors was obtained from the United States Census Bureau's 2002 County Business Patterns, which provides the number of establishments at both the state and county level. County Business Patterns provides facility size in terms of employee size ranges. Therefore to calculate the energy consumption and appropriate CHP system size for facilities of different sizes, the energy consumption per employee was found for each facility type. The median number of employees in each facility size category was multiplied by the average electric demand per employee to put the facilities into categories by electric demand size ranges. For the commercial/institutional sector, the appropriate sizes for CHP systems in different facility types were obtained from the NYSERDA and CEC reports. For industrial facilities, system sizes were based on electrical to thermal energy ratios calculated from IAC data and the power to thermal output of available CHP equipment.

Residential energy consumption data for multi-unit buildings is provided in RECS in terms of consumption per unit. The approximate number and size of residential buildings in Massachusetts was calculated using data from RECS, the Census Bureau and the National Multi Housing Council. Average electric demand per unit was multiplied by the number of units per building to determine total demand per building. The system size was based on the electrical to thermal energy ratio calculated from RECS data and the power to thermal output of available CHP equipment.

This analysis resulted in the number of sites in each sector, broken down by CHP system size ranges. To determine the remaining potential, referred to as potential, for CHP in Massachusetts, the number of sites with existing CHP systems was deducted from that total.

7.2 Total 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 generating capacity in the state. Subtracting the existing CHP systems in those facility types gives 18,549 remaining sites with CHP potential of 4,751 MW. Table 7.1 details the potential number of systems and total capacity.

Table 7.1: CHP Potential in Massachusetts

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

Most of the potential, both in terms of number of installations and total capacity, is in the commercial/institutional sector. Figure 7.1 shows the distribution of the number of potential CHP systems by sector, while Figure 7.2 shows the distribution of the electrical capacity for CHP. The commercial/institutional sector has had the least market penetration to date, though as shown in Figure 7.3 the penetration has been limited in all sectors.

Figure 7.1: Distribution of the Potential CHP Systems in Massachusetts

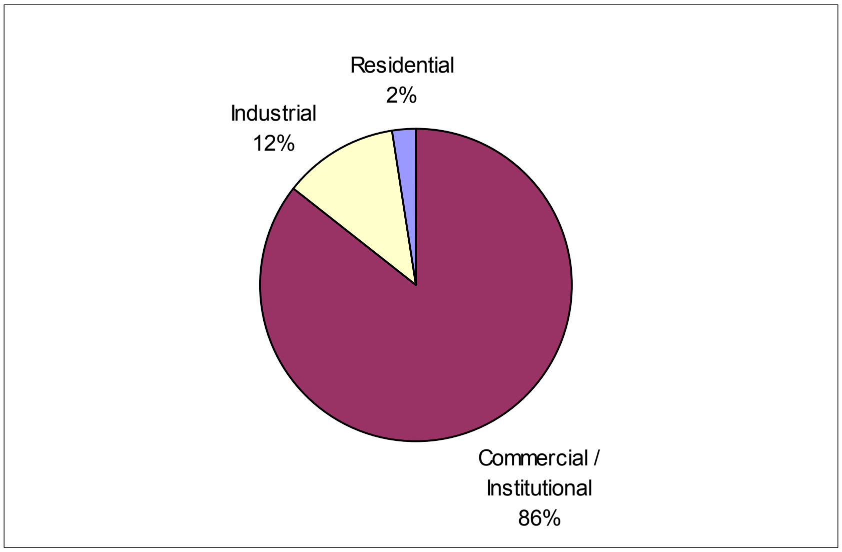


Figure 7.2: Distribution of the Potential CHP Capacity in Massachusetts

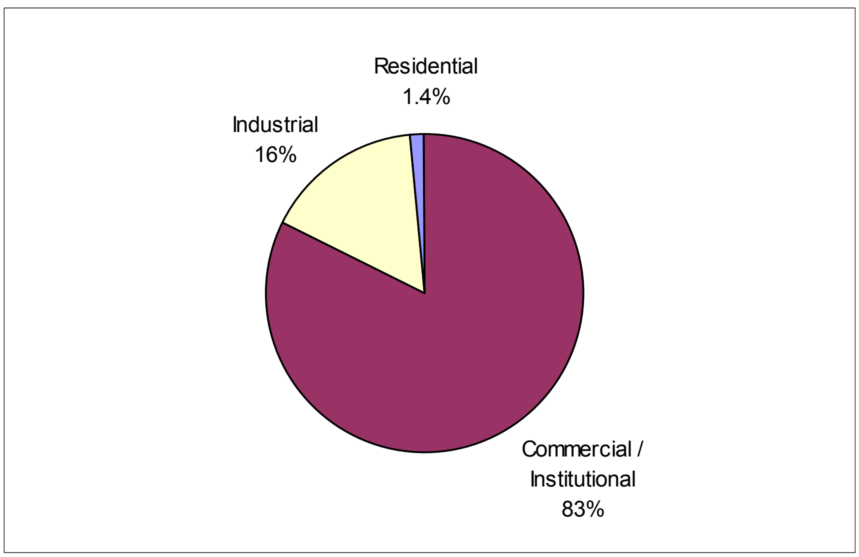
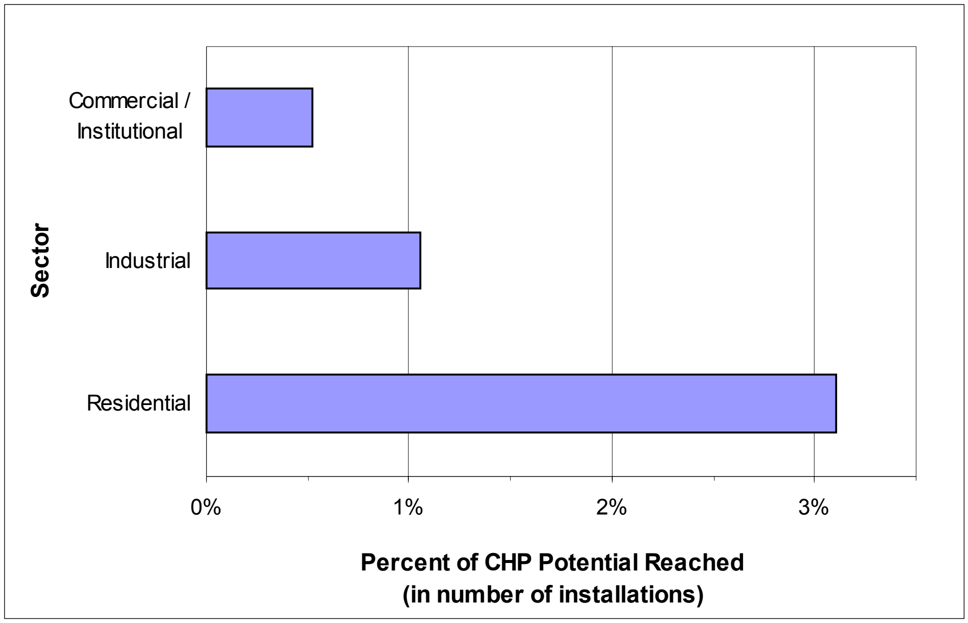


Figure 7.3: Penetration of Massachusetts CHP Market by Sector



The average size of the potential systems is 256 kW each, with the largest average system size in the industrial sector and the smallest in the residential sector. As shown in Figure 7.4, most of the potential systems are in the 50 to 500 kW size range, which is the size with the least market penetration to date. There has been significant market penetration in the largest systems over 20 MW, followed by systems in the 5 to 20 MW range. Figure 7.5 illustrates the market penetration in each size range.

Figure 7.4: Size of Potential CHP Systems in Massachusetts

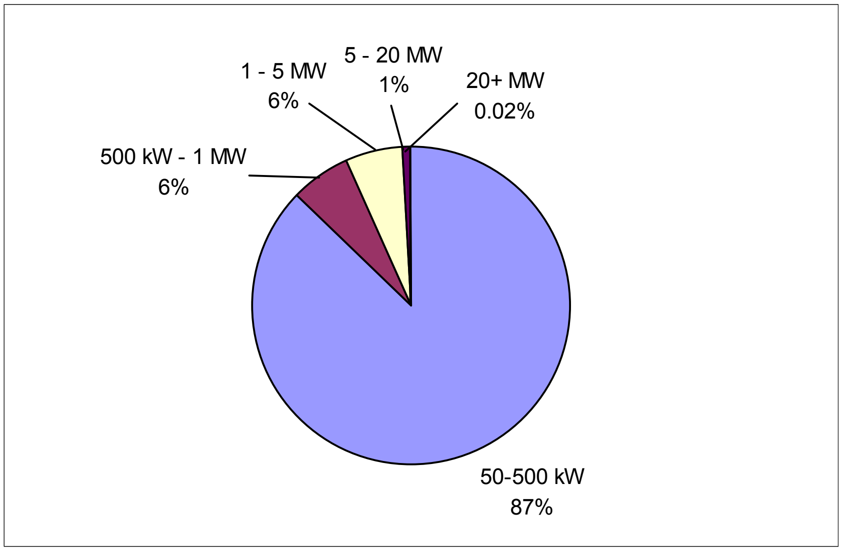
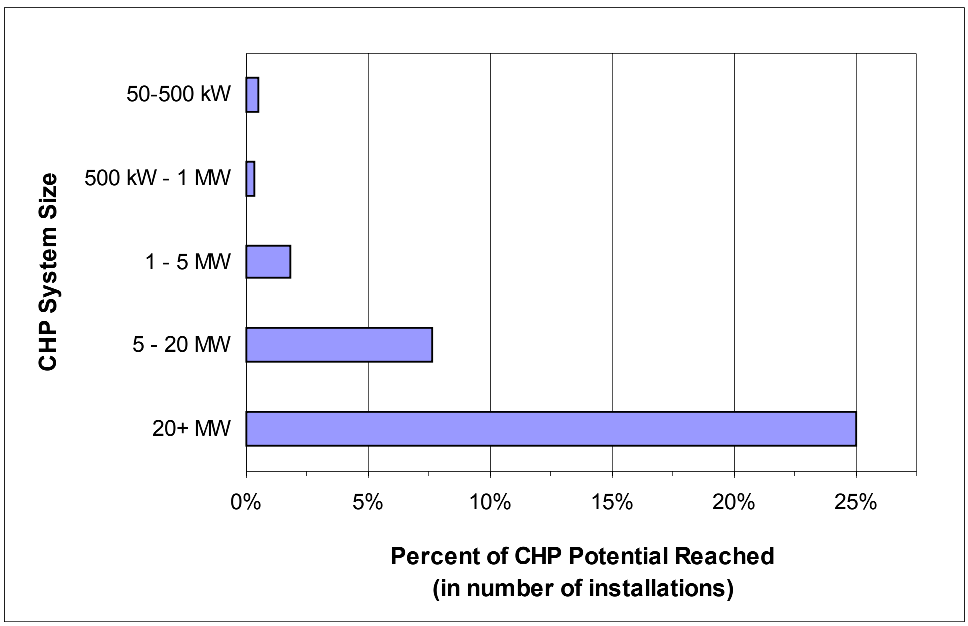


Figure 7.5: Penetration of Massachusetts CHP Market by System Size



7.3 Commercial & Institutional Sector

This study analyzed eighteen types of commercial/institutional facilities that have been identified to be well suited to CHP. Thermal loads considered in the commercial/institutional sector include both heating and cooling. 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. Table 7.2 details the potential by facility type.

Table 7.2: Commercial and Institutional CHP Potential in Massachusetts

Facility Type	# of Sites	Total Capacity (MW)	Average System Size (kW)	Primary Thermal Applications				
				Hot water	Space heating	Space cooling	Refrigeration	Pools
Car washes	67	10	150	X				
Colleges & universities	99	444	4,485	X	X	X		X
Correctional institutions	36	27	742	X	X			
Golf & country clubs	147	34	230	X	X	X		X
Grocery stores	843	309	366	X	X	X	X	
Health clubs	364	82	226	X	X	X		X
Hospitals	121	301	2,486	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	192	217	X	X	X		
Office buildings	5,652	1,455	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	52	164	X	X	X		X
Warehouses, refrigerated	11	2	150	X			X	
Water & sewage treatment plants	147	128	867	Process heating				
TOTAL	15,858	3,890	245	-				

The most potential, both in terms of number of systems and capacity, is in office buildings. Depending on building size, CHP systems in office buildings can range from the smallest 50 kW systems to large systems with several megawatts of capacity. Figure 7.6 illustrates that the other facility types with the greatest potential number of systems are retail stores and restaurants. CHP in retail stores can range from 50 kW to over 1 MW. Many stores are in malls or other buildings with multiple stores, so some of these systems could potentially be combined into larger systems serving many businesses at one location. CHP in restaurants would primarily be smaller systems in the 50-500 kW range.

As shown in Figure 7.7, office buildings are followed by colleges and universities, retail stores and hospitals for the greatest combined potential CHP capacity. While there are fewer colleges and hospitals, they are generally larger in size and energy consumption than most of the other commercial/institutional facilities, so they make up a large segment of the CHP market in terms of electrical capacity.

Figure 7.6: Commercial and Institutional CHP Potential in Massachusetts by Number of Systems

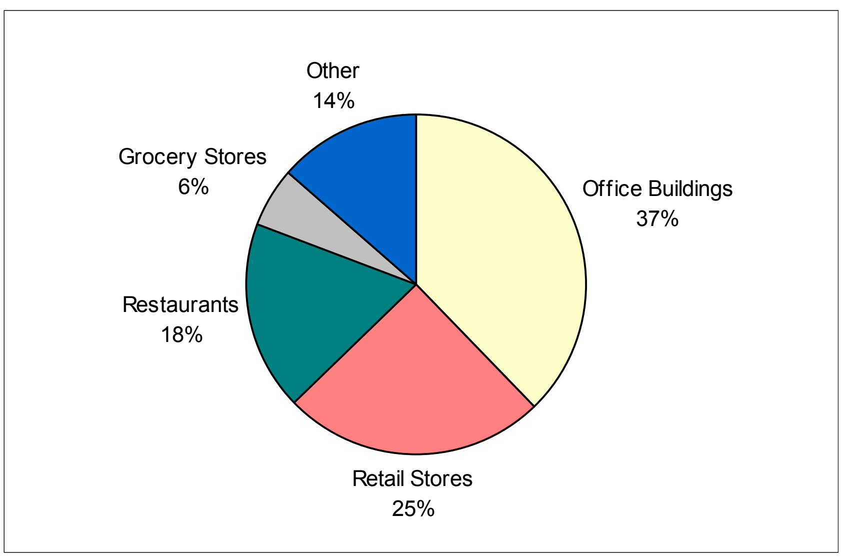
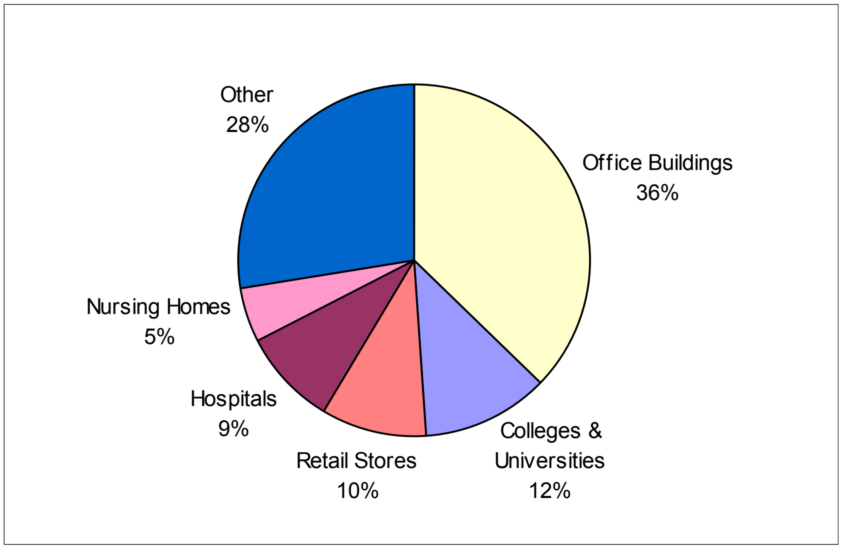


Figure 7.7 Commercial and Institutional CHP Potential in Massachusetts by Total Capacity



The average size of the potential systems is 247 kW each, with the largest average system size in colleges and universities, followed by hospitals. Most of the potential systems are in the 50-500 kW size range. Figure 7.8 shows the average system size for each facility type.

Figure 7.8: Average Potential Commercial and Institutional CHP System Sizes

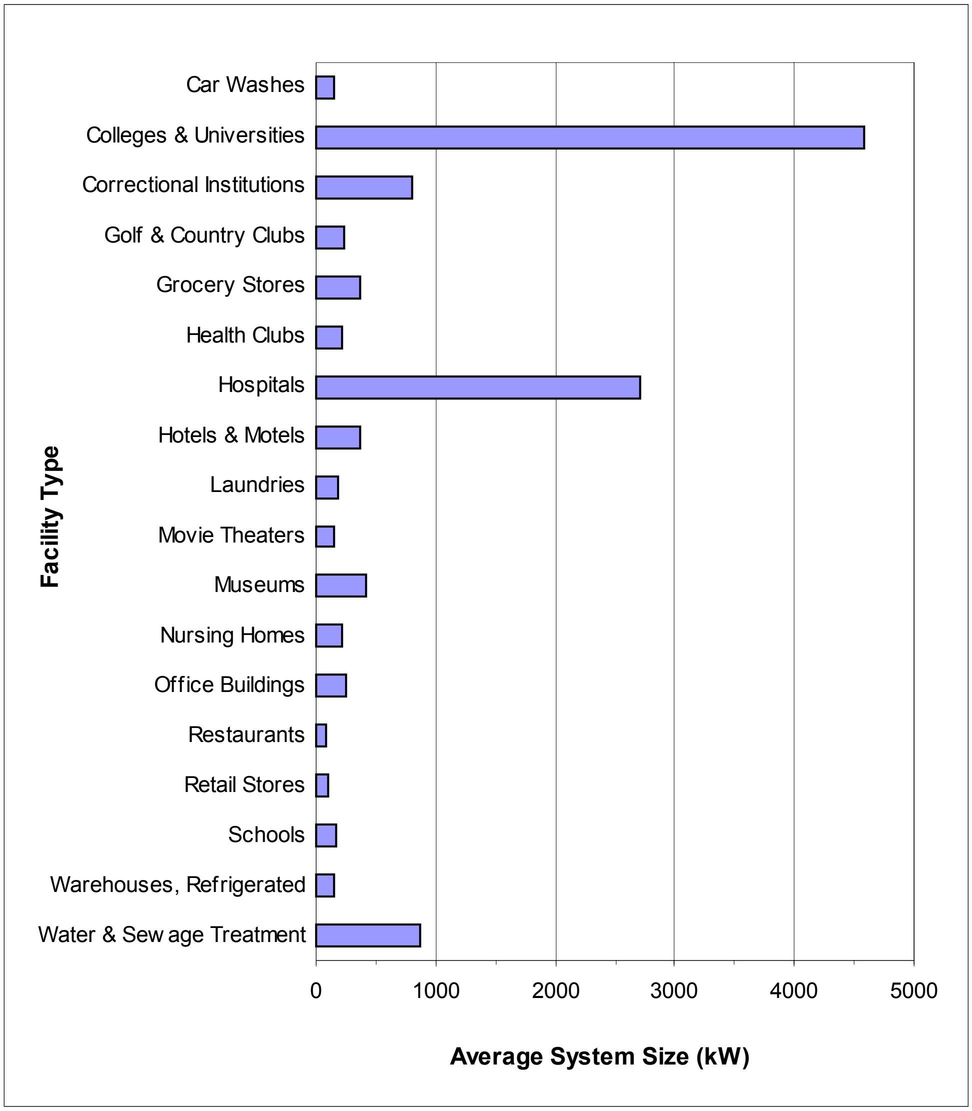
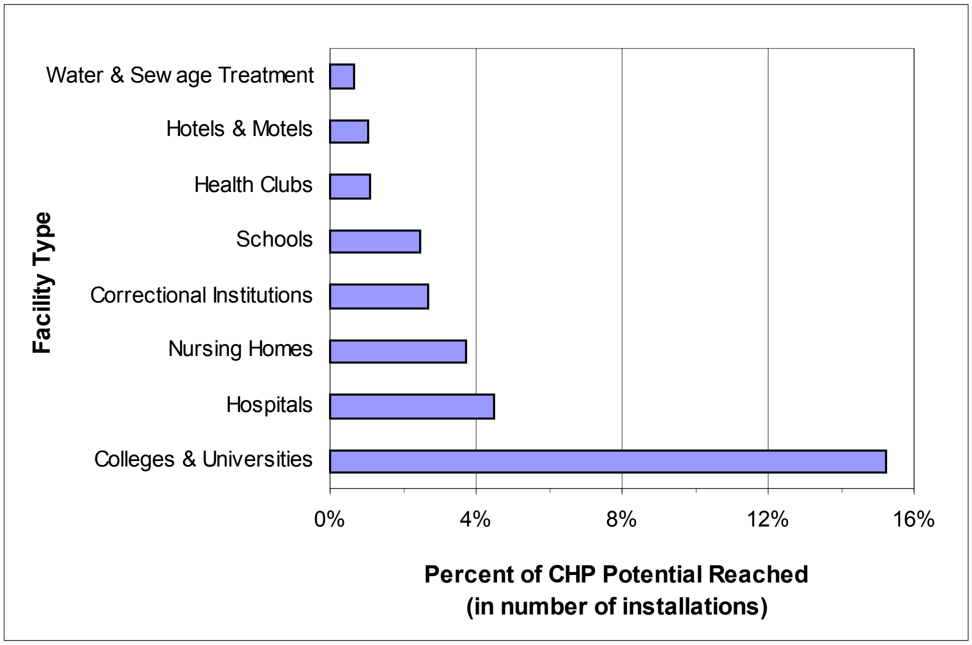


Figure 7.9 shows the current market penetration in the types of facilities that have existing CHP systems in Massachusetts. The most market penetration by far is in colleges and universities, followed by hospitals and nursing homes.

Figure 7.9: Penetration of Massachusetts Commercial and Institutional CHP Market



7.4 Industrial Sector

This study analyzed thirteen manufacturing industries that have been identified to be well suited to CHP. Because of limitations in the available energy consumption data, 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 gave a remaining potential of 774 MW at 2,254 sites. Table 7.3 details the potential by facility type.

This analysis was performed with industries grouped by NAICS code. This six-digit system recently replaced the four-digit Standard Industrial Classification (SIC) code system. There is not always a direct correlation between NAICS and SIC groups, but the SIC groups that best correspond are listed in Table 7.3 for reference because some applications and related reports still use the SIC system.

Table 7.3: Industrial CHP Potential in Massachusetts

NAICS Code	SIC Code(s)	Industry Description	# of Sites	Total Capacity (MW)	Average System Size (kW)
311	20	Food	330	131	396
313	22	Textiles	91	55	601
321	24	Wood products	38	5	123
322	26	Paper	162	162	1,000
325	28	Chemicals	135	78	575
326	30	Plastics & rubber products	99	13	131
331	33	Primary metals	76	23	302
332	34,35	Fabricated metal products	760	215	283
333	35	Machinery	119	36	305
334	35,36,38	Computer & electronic products	246	106	430
335	36	Electrical equipment, appliances & components	63	25	402
336	37	Transportation equipment	22	13	585
337	25	Furniture	136	16	120
TOTAL			2,277	877	385

This analysis considers the total energy used for heating in each industry, but the source data does not include specifics such as the form or temperature of heating required. In some cases, such as manufacturing processes that require extremely high temperatures, the thermal output from CHP will not be able to satisfy the specific thermal loads of a 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.

Figure 7.10 illustrates the industries with the greatest potential number of systems, and Figure 7.11 illustrates those with the greatest combined potential CHP capacity. The size of each industry in Massachusetts is shown in Figure 7.12 for comparison between an industry's size and its potential for CHP.

Figure 7.10: Industrial CHP Potential in Massachusetts by Number of Systems

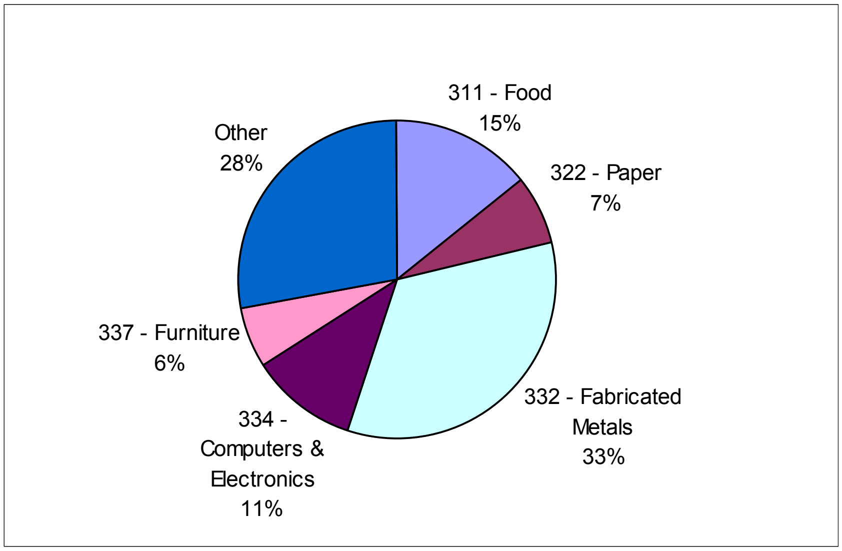


Figure 7.11: Industrial CHP Potential in Massachusetts by Total Capacity

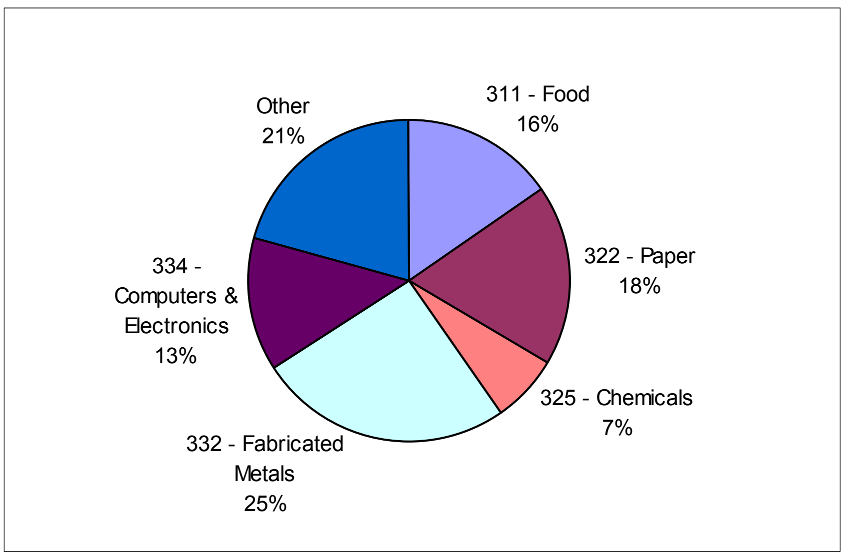
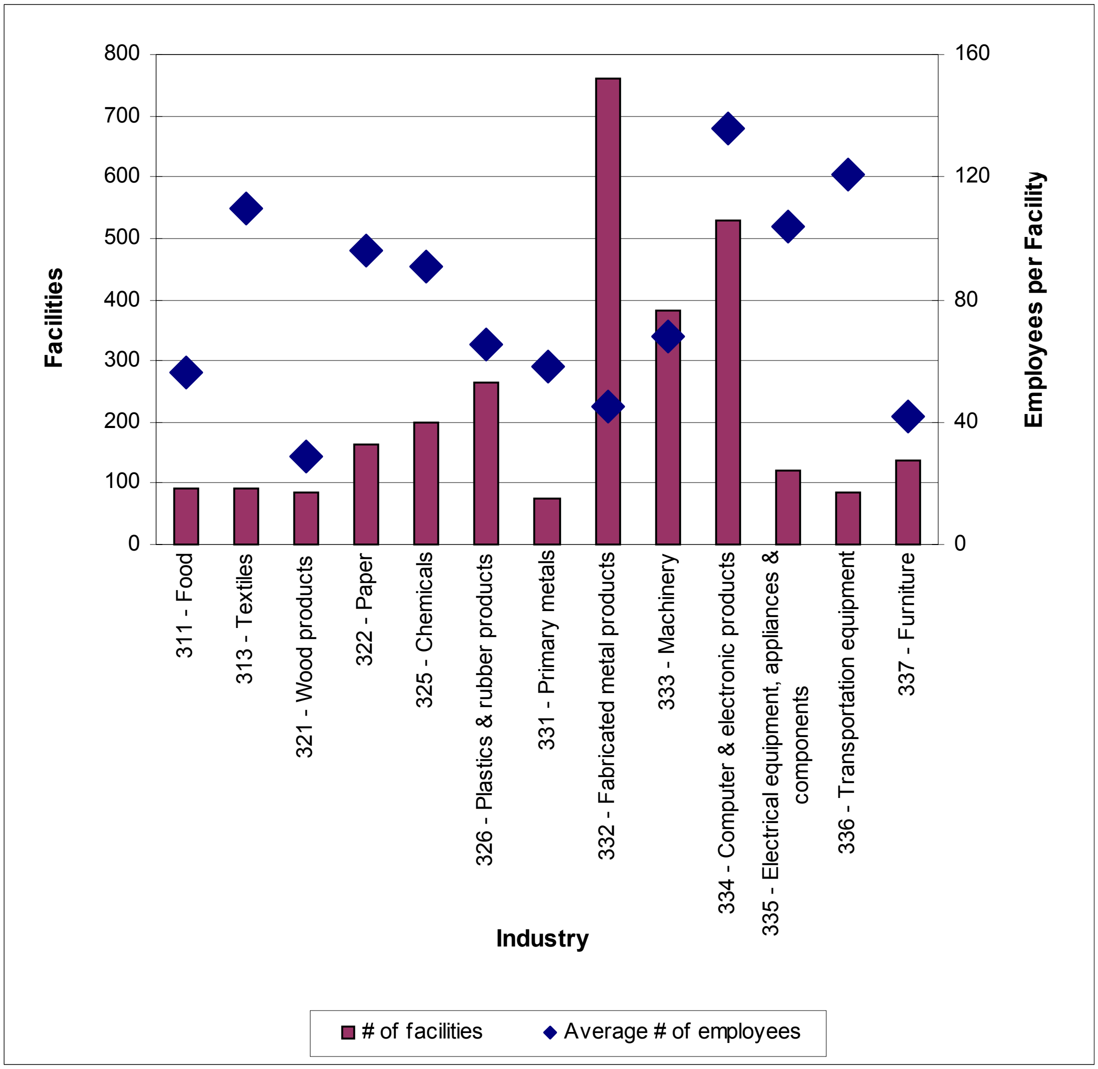


Figure 7.12: Size of the Manufacturing Industries in Massachusetts



The most potential, both in terms of number of systems and capacity, is in fabricated metal products (NAICS group 332). Based on the number of facilities, this is the largest manufacturing industry in the state, with 18% of the industrial facilities and 11% of the industrial workforce. In Massachusetts this industry is mainly made of machine shops; turned product; and screw, nut, and bolt manufacturing (NAICS 3327) and architectural and structural metals manufacturing (NAICS 3323). Of the more than 700 fabricated metals facilities in Massachusetts, 82% are small plants with 10 to 49 employees, so the potential CHP systems are primarily in the 50-500 kW range.

The other industries with the greatest potential number of systems are food (NAICS 311) and computer and electronic products (NAICS 334). For the greatest combined potential CHP capacity, the fabricated metals industry is followed by paper (NAICS 322) and food (NAICS 311) industries. The computer and electronics industry is one of the largest in the state, with 22% of the industrial workforce and 12% of the industrial facilities. 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.

The average size of the potential systems is 343 kW each, with the largest average system size in paper mills, which are amongst the largest and most energy intensive facilities in Massachusetts. Most of the potential systems are in the 50-500 kW size range. Figure 7.13 shows the average system size for each industry.

Figure 7.13: Average Potential Industrial CHP System Sizes

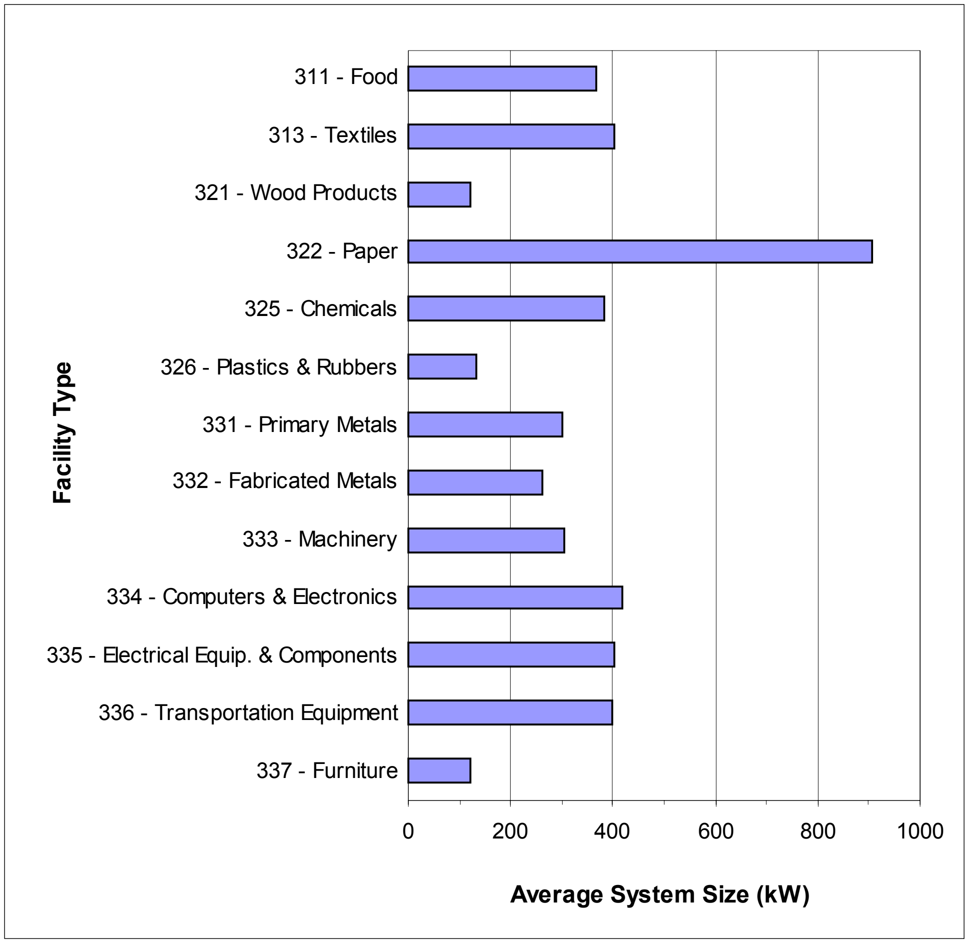
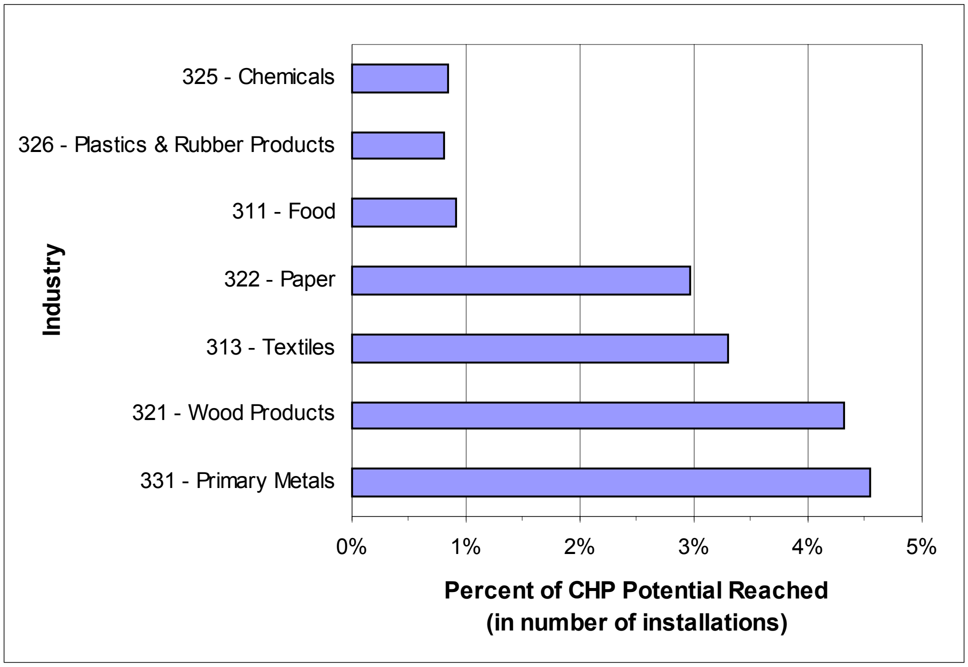


Figure 7.14 shows the current market penetration in the industries that have existing CHP systems in Massachusetts. No industry is found to have significant market penetration to date.

Figure 7.14: Penetration of Massachusetts Industrial CHP Market



7.5 Residential Sector

In the residential sector, CHP is most feasible for apartment and condominium buildings with 100 or more units. The 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 at 451 sites. Subtracting the existing residential CHP systems gave a remaining potential of 66 MW at 438 sites. Table 7.4 summarizes the potential in residential buildings. There has been 3% market penetration in the residential sector to date.

Table 7.4: Residential CHP Potential in Massachusetts

# of Sites	Total Capacity (MW)	Average System Size (kW)
438	66	150

Of these, about 60 buildings are federal low-income public housing, according to the United States Department of Housing and Urban Development (HUD).[40] In some public housing, utility costs are paid for the building as a whole and included in the rent, rather than billed to individual units. These buildings are especially well suited for CHP logistically because there is no effort required to measure energy consumption and distribute the cost of installing and operating a CHP system between a number of tenants.

7.6 Agricultural Sector

CHP may also be used in some applications in the agricultural sector. The Pace Energy Project at Pace University recently investigated the potential for CHP in the agricultural sector in a report titled Current and Potential CHP Use in the NY/New England Agricultural Industry. This report focuses on dairy farming, which is the predominant agricultural business in the region. Large dairy farms are well suited to CHP because they are energy intensive and power reliability is very important. The majority of the electricity on dairy farms is used for motors, and there is significant need for hot water as well as cooling. Dairy farms also have the potential to use manure-derived biogas as a fuel in their CHP systems, though current technology only makes this feasible on large farms with at least 500 cows.[41] The majority of the dairy farming in the region is in the states of New York and Vermont, however, with very little dairy production in Massachusetts. According to this report, there are not believed to be any dairy farms in Massachusetts that are large enough to make CHP cost effective. The United States Department of Agriculture's (USDA) National Agricultural Statistics Service data shows that the majority of the farms in Massachusetts are in crop production. Massachusetts farms are typically relatively small, with 60% of them under

---

[40] U.S. Department of Housing and Urban Development, Robert Groberg & Dianne Thompson.

[41] Thomas Bourgeois and Mackenzie Schoonmaker, Current and Potential CHP Use in the NY/New England Agricultural Industry, page 7.

50 acres. Just 12% of Massachusetts farms are 180 or more acres, compared to 34% nationally and 33% in New York and Vermont.[42]

Because agricultural production in Massachusetts is relatively small-scale and low in energy intensity, there is not believed to be significant potential for CHP in the Massachusetts agricultural sector.

7.7 Comparison of Massachusetts to National Potential

The distribution of the potential for CHP in Massachusetts is quite different than the distribution determined in the national reports. While there may be some inconsistency due to differences in the methodologies and data sources used for each report, this analysis is similar enough to the EIA and NYSERDA reports to make some meaningful comparisons. In Massachusetts 83% of the potential electrical capacity is in the commercial/institutional sector, and similarly the New York report found that 77% of that state's potential is in the commercial/institutional sector. At the national level, however, more than half of the potential capacity is reported to be in the industrial sector. Both states have far more of their potential in smaller systems than the country does overall. These differences are likely due to the industrial makeup of different parts of the country. For example, Massachusetts is known more for large commercial/institutional facilities such as hospitals and colleges and universities than for large industrial facilities, and Massachusetts and New York likely have a higher proportion of mid to large office buildings than many states that are less urban.

There is less variation within each sector. At both the state and national levels, the greatest commercial/institutional potential capacity was found to be in office buildings, and the greatest market penetration in colleges and universities. At both levels, the commercial/institutional potential is primarily in the smallest system sizes.

[42] U.S. Department of Agriculture, 2002 Census of Agriculture, pages 230, 232, 234.

The paper and food industries are amongst the top in potential industrial capacity at both the state and national levels. Nationally there is still significant potential in large industrial systems of at least 20 MW, but in Massachusetts there wasn't found to be any remaining potential for systems that large.

In the United States, the industrial market penetration of 33% (in terms of total installed capacity) is far higher than the 19% in Massachusetts. At both levels there has not been significant penetration of the commercial/institutional market.

7.8 Economics

The technical potential is based on energy consumption profiles, without taking economic factors into account. Economic analysis must be performed to determine the true viability of a potential CHP system. There are many variables that affect the economic viability of each project, including electric and gas utility rates and charges, business factors and government policies that would affect the system. With three major electric utility companies and several gas companies across Massachusetts, there is significant variation in rates and therefore in the economics of CHP. Several examples are given to provide a model for basic economic analysis and to evaluate the economic viability of CHP for some key facility types.

7.8.1 Method for Economic Analysis

This analysis considers CHP systems that use reciprocating engines fueled with natural gas as their prime movers. It is assumed that all electricity at these facilities is currently purchased from the utility, all heat is currently generated on-site using natural gas and all cooling is generated with electric chillers. The CHP systems are designed to run during the facility's operating hours and provide the base electrical load for each facility, so selling excess electricity to the grid is not considered in this analysis.

The current utility costs of meeting the facility's electric and thermal demand is calculated as follows.

$$AC_E = E_T \times MC_E + D_T \times MC_D \times M$$

AC_E	=	Annual cost of purchased electricity [$]
E_T	=	Total annual electricity consumption [kWh]
MC_E	=	Marginal cost of electricity [$/kWh]
D_T	=	Average monthly peak electrical demand [kW]
MC_D	=	Marginal cost of electrical demand [$/kW]
M	=	Number of months for which demand is billed; 12

$$AC_H = NG_T \times MC_{NGH}$$

AC_H	=	Annual cost for heating [$]
NG_T	=	Total annual natural gas consumption [MMBtu]
MC_{NGH}	=	Marginal cost of natural gas for heating [$/MMBtu]

The total cost of energy without CHP is therefore

$$ACOE_{original} = AC_E + AC_H$$

$ACOE_{original}$ = Annual cost of energy [$]

And the total heating demand is calculated as follows.

$$H_T = NG_T \times \varepsilon$$

H_T	=	Total annual heating demand [MMBtu]
ε	=	Heating system efficiency; assumed 80%

Annual electric and thermal generation from the CHP system are calculated using the electrical capacity and power to heat ratio specified for the CHP equipment. It is assumed that over a year of operation the CHP system is loaded at 80% of maximum capacity and that the facility can use 80% of the thermal energy generated with the CHP system.

$$E_G = KW \times H \times LF_C$$

E_G	=	Annual electricity generation [kWh]
KW	=	Electrical capacity of CHP system [kW]
H	=	Annual hours of operation [hrs]
LF_C	=	CHP load factor; assumed 80%

$$H_G = \frac{E_G \times C}{PHR} \times LF_H$$

H_G = Annual useful heat generation [MMBtu]
C = Conversion factor; 0.003413 MMBtu/kWh
PHR = Power to heat ratio for CHP equipment [MMBtu/MMBtu]
LF_H = Heating load factor; assumed 80%

The annual capital cost is calculated as follows, assuming the CHP equipment and installation is paid for with a loan.

$$AC_C = C_{CAP} \times KW \times \left(\frac{i(1+i)^Y}{(1+i)^Y - 1} \right)$$

AC_C = Annual capital cost for CHP system [$]
C_{CAP} = Installed capital cost of CHP system [$/kW]
i = Interest rate; assumed 10%
Y = Financing period [years]; assumed 10

The annual maintenance cost for the CHP system is calculated as follows.

$$AC_{O\&M} = C_{O\&M} \times E_G$$

$AC_{O\&M}$ = Annual cost of operation and maintenance [$]
$C_{O\&M}$ = CHP operation & maintenance cost [$/kWh]

A gas utility may charge one customer different rates depending on the way they use the natural gas. Most gas consumption by customers using gas primarily for heating will be in the colder months; those using gas for electricity generation and cooling as well as heating will have a more level consumption profile and will often pay a lower rate for natural gas. The cost of fuel for the CHP system is calculated as follows.

$$AC_F = HR \times E_G \times MC_{NGC}$$

AC_F = Annual fuel cost for CHP [$]
HR = Heat rate of CHP equipment [MMBtu/kWh]
MC_{NGC} = Marginal cost of natural gas with CHP [$/MMBtu]

Electricity will be purchased from the utility to supplement the on-site generation, and existing equipment will be used to generate additional heating. It is assumed that the annual average for demand billed by the utility will be 50% less than the demand before the installation of CHP. The calculation of supplemental utility costs is similar to calculation of the original electric and gas costs. The rates might be different, however, because the customer will purchase far less electricity and more natural gas once they have a CHP system on-site.

$$AC_{ES} = \left(E_T - E_G\right) \times MC_{ES} + \left(0.5 \times D_T\right) \times MC_{DS} \times M$$

AC_{ES}	=	Annual cost of supplemental electricity [$]
MC_{ES}	=	Marginal cost of supplemental electricity [$/kWh]
MC_{DS}	=	Marginal cost of supplemental electrical demand [$/kW]
M	=	Number of months for which demand is billed; 12

$$AC_{HS} = \frac{\left(H_T - H_G\right)}{\varepsilon} \times MC_{NGC}$$

AC_{HS}	=	Annual cost for supplemental heating [$]

As discussed in Chapters 3 and 6, some electric utilities charge a standby rate to customers who are generating electricity on-site. In Massachusetts, NSTAR is currently the only utility that charges a standby rate. The standby rate is calculated as follows.

$$AC_S = D_T \times MC_S \times M$$

AC_S	=	Annual electric standby cost [$]
MC_S	=	Marginal cost of standby [$/kW]
M	=	Number of months for which standby is billed; 12

The annual cost of energy with CHP is therefore

$$ACOE_{CHP} = AC_C + AC_{O\&M} + AC_F + AC_{ES} + AC_{HS} + AC_S$$

Then the annual benefit of CHP in dollars saved is

$$AB\$ = ACOE_{original} - ACOE_{CHP}$$

Or in terms of the percentage of energy costs saved annually with CHP

$$AB\% = \frac{AB\$}{ACOE_{original}}$$

If these values for annual benefit are negative then the cost of energy will increase over the specified financing period for the CHP system, or the payback time for the CHP system would be longer than this financing period.

Another way of looking at the economics of CHP is the simple payback period, or the number of years that it will take for the investment to pay for itself through reduced energy costs. This does not include the interest costs for any financing of CHP equipment, but it is frequently used in industry to consider the value of investments. The simple payback is

$$SP = \frac{AC_{O\&M} + AC_{F} + AC_{ES} + AC_{HS} + AC_{S}}{ACOE_{original}}$$

Another economic factor associated with CHP is emission offset purchases or emission reduction credits. Emission credits are sold on the market to provide an incentive for facilities to reduce their emissions. A facility that shows a reduction can generate revenue by selling their credits, and a facility that exceeds emissions limits may need to purchase credits. With their significant increase in efficiency over separate electricity and thermal energy generation, CHP reduces overall emissions, but on-site emissions may be increased. It is assumed in this analysis that the customer neither earns nor purchases emission credits. For more information on this topic, see Chapter 5 of Investigation Into the Systemwide Economic Benefits of Combined Heat and Power Generation In the New England Market by Christopher Beebe.

7.8.2 Economic Examples

The seven facilities considered as economic examples are shown in Table 7.5. This selection covers a variety of facility types, sizes, and locations, but all have average electric demand less than 1 MW since that is the area with both the most potential and the least market penetration. Details of the economic calculations are shown in Appendix D.

Table 7.5: Sample Facilities for Economic Analysis

Sector	Facility	Location	Size	Annual Operating Hours
Residential	Apartment Building	Cambridge	200 units	8,760
Industrial	Fabricated Metals	Pittsfield	75 employees	5,300
	Food Processing	Lawrence	50 employees	5,800
Commercial/ Institutional	Health Club	Quincy	16 employees	5,408
	Hotel	Worcester	50 employees	8,760
	Nursing Home	Plymouth	45 employees	8,760
	Office Building	Boston	325 employees	3,900

In these examples, it is assumed that CHP systems that use the thermal output to provide both heating and cooling are installed in the commercial/institutional and residential facilities and that CHP systems that provide only heating are installed in the industrial facilities.

The utility service areas in which each sample facility is located are shown in Table 7.6.

Table 7.6: Utilities for Sample Facilities

Facility	Location	Electric Utility	Gas Utility
Apartment Building	Cambridge	NSTAR	NSTAR
Fabricated Metals	Pittsfield	WMECO	Berkshire Gas
Food Processing	Lawrence	National Grid	Bay State Gas
Health Club	Quincy	National Grid	Keyspan
Hotel	Worcester	National Grid	NSTAR
Nursing Home	Plymouth	NSTAR	NSTAR
Office Building	Boston	NSTAR	Keyspan

Table 7.7 shows the size of the CHP system chosen for each sample facility and compares the annual energy costs with and without CHP.

Table 7.7: CHP Cost Comparison for Sample Facilities

Facility	CHP Electrical Capacity (kW)	Absorption Chiller Capacity (tons)	Original Annual Cost of Energy	Annual Cost of Energy with CHP
Apartment Building	100	75	$297,835	$290,735
Fabricated Metals	325	-	$338,179	$367,561
Food Processing	275	-	$532,997	$496,959
Health Club	50	50	$82,538	$87,963
Hotel	125	125	$318,245	$291,798
Nursing Home	50	50	$149,975	$134,178
Office Building	725	475	$973,788	$827,829

Table 7.8 shows the benefit of the CHP systems in the sample facilities. As explained above, the annual benefit and percent difference include the annual financing cost for capital, while the simple payback period does not. For the financing terms used in these examples, a positive annual benefit corresponds to a simple payback period of up to approximately six years.

Table 7.8: CHP Cost Benefits for Sample Facilities

Facility	Annual Benefit	Annual Benefit Percentage	Simple Payback Period (years)
Apartment Building	$4,555	2%	5.5
Fabricated Metals	-$29,382	-9%	11
Food Processing	$36,038	7%	3.7
Health Club	-$6,094	-7%	8.3
Hotel	$27,858	9%	4.0
Nursing Home	$14,259	10%	3.8
Office Building	$130,585	13%	4.0

For most of the facilities, this shows significant savings to be possible with the installation of a CHP system. For the sample fabricated metals plant and health club, however, the annual benefit is a negative value, meaning this simple analysis finds an increase in annual costs over the ten year financing period. While a net benefit would still be possible over the life of the system, the payback time for those investments would be longer than the ten year financing period assumed in this analysis. In some cases, a facility may benefit from using CHP even if there is a slight increase in energy costs; for example, many existing CHP systems were installed primarily to obtain more reliable power.

7.8.3 Factors In Economic Viability

These examples demonstrate the impact of utility rates and charges in the economics of CHP. The difference between the unit prices (in dollars per million Btu) of electricity and gas is known as the spark spread. This can be a useful indicator of the viability of CHP in a particular location, though it does not include other important factors such as the cost of demand. The higher this spark spread is, the more likely that CHP will be financially beneficial. The spark spread varies due to differences in locations, utility companies and utility rate classes. The fabricated metals plant and health club are the two sample facilities with the lowest spark spreads, as shown in Table 7.9, and also the two for which CHP would not reduce energy costs over the ten year financing period.

Table 7.9: Spark Spread for Sample Facilities

Facility	Spark Spread ($/MMBtu)
Apartment Building	$35
Fabricated Metals	$19
Food Processing	$33
Health Club	$25
Hotel	$29
Nursing Home	$33
Office Building	$44

Because the sample office building is located in NSTAR's electric territory, it would be subject to standby charges. In this case the standby charges raise the annual cost of generating energy with CHP by nearly $77,000. Without the standby charge, the annual benefit of CHP in the same facility would increase from 13% to 21% of total energy costs, and the simple payback period would be reduced from 4.0 to 3.3 years.

The requirement of a sizeable initial investment is often an obstacle to CHP installations, as discussed in Chapter 3. This analysis assumed a ten year financing period for all CHP installations. The loan and payback periods considered acceptable for new equipment varies between industries. In many manufacturing facilities, an investment of this type would not be considered unless the simple payback period was less than five years, despite significant savings potential in the longer term. Longer payback periods are more acceptable in some other types of facilities, such as residential buildings or low-turnover commercial facilities such as hotels. The ability to make longer-term investments is likely a reason for the relatively high market penetration of CHP in colleges and universities. Programs or policies that assist businesses in making this investment could have a considerable impact on the number of CHP systems being installed.

Use of CHP can provide benefits beyond the generating facility itself. As explained in Chapter 3, increased use of CHP would benefit society through reduced pollutant emissions and environmental damage, alleviated strain on congested transmission and distribution systems and conservation of valuable fuel resources. These other components of the true cost of energy consumption are known as externalities, and they are generally not tied directly to the cost of energy paid for by consumers. Incorporation of these costs into energy pricing would more accurately reflect the cost of energy and would be expected to improve the economics of CHP. <u>Life-Cycle Costing of Electric Power Generation Plants in New England: A Complete Fuel Cycle Approach Incorporating Externalities</u> by Ian Roth provides further analysis on the cost of externalities.

CHAPTER 8
RECOMMENDATIONS AND CONCLUSION

8.1 Recommendations for Future Work

An individual study will continue to be necessary to determine the viability of CHP at each specific site, but understanding of the CHP market could be furthered by building on this research in the following ways.

8.1.1 Data and Target Facility Types

The level of detail in this analysis was limited largely by the available data. Due to the confidentiality requirements for DOE surveys, the primary sources for this study provide data mostly at the national or regional level. CBECS provides national data for commercial/institutional facilities, but a significant amount of the energy use in commercial facilities is for space heating and cooling, so commercial energy usage varies significantly across the country. MECS provides data at the regional level, which does not support consideration of the mix of sub-industries specific to each state. If it were possible to obtain more localized information, it would allow for a more precise analysis of energy consumption and CHP potential in Massachusetts. MECS data is provided for each industry group at the 3-digit NAICS level and CBECS does not provide specific data for a few of the target facility types, so more specific information on energy consumption in the industry sub-groups and more specific facility types would also be valuable for a more in-depth analysis.

Further analysis could also improve upon the selection of target industries. For this analysis, that was based primarily on the previous studies, but as explained in Chapter 7, the primary thermal loads in some industries or sub-industries may not match with the types of thermal output possible with CHP. With further analysis of the specific type of thermal energy needed in each industry or sub-industry level, the target industries could be narrowed down to better include only those best suited to CHP.

8.1.2 Economics and Market Penetration

Additional economic analysis could assess future market penetration, provide a better understanding of the impact of specific policies, and consider other economic factors.

Because the total technical potential determined in this report is not expected to ever be reached, it would be valuable to determine what portion of that would be an achievable goal. As in the NYSERDA and CEC studies, the future market penetration could be estimated both under current circumstances and in the case of improved policies and advanced technologies.

Where additional staff or pollution control equipment are required by the state regulations explained in Chapter 6, there is significant cost beyond those included in this economic analysis. Other additional costs may include equipment upgrades to allow for interconnection with the grid or the purchase of emission offsets if required; benefits may include selling emission reduction credits if possible or participating in a load response program.

Some of the benefits of CHP, such as electric reliability, are more difficult to quantify than the direct energy costs. Further analysis might identify the types of facilities where this would be a driving factor then quantify the value of increased reliability for inclusion in the cost benefit analysis.

This economic analysis used current utility rates, but some utilities use different rates in the summer and winter months and rates may change often based on a variety of other factors. Advanced economic analysis could consider rates over the long term and include prediction of future rates.

8.1.3 Geographic Analysis

Another opportunity to provide more specifics lies in geographic analysis of the potential within Massachusetts. The data provided in County Business Patterns could be used to group most of the target facilities by county. A more useful breakdown would be by the utility service areas shown in Figures 4.1 and 4.2, since the policies of the electric utility and the availability of natural gas service are critical to the viability of a CHP project. Geographic Information System (GIS) technology could be used for more advanced geographic analysis, such as NYSERDA's Geographic Location Assessment Tool which assesses the suitability of specific locations for CHP or DG. Factors that could be included in geographic analysis include natural gas availability and rates, proximity to landfill gas as an alternate fuel, electric utility rates and charges and locational marginal pricing, electric grid networks and congestion zones, proximity to electric transmission lines, and proximity to areas of critical environmental concern designated by the Massachusetts Secretary of Environmental Affairs.

8.2 Conclusions

This thesis provides a better understanding of the status of CHP in Massachusetts and the potential for future installations. Many factors influencing the use of CHP and much of the related policy is specific to each state and often further specific to utility service area, so this state-specific analysis will serve a purpose in evaluating and taking action on the issues surrounding this efficient energy generation technology in Massachusetts.

The market penetration of CHP in Massachusetts is far lower than at the national level. While there is technical potential for nearly 5,000 MW of CHP in Massachusetts commercial/institutional, industrial and residential facilities, the current installed capacity is only 375 MW. Because technical potential is based only on technological feasibility, full market penetration is never expected. But increased use of CHP could provide many benefits, especially in a state that has electricity costs 41% above the national average, that has been designated by the EPA as an ozone nonattainment area, and that has an aging electricity infrastructure which has experienced grid congestion.

The economic analysis shows that the economic viability of CHP is highly variable, and in some cases significant savings is possible with CHP. The economics depend on many factors including the facility's electric and thermal energy demand and number of operating hours, the electric efficiency and power to heat ratio of installed CHP equipment, the financing for the equipment, and the costs of purchased electricity, fuel for CHP and other electric utility charges.

APPENDIX A
COMMERCIAL/INSTITUTIONAL CALCULATIONS

The analysis of commercial/institutional facilities focused on the types of facilities shown in Table A.1. Previous studies, including those by NYSERDA and CEC, have identified these facilities as well suited for CHP, based on their thermal energy loads, ratio of electric to thermal energy demand, and operating hours.

Table A.1: Commercial and Institutional Facility Types with Significant Potential for CHP

Facility Type	Primary Thermal Applications					NAICS Code
	Hot water	Space heating	Space cooling	Refrigeration	Pools	
Car washes	X					811192
Colleges & universities	X	X	X		X	61121, 61131
Correctional institutions	X	X				92214
Golf & country clubs	X	X	X		X	71391
Grocery stores	X	X	X	X		44511
Health clubs	X	X	X		X	71394
Hospitals	X	X	X			62211
Hotels & motels	X	X	X		X	72111
Laundries, commercial/industrial	X					81232, 812332
Movie theaters	X	X	X			512131
Museums	X	X	X			7121
Nursing homes & assisted living	X	X	X			62311, 623311
Office buildings	X	X	X			-
Restaurants, excluding fast-food	X	X	X	X		72211
Retail stores	X	X	X			452, 448, 442, 443
Schools	X	X	X		X	61111
Warehouses, refrigerated	X			X		49312
Water & sewage treatment plants	Process heating					22131, 22132

In existing commercial/institutional buildings, it is generally easiest to use the thermal output from CHP to provide hot water because it integrates well with existing equipment and hot water demand is more consistent year-round than most other thermal loads. The ratio of electric to hot water demand makes correctional institutions, education, health care, lodging and some public assembly buildings ideal for CHP, according to the NYSERDA report. Seasonal space heating can be provided with CHP most easily when the existing system uses hot water or steam. With the inclusion of space heating in the ratio of electric to thermal demand, CHP can be used in certain types of office buildings, retail and service facilities. Cooling, refrigeration and dehumidification can also be generated with CHP using absorption chillers and desiccant dehumidification. This allows for larger and more economical CHP systems in education, health care and lodging, and also makes CHP feasible in grocery stores, more public assembly buildings, restaurants and refrigerated warehouses.

EIA publishes the Commercial Buildings Energy Consumption Survey every four years. CBECS provides information about energy consumption in facilities across the country, based on a survey of a sampling of facilities. The 1999 survey is the most recent for which energy consumption information is available. Most of the CBECS data is provided at only the national level, due to sample sizes and confidentiality requirements for survey participants.

CBECS provides energy information for commercial/institutional facilities grouped by principal building activity (PBA). These are 13 broad categories based on the activity for which the most floor space is used in a building, with most categories further broken down into subcategories. Data for colleges and universities is provided in two CBECS PBA categories. The Education category includes classroom buildings, and Lodging includes dormitory buildings and fraternity and sorority houses. Analysis of colleges and universities was therefore based on an average of these two categories from CBECS. CBECS does not provide information on water and sewage treatment plants, so energy consumption for this type of facility was estimated based on the NYSERDA report. Table A.2 shows each facility type and the CBECS PBA category that was used for its energy consumption data.

Table A.2: Facility Types and Corresponding CBECS Categories

Facility Type	CBECS Category	CBECS Sub-Category
Car washes	Service	Other service
Colleges & universities	Education	College / University
	Lodging	Dormitory / Fraternity / Sorority
Correctional institutions	Public Order and Safety	Jail / Prison / Reformatory
Golf & country clubs	Public Assembly	Recreation
Grocery stores	Food Sales	Grocery store / Food market
Health club	Public Assembly	Recreation
Hospitals	Health Care	Hospital / inpatient health
Hotels & motels	Lodging	Hotel
		Motel / Inn / Resort
Laundries, commercial/industrial	Service	Dry cleaner / Laundromat
Movie theaters	Public Assembly	Entertainment
Museums	Public Assembly	Library / Museum
Nursing homes & assisted living	Lodging	Nursing home / Assisted Living
Office buildings	Office	-
Restaurants, excluding fast-food	Food Service	-
Retail stores	Mercantile	-
Schools	Education	Elementary / middle / high school
Warehouses, refrigerated	Warehouse and Storage	Refrigerated
Water & sewage treatment plants	N/A (energy consumption estimated from NYSERDA report)	

The size of potential CHP systems was calculated based on the average electrical demand during the facility's operating hours, to optimize use in conjunction with the electrical grid. To determine this demand, the net annual electricity consumption (kWh) is multiplied by a load factor to account for base electrical load used outside of operating hours and divided by the average annual operating hours for that type of facility. (This load factor was estimated to be 92%. Actual values depend on operations and operating hours at each facility. The load factor was not used for facility types that are typically operational at all hours.)

The number and size of most facilities was obtained from the United States Census Bureau's 2002 County Business Patterns, which provides the number of establishments at both the state and county level.

Other data sources were used for three facility types that are not listed in County Business Patterns. Public administration buildings are not included in County Business Patterns, so the number of water and sewage treatment plants was estimated using information from the Massachusetts Water Pollution Control Association, and the number of correctional institutions in Massachusetts was obtained from the Federal Bureau of Prisons, Massachusetts Department of Corrections and county sheriff's offices. County Business Patterns could not be used for office buildings because it provides the number of individual business establishments that are in office buildings rather than the number of buildings. The approximate number and size of office buildings in Massachusetts was therefore calculated using data from CBECS. There are a total of 47,000 office buildings in New England, according to CBECS, and 45% of New England's population is in Massachusetts, according to the Census Bureau. It was therefore assumed that Massachusetts has 45% of the office buildings in New England, or 21,000 buildings. CBECS provides a national breakdown of office buildings by the number of employees, so the sizes of the office buildings in Massachusetts was determined by assuming this distribution is comparable at the state level.

All facilities with five or more employees were considered in this analysis, but results showed CHP to generally not be feasible for facilities with less than ten or twenty-five employees, depending on the type of facility. County Business Patterns groups facilities by the NAICS codes, with breakdown by employee size ranges. Therefore to calculate the current energy consumption and appropriate CHP system size for facilities of different sizes, the energy consumption per employee was found for each facility type.

Table A.3 shows average energy consumption per employee and the average number of operating hours for each facility type. Energy consumption for each PBA was calculated using CBECS Tables B1, C9, C15, C21 and C25. Data for PBA sub-categories was obtained from the special section on 1999 Building Activities on the EIA website. Operating hours were estimated based on CBECS and other business information.

Table A.3: Average Energy Consumption per Employee in Massachusetts Facilities

Facility Type	# of Facilities	Average Annual Operating Hours	Average Per Employee	
			Annual Electricity Use (MWh)	Average Hourly Electric Demand (kW)
Car washes	146	3,276	11	3.0
Colleges & universities	125		28 Average	5.4 Average
Education		3,120	13	3.9
Lodging		6,570	43	6.1
Correctional institutions	40	8,760	17	1.9
Golf & country clubs	207	4,000	25	5.8
Grocery stores	1,318	6,136	40	6.0
Health clubs	527	5,616	25	4.1
Hospitals	131	8,760	15	1.7
Hotels & motels	454	8,760	29	3.3
Laundries, commercial/industrial	432	3,276	12	3.4
Movie theaters	101	4,380	9	2.0
Museums	97	2,808	18	5.9
Nursing homes & assisted living	2,026	8,760	13	1.5
Office buildings	15,296	2,756	9	2.8
Restaurants, excluding fast-food	3,634	4,368	16	3.3
Retail stores	6,653	3,380	13	3.7
Schools	500	2,600	8	2.9
Warehouses, refrigerated	25	8,760	18	2.1
Water & sewage treatment plants	148	8,760	219	25

Facilities were then grouped into categories by number of employees, and the median number of employees in each category was multiplied by the average electric demand per employee to put the facilities into categories by electric demand size ranges. The appropriate sizes for CHP systems in different facility types were based on those recommended in the NYSERDA and CEC reports. These values, shown in Table A.4, are based on electrical and thermal loads and the power to thermal output of available CHP equipment. The minimum CHP system used is 50 kW, based on equipment currently available.

Table A.4: Recommended CHP System Sizes, by Average Site Electrical Demand

Facility Electric Demand Range	50 - 500 kW	500 kW - 1 MW	1 - 5 MW	5 - 20 MW	20+ MW
Facility Type	**Appropriate CHP System Size**				
	(kW)	**(kW)**	**(MW)**	**(MW)**	**(MW)**
Car washes	150	-	-	-	-
Colleges & universities	150	750	2.5	12.5	25
Correctional institutions	150	750	2.5	12.5	-
Golf & country clubs	150	750	2.5	-	-
Grocery stores	75	375	1.25	-	-
Health clubs	150	750	2.5	-	-
Hospitals	180	900	3.0	15.0	-
Hotels & motels	180	900	3.0	-	-
Laundries, commercial/industrial	150	750	2.5	-	-
Movie theaters	150	-	-	-	-
Museums	150	750	2.5	-	-
Nursing homes & assisted living	180	900	3.0	-	-
Office buildings	60	300	1.0	5.0	-
Restaurants, excluding fast-food	75	375	1.25	-	-
Retail stores	75	375	1.25	-	-
Schools	75	375	1.25	-	-
Warehouses, refrigerated	150	750	2.5	-	-
Water & sewage treatment plants	150	750	2.5	12.5	-

The information in Table A.4 was used with the facility size information from County Business Patterns to determine the capacity for CHP systems in Massachusetts, as shown in Tables A.5-A.6. Table A.5 details the potential by current average electrical demand and potential CHP system size. Table A.6 shows the total potential for commercial/institutional CHP systems in Massachusetts.

Table A.5: Potential for Commercial and Institutional CHP in Massachusetts

Facility Electric Demand Range	**50 - 500 kW**		**500 kW - 1 MW**		**1 - 5 MW**		**5 - 20 MW**		**20+ MW**	
Facility Type	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**
Car washes	67	10	-	-	-	-	-	-	-	-
Colleges & universities	42	6	9	7	38	95	25	313	4	100
Correctional institutions	18	3	12	9	7	18	-	-	-	-
Golf & country clubs	139	21	4	3	4	10	-	-	-	-
Grocery stores	525	39	148	56	171	214	-	-	-	-
Health clubs	328	49	38	29	2	5	-	-	-	-
Hospitals	26	5	31	28	63	189	7	105	-	-
Hotels & motels	334	50	27	24	23	69	-	-	-	-
Laundries, commercial/industrial	205	31	4	3	2	5	-	-	-	-
Movie theaters	59	9	-	-	-	-	-	-	-	-
Museums	52	8	4	3	6	15	-	-	-	-
Nursing homes & assisted living	873	157	39	35	3	9	-	-	-	-
Office buildings	4,577	275	416	125	561	561	99	495	-	-
Restaurants, excluding fast-food	2,644	198	50	19	2	3	-	-	-	-
Retail stores	3,576	268	138	52	45	56	-	-	-	-
Schools	271	20	37	14	16	20	-	-	-	-
Warehouses, refrigerated	11	2	-	-	-	-	-	-	-	-
Water & sewage treatment plants	100	15	20	15	24	60	4	50	-	-
CHP System Size Range	**50 - 500 kW**		**500 kW - 1 MW**		**1 - 5 MW**		**5 - 20 MW**		**20+ MW**	

Table A.6: Total Potential for Commercial and Institutional CHP in Massachusetts

Facility Type	# of Sites	Total MW	Average System Size (kW)
Car washes	67	10	150
Colleges & universities	118	521	4,411
Correctional institutions	37	29	789
Golf & country clubs	147	34	230
Grocery stores	844	309	366
Health clubs	368	83	225
Hospitals	127	327	2,571
Hotels & motels	384	143	373
Laundries, commercial/industrial	211	39	184
Movie theaters	59	9	150
Museums	62	26	416
Nursing homes & assisted living	915	201	220
Office buildings	5,653	1,456	257
Restaurants, excluding fast-food	2,696	220	81
Retail stores	3,759	376	100
Schools	324	54	167
Warehouses, refrigerated	11	2	150
Water & sewage treatment plants	148	140	946
TOTAL	15,937	4,022	252

To determine the remaining potential for CHP, the number of sites with existing CHP systems was deducted from the total number of sites. The total remaining potential capacity was based on this number of sites and the average system size from Table A4. The remaining potential for CHP in Massachusetts commercial/institutional sites is shown in Tables A.7-A.8.

Table A.7: Remaining Potential Commercial and Institutional Sites for CHP in Massachusetts

CHP System Size Range	50 - 500 kW		500 kW - 1 MW		1 - 5 MW		5 - 20 MW		20+ MW	
Facility Type	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**
Car washes	67	10	-	-	-	-	-	-	-	-
Colleges & universities	35	5	5	4	34	85	22	275	3	75
Correctional institutions	18	3	12	9	6	15	-	-	-	-
Golf & country clubs	139	21	4	3	4	10	-	-	-	-
Grocery stores	524	39	148	56	171	214	-	-	-	-
Health clubs	324	49	38	29	2	5	-	-	-	-
Hospitals	26	5	29	26	60	180	6	90	-	-
Hotels & motels	330	50	27	24	23	69	-	-	-	-
Laundries, commercial/industrial	205	31	4	3	2	5	-	-	-	-
Movie theaters	59	9	-	-	-	-	-	-	-	-
Museums	52	8	4	3	6	15	-	-	-	-
Nursing homes & assisted living	844	152	34	31	3	9	-	-	-	-
Office buildings	4,577	275	416	125	560	560	99	495	-	-
Restaurants, excluding fast-food	2,644	198	50	19	2	3	-	-	-	-
Retail stores	3,576	268	138	52	45	56	-	-	-	-
Schools	269	20	31	12	16	20	-	-	-	-
Warehouses, refrigerated	11	2	-	-	-	-	-	-	-	-
Water & sewage treatment plants	100	15	20	15	24	60	3	38	-	-
TOTAL	13,800	1,158	960	409	963	1,321	132	928	3	75

Table A.8: Total Remaining Potential Commercial and Institutional Sites for CHP in Massachusetts

Facility Type	# of Sites	Total MW	Average System Size (kW)
Car washes	67	10	150
Colleges & universities	99	444	4,485
Correctional institutions	36	27	742
Golf & country clubs	147	34	230
Grocery stores	843	309	366
Health clubs	364	82	226
Hospitals	121	301	2,486
Hotels & motels	380	143	376
Laundries, commercial/industrial	211	39	184
Movie theaters	59	9	150
Museums	62	26	416
Nursing homes & assisted living	881	192	217
Office buildings	5,652	1,455	257
Restaurants, excluding fast-food	2,696	220	81
Retail stores	3,759	376	100
Schools	316	52	164
Warehouses, refrigerated	11	2	150
Water & sewage treatment plants	147	128	867
TOTAL	15,858	3,890	245

APPENDIX B
INDUSTRIAL CALCULATIONS

The analysis of industrial facilities focused on the industries that have been determined in previous studies to be well suited for CHP, based on their thermal energy loads, electric to thermal energy demand ratios, and at least 3,000 annual hours of operation.

The primary data source used for analysis of industrial facilities was the Manufacturing Energy Consumption Survey, published every four years by the EIA. MECS provides composite energy consumption information for all manufacturing facilities in the United States, extrapolated from a survey of a sampling of facilities. In addition to national data, most of the data is available at the industry (grouped by NAICS codes) and regional (grouped by the four U.S. Census Regions) levels. Due to confidentiality requirements for survey participants, no data is available at the state or facility level.

This six-digit NAICS codes recently replaced the four-digit SIC code system. Table B.1 shows the general correlation between the relevant NAICS and SIC groups for reference because some applications and related reports still use the SIC system.

Table B.1: Correlation Between SIC and NAICS Groups

NAICS Code	SIC Code(s)	Industry Description
311	20	Food
313	22	Textiles
321	24	Wood products
322	26	Paper
325	28	Chemicals
326	30	Plastics & rubber products
331	33	Primary metals
332	34,35	Fabricated metal products
333	35	Machinery
334	35,36,38	Computer & electronic products
335	36	Electrical equipment, appliances & components
336	37	Transportation equipment
337	25	Furniture

State level energy consumption was estimated using the method explained in the report Identification of Northeast Regional Industries of the Future from Alfred University and the University of Massachusetts Amherst. The northeast region includes nine states: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. Massachusetts' share of the industries in the region was determined using the 2003 Annual Survey of Manufactures published by the United States Census Bureau. For each industry of interest, six economic indicators from Annual Survey of Manufactures (total number of employees, total payroll, number of production workers, hours worked by production workers, value added, and total value of shipments) were totaled for all states in the northeast region. Massachusetts' percentage of each indicator was calculated as shown in Table B.2, and the average of those percentages was used to determine the share of each industry in the state. One industry that is well suited to CHP, petroleum and coal products manufacturing (NAICS 324), is not included here because the size of that industry is negligible in Massachusetts.

Most source data was available, and therefore most analysis was performed, at the three-digit NAICS level. For paper manufacturing (NAICS 322) and primary metal manufacturing (NAICS 331), an extra effort was made to use the four-digit NAICS level where available because the makeup and energy intensity of these industries vary significantly across the region. The statewide energy consumption totals for these industries were obtained by totaling the consumption for the sub-industries (four-digit NAICS level) existing in Massachusetts, based on the percentage of the sub-industries in Table B.2.

Table B.2: Massachusetts' Share of All Industry in the Northeast Region

NAICS Code	Industry Description	Massachusetts Share of Northeast Region						
		All employees		Production workers		Value added ($)	Total value of shipments ($)	Average
		#	Payroll ($)	#	Hours			
311	Food	10%	11%	10%	10%	8%	9%	10%
313	Textiles	24%	25%	24%	25%	23%	23%	24%
321	Wood products	7%	7%	6%	6%	6%	6%	6%
322	Paper	16%	15%	16%	16%	12%	13%	15%
3221	Pulp, paper & paperboard mills	14%	12%	12%	12%	7%	8%	11%
3222	Converted paper product manufacturing	18%	18%	17%	18%	16%	17%	17%
325	Chemicals	11%	11%	11%	11%	8%	8%	10%
326	Plastics & rubber products	13%	13%	12%	12%	14%	14%	13%
331	Primary metals	6%	5%	6%	6%	4%	4%	5%
3314	Nonferrous metal (except alum.) production & processing	12%	12%	11%	12%	10%	11%	11%
3315	Foundries	7%	7%	7%	9%	7%	6%	7%
332	Fabricated metal products	13%	14%	13%	13%	15%	14%	14%
333	Machinery	14%	16%	14%	13%	15%	14%	14%
334	Computer & electronic products	26%	28%	24%	24%	38%	35%	29%
335	Electrical equipment, appliances & components	20%	21%	18%	18%	18%	18%	19%
336	Transportation equipment	6%	7%	5%	5%	9%	9%	7%
337	Furniture	10%	11%	9%	11%	11%	11%	10%

The percentage of industry in Massachusetts was multiplied by MECS regional data to calculate the state's energy consumption levels. The primary source of energy consumption data was Table 3.1 from the 2002 MECS, which provides a breakdown of electricity and fuel consumption (excluding fuels used as a feedstock) by region and industry. Statewide consumption is shown in Table B.3.

To use fuel consumption data to determine thermal energy demand, use of fuel for thermal applications needed to be separated from other applications such as electricity generation, machine drive, and on-site transportation. MECS Table 5.2, which provides a national breakdown of the end use of fuels (excluding fuels used as a feedstock) in each industry, was used to determine the percentage of fuel in each industry that is used for thermal applications, as shown in Table B.3.

Table B.3: Massachusetts Industry Information

NAICS Code	Industry Description	# of Facilities	Average Annual Opera-ting Hours	Statewide Annual Energy Consumption			
				Total Fuel (trillion Btu)	Electricity (million kWh)	All Fuels Except Electricity	
						Total (trillion Btu)	% Used for Thermal Applic-ations
311	Food	330	5,800	9.0	645	6.8	81%
313	Textiles	91	6,400	5.8	323	4.7	79%
321	Wood products	86	4,200	1.4	83	1.1	93%
322	Paper	162	6,000	31.1	1,028	27.6	85%
325	Chemicals	198	4,900	16.3	1,238	12.1	81%
326	Plastics & rubber products	264	6,400	6.0	979	2.6	85%
331	Primary metals	76	4,600	7.0	428	5.5	96%
332	Fabricated metal products	760	5,300	7.5	879	4.5	89%
333	Machinery	383	4,300	3.9	527	2.1	85%
334	Computer & electronic products	530	5,100	17.8	3,257	6.7	87%
335	Electrical equipment, appliances & components	122	4,900	3.2	375	1.9	88%
336	Transportation equipment	84	5,500	3.4	282	2.5	83%
337	Furniture	136	3,500	0.6	87	0.3	92%

To size a CHP system that will be used in conjunction with the electrical grid, it is best to consider average electrical demand rather than the peak demand typically measured by the electrical utility for billing purposes.

To determine this demand, the net electricity consumption (kWh) is multiplied by a load factor to account for base electrical load used outside of facility operating hours and divided by the average annual operating hours for that industry. (This load factor was estimated to be 92%. Actual values depend on operations and operating hours at each facility. A relatively high estimate was made, since the facilities best suited for CHP will have longer operating hours and therefore a higher load factor.) The number of operating hours, shown in Table B.3, was determined from data collected by the Department of Energy's Industrial Assessment Center (IAC) at the University of Massachusetts Amherst. IAC data consists of averages from the 377 facilities throughout New England that have been visited since 1990. Exceptions are the Electrical Equipment, Appliances & Components (NAICS 335), Transportation Equipment (336), and Furniture (337) industries, for which five or fewer assessments have been performed in New England; in these cases an average of local data and data collected by the other IACs around the country since 1990 is used.

Energy consumption for individual facilities was determined using consumption per employee figures that were calculated for each industry by dividing the state level data for each industry by the number of employees that industry has in the state. The number and size of companies in each industry was obtained from the Census Bureau's 2002 County Business Patterns, which provides the number of employees and facilities (with breakdown by employee size ranges) in each industry at both the state and county level. This analysis of industrial applications considers only establishments with ten or more employees, as any smaller facility is unlikely to participate in energy intensive manufacturing activities, to meet the minimum annual operating hours recommended for CHP, or to be able to make the investment in CHP equipment. Average consumption per facility and per employee are shown in Tables B.4 and B.5.

Table B.4: Average Energy Consumption in Massachusetts Facilities

NAICS Code	Industry Description	Average Per Facility			
		# of Emp-loyees	Annual Electricity Use (MWh)	Average Hourly Electricity Demand (kW)	Annual Use of All Fuels Except Electricity (MMBtu)
311	Food	56	1,956	310	20,659
313	Textiles	110	3,545	510	51,535
321	Wood products	29	964	211	12,787
322	Paper	96	6,344	973	170,305
325	Chemicals	91	6,254	1,174	61,084
326	Plastics & rubber products	65	3,710	533	9,917
331	Primary metals	58	5,628	1,126	72,864
332	Fabricated metal products	45	1,156	201	5,914
333	Machinery	68	1,375	294	5,362
334	Computer & electronic products	136	6,144	1,108	12,593
335	Electrical equipment, appliances & components	104	3,072	577	15,460
336	Transportation equipment	121	3,363	563	29,452
337	Furniture	42	639	168	2,431

Table B.5: Average Energy Consumption per Employee in Massachusetts Facilities

NAICS Code	Industry Description	Average Per Employee			
		Annual Electricity Use (MWh)	Average Hourly Electricity Demand (kW)	Annual Use of All Fuel Except Electricity (MMBtu)	Annual Thermal Use of All Fuels Except Electricity (MMBtu)
311	Food	35	5.5	367	298
313	Textiles	32	4.6	468	369
321	Wood products	33	7.3	441	411
322	Paper	66	10.1	1,774	1,514
325	Chemicals	69	12.9	673	542
326	Plastics & rubber products	57	8.2	153	130
331	Primary metals	98	19.6	1,266	1,214
332	Fabricated metal products	25	4.4	130	115
333	Machinery	20	4.3	78	67
334	Computer & electronic products	45	8.1	92	80
335	Electrical equipment, appliances & components	30	5.6	149	130
336	Transportation equipment	28	4.7	244	203
337	Furniture	15	4.0	58	54

The ratio of electric to thermal energy demand (E/T) is critical to sizing CHP systems. IAC data is used to determine the E/T for an average facility in each industry, shown in Table B.6. E/T is a dimensionless ratio, which was calculated using the quantity of purchased electricity (converted to MMBtu) and the quantity of purchased fuel (MMBtu) multiplied by the percentage of fuel in that industry that is used for thermal applications. This could not be obtained from MECS because it does not provide any facility-level information.

Table B.6: Electricity to Thermal Energy Ratios

NAICS Code	Industry Description	Electricity / Thermal Energy Ratio (MMBtu/MMBtu)
311	Food	1.2
313	Textiles	1.1
321	Wood products	4.0
322	Paper	0.9
325	Chemicals	3.0
326	Plastics & rubber products	9.0
331	Primary metals	3.8
332	Fabricated metal products	1.2
333	Machinery	2.7
334	Computer & electronic products	6.5
335	Electrical equipment, appliances & components	2.8
336	Transportation equipment	2.8
337	Furniture	1.7

When the E/T ratio is similar to the power to heat output ratio for CHP equipment, CHP systems sized based on electrical demand can be used to satisfy both the thermal and average electrical loads. Therefore for industries with average E/T up to 1.2, the CHP capacity is based on electrical demand. These industries are Food (NAICS 311), Textiles (313), Paper (322), and Fabricated Metal Products (332). In cases with higher E/T ratios, a CHP system sized to satisfy electrical demand would produce excess thermal energy. Therefore for industries with average E/T greater than 1.2, the CHP capacity is based on thermal demand, using an average power to heat output ratio of 0.85 for CHP systems based on equipment data provided in the CEC report. These industries are Wood (321), Chemicals (325), Plastics & Rubber (326), Primary Metals (331), Machinery (333), Computer and Electronic Products (334), Electrical Equipment, Appliances and Components (335), Transportation Equipment (336), and Furniture (337).

According to this data, several industries have an average E/T ratio above the 0.5-2.5 range generally recommended for CHP. One of these industries, SIC 36, Electrical and

Electronic Equipment, which corresponds mainly to NAICS 334 and 335, was not included in the NYSERDA report, presumably because of its high E/T. These industries were included in this analysis, however, because CHP may still be feasible. A CHP system sized based on thermal demand as described above will provide a relatively small amount of the electrical demand for a facility with high E/T, but the facility could still benefit from using CHP. Computer and Electronic Products (NAICS 334) facilities in particular may see advantages beyond efficiency, such as increased electric reliability which can be very valuable in many high-tech manufacturing operations. As one of the largest industries in the state, with 26% of the industrial facilities employing 100 or more and 44% of those employing 500 or more, it is important to include the computer and electronics industry in the study of potential energy efficiency measures in Massachusetts.

This analysis assumes that all facilities will work in parallel with the electrical grid, so systems are sized to maximize efficiency rather than to satisfy full electrical loads. Facilities will be excluded if the calculated CHP system size is less than 50 kW, as systems below that size are not generally feasible.

These criteria were combined with the consumption per employee figures in Table B.5 and facility size information from the County Business Patterns to determine the capacity for industrial CHP systems in Massachusetts, as shown in Tables B.7-B.9. Table B.7 shows facilities grouped by current average electrical demand. Table B.8 shows facilities grouped by potential CHP system size. Table B.9 shows the total industrial CHP potential in Massachusetts.

Table B.7: Potential Industrial Sites for CHP in Massachusetts, by Average Site Electrical Demand

Facility Electric Demand Range		50 – 250 kW			250 - 500 kW			500 - 750 kW		
NAICS Code	**Industry Description**	**# of Sites**	**Total MW**	**Avg Size (kW)**	**# of Sites**	**Total MW**	**Avg Size (kW)**	**# of Sites**	**Total MW**	**Avg Size (kW)**
311	Food	241	36	150	53	19	350	0	-	-
313	Textiles	53	8.0	150	16	5.6	350	0	-	-
321	Wood products	*	-	-	29	2.1	74	4	0.5	132
322	Paper	14	2.1	150	52	18	350	0	-	-
325	Chemicals	*	-	-	65	6.4	98	0	-	-
326	Plastics & rubber products	*	-	-	*	-	-	56	3.3	59
331	Primary metals	0	-	-	20	1.6	79	29	4.1	141
332	Fabricated metal products	607	91	150	90	32	350	0	-	-
333	Machinery	*	-	-	53	5.9	112	0	-	-
334	Computer & electronic products	*	-	-	*	-	-	105	9	82
335	Electrical equipment, appliances & components	*	-	-	27	2.9	106	0	-	-
336	Transportation equipment	*	-	-	10	1.0	105	0	-	-
337	Furniture	111	8	74	13	2.2	172	9	2.8	307
TOTAL		1,026	145	142	428	96	224	203	19	95

* While there are facilities in this demand range, they are excluded because the calculated CHP system size is less than 50 kW.

Table B.7 continued

Facility Electric Demand Range		750 kW - 1 MW			1 - 2 MW			2 - 5 MW		
NAICS Code	Industry Description	# of Sites	Total MW	Avg Size (kW)	# of Sites	Total MW	Avg Size (kW)	# of Sites	Total MW	Avg Size (kW)
311	Food	19	17	875	0	-	-	17	60	3,500
313	Textiles	15	13	875	4	6.0	1,500	2	7.0	3,500
321	Wood products	0	-	-	4	1.3	316	1	0.7	738
322	Paper	42	37	875	46	69	1,500	6	21	3,500
325	Chemicals	31	7.6	244	0	-	-	33	32	978
326	Plastics & rubber products	0	-	-	32	4.5	142	7	2.3	331
331	Primary metals	0	-	-	15	5.1	338	9	7.1	789
332	Fabricated metal products	44	39	875	12	18	1,500	6	21	3,500
333	Machinery	44	12	280	16	7.7	479	5	5.6	1,118
334	Computer & electronic products	0	-	-	81	16	197	31	14	459
335	Electrical equipment, appliances & components	24	6.3	264	0	-	-	11	12	1,057
336	Transportation equipment	9	2.4	262	1	0.4	450	0	-	-
337	Furniture	0	-	-	2	1.5	737	1	1.7	1,719
TOTAL		228	134	586	213	129	608	129	184	1,427

Table B.7 continued

Facility Electric Demand Range		5 - 10 MW			10 - 20 MW			20+ MW		
NAICS Code	Industry Description	# of Sites	Total MW	Avg Size (kW)	# of Sites	Total MW	Avg Size (kW)	# of Sites	Total MW	Avg Size (kW)
311	Food	0	-	-	0	-	-	0	-	-
313	Textiles	0	-	-	1	15	15,000	0	-	-
321	Wood products	0	-	-	0	-	-	0	-	-
322	Paper	2	15	7,500	0	-	-	0	-	-
325	Chemicals	3	6.3	2,095	0	-	-	3	25	8,380
326	Plastics & rubber products	4	2.8	710	0	-	-	0	-	-
331	Primary metals	3	5.1	1,691	0	-	-	0	-	-
332	Fabricated metal products	0	-	-	1	15	15,000	0	-	-
333	Machinery	0	-	-	1	4.8	4,791	0	-	-
334	Computer & electronic products	16	16	984	0	-	-	13	51	3,935
335	Electrical equipment, appliances & components	0	-	-	1	4.5	4,529	0	-	-
336	Transportation equipment	0	-	-	2	9	4,500	0	-	-
337	Furniture	0	-	-	0	-	-	0	-	-
TOTAL		28	45	1,605	6	48	8,053	16	76	4,769

Table B.8: Potential Industrial Sites for CHP in Massachusetts, by CHP System Size

CHP System Size Range		50 – 500 kW		500 kW - 1 MW		1 – 5 MW		5 - 20 MW	
NAICS Code	Industry Description	# of Sites	Total MW	# of Sites	Total MW	# of Sites	Total MW	# of Sites	Total MW
311	Food	294	55	19	17	17	60	0	0
313	Textiles	69	14	15	13	6	13	1	15
321	Wood products	37	4	1	1	0	0	0	0
322	Paper	66	20	42	37	52	90	2	15
325	Chemicals	96	14	33	32	3	6	3	25
326	Plastics & rubber products	95	10	4	3	0	0	0	0
331	Primary metals	64	11	9	7	3	5	0	0
332	Fabricated metal products	697	123	44	39	18	39	1	15
333	Machinery	113	26	0	0	6	10	0	0
334	Computer & electronic products	217	39	16	16	13	51	0	0
335	Electrical equipment, appliances & components	51	9	0	0	12	16	0	0
336	Transportation equipment	20	4	0	0	2	9	0	0
337	Furniture	133	13	2	1	1	2	0	0
TOTAL		1,952	341	185	165	133	301	7	70

Table B.9: Total Potential Industrial Sites for CHP in Massachusetts

NAICS Code	Industry Description	# of Sites	Total MW
311	Food	330	131
313	Textiles	91	55
321	Wood products	38	5
322	Paper	162	162
325	Chemicals	135	78
326	Plastics & rubber products	99	13
331	Primary metals	76	23
332	Fabricated metal products	760	215
333	Machinery	119	36
334	Computer & electronic products	246	106
335	Electrical equipment, appliances & components	63	25
336	Transportation equipment	22	13
337	Furniture	136	16
TOTAL		2,277	877

The sizes of existing CHP systems differ from the potential CHP system sizes calculated in this study because of different approaches used for sizing. For example, some CHP systems produce excess electricity to be sold to the electric grid, some systems produce excess steam to be sold to a neighboring facility, and some systems are designed to provide backup power so the electrical capacity is based on emergency power needs rather than on optimal efficiency or energy prices. CHP power to heat output ratios vary depending on the specific equipment used, so the actual system sizes will differ somewhat from the averages for current equipment used in this analysis. Furthermore, the volume of manufacturing operations and the number of employees at some facilities has changed since the installation of a CHP system, so some existing systems are undersized or oversized for current operations.

To determine the remaining potential for CHP, the number of sites with existing CHP systems was deducted from the total number of sites. The total remaining potential capacity was based on this number of sites and the average system sizes calculated above. The remaining potential for CHP in Massachusetts industrial sites is shown in Tables B.10-B.11.

Table B.10: Remaining Potential Industrial Sites for CHP in Massachusetts, by CHP System Size

	CHP System Size Range	**50 – 500 kW**		**500 kW - 1 MW**		**1 – 5 MW**		**5 - 20 MW**	
NAICS Code	**Industry Description**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**	**# of Sites**	**Total MW**
311	Food	294	55	19	17	14	49	0	0
313	Textiles	69	14	15	13	4	9	0	0
321	Wood products	37	4	1	1	0	0	0	0
322	Paper	65	20	41	36	49	85	0	0
325	Chemicals	96	14	33	32	2	4	0	0
326	Plastics & rubber products	95	10	4	3	0	0	0	0
331	Primary metals	64	11	9	7	3	5	0	0
332	Fabricated metal products	697	123	43	38	18	39	0	0
333	Machinery	112	26	0	0	6	10	0	0
334	Computer & electronic products	216	39	16	16	12	47	0	0
335	Electrical equipment, appliances & components	51	9	0	0	12	16	0	0
336	Transportation equipment	20	4	0	0	1	4	0	0
337	Furniture	133	13	2	1	1	2	0	0
TOTAL		1,949	340	183	163	122	271	0	0

Table B.11: Total Remaining Potential Industrial Sites for CHP in Massachusetts

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

APPENDIX C
RESIDENTIAL CALCULATIONS

In the residential sector, CHP is most feasible for medium to large apartment and condominium buildings. Smaller CHP equipment for single family homes and smaller residential buildings are in development, but are not yet commercially available in the United States. The thermal output from CHP can be used to provide space heating and cooling or domestic hot water.

EIA publishes the Residential Energy Consumption Survey every four years. RECS provides information about residential energy consumption across the country, based on a survey of a sampling of households. The primary source of energy consumption data for this analysis was Public Use File 11 from the 2001 RECS, which provides electricity and fuel consumption for the sampled households. The public use files identify household locations by region. The New England region includes six states: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

To determine energy consumption in multi-unit buildings, energy consumption per household was analyzed for units in New England that are in buildings with five or more units. The size of potential CHP systems was calculated based on average electrical demand, to optimize use in conjunction with the electrical grid. To determine this demand, the net annual electricity consumption (kWh) is divided by the number of hours in a year, 8,760 hours. The average consumption of units in multi-unit buildings is shown in Table C1.

Table C.1: Average Energy Consumption by New England Households in Multi-Unit Buildings

# of Residents Per Unit	Size of Unit (square feet)	Annual Electricity Use (kWh)	Annual Fuel (Natural Gas & Oil) Use (MMBtu)	Average Hourly Electric Demand (kW)
1.8	819	4,399	27.8	0.50

According to these calculations, CHP is feasible in residential buildings with 100 or more units, where the average electric demand of 50 kW matches the size of the smallest commercial CHP systems. Buildings with 100 to 1,000 units (approximately the largest buildings in Massachusetts) fall into the average electric demand range of 50 to 500 kW.

The ratio of electric to thermal energy demand (E/T) was calculated using the quantities of electricity (converted to MMBtu) and fuel (MMBtu) provided in RECS. The average E/T is 0.25 when the total electricity is simply divided by the fuel. This represents the current breakdown of energy usage by counting electric heating toward the electric demand. When the total electricity minus the amount used for space and water heating is divided by the sum of electricity and fuel used for space and water heating, the average E/T is 0.41. This value better represents the actual energy profile by counting electric heating as a thermal load, but using this calculation would complicate some potential CHP installations, as existing electric heating is generally less easily integrated into CHP systems. Further analysis could also consider the electricity used for space cooling as a thermal load, to better evaluate the potential for CHP systems that provide cooling.

The specific E/T value for Massachusetts might be slightly higher than those calculated for all of New England, as the state has more demand for electrical air conditioning and less demand for heating fuel than the colder northern New England states.

This approximate E/T ratio is slightly below the power to heat output ratio for most CHP equipment, so CHP systems sized based on electrical demand will satisfy most of the thermal and electrical loads in these residential buildings. If necessary, additional equipment could be used to supplement CHP systems to meet the full thermal loads, and supplemental electricity would be purchased from the utility.

The approximate number of residential buildings in Massachusetts was calculated using data from RECS, the United States Census Bureau and the National Multi Housing

Council. RECS was used to calculate that there are 197,800 households in New England that are in buildings with at least 51 units. Then using the National Multi Housing Council's information on the distribution of apartments by building size, it was estimated that there are 682 buildings in New England with 100 to 1,000 units. According to the Census, 45% of New England's population is in Massachusetts, but because of its larger urban and suburban populations, Massachusetts has a larger proportion of the region's multi-unit residential buildings. Assuming this proportion to be two-thirds, there are approximately 451 relevant buildings in Massachusetts.

Table C.2 details the potential for residential CHP systems in Massachusetts. To determine the remaining potential for CHP, the number of sites with existing CHP systems was deducted from the total number of sites. The total remaining potential capacity was based on this number of sites and an average system size of 150 kW. The remaining potential for CHP in residential buildings in Massachusetts is 66 MW at 438 sites.

Table C.2: Potential for Residential CHP in Massachusetts

	# of Sites	Total MW
Total Potential	451	68
Existing CHP	13	2
Remaining Potential	438	66

APPENDIX D
ECONOMIC CALCULATIONS

The current utility rates (as of December 2005/January 2006) for each of the sample facilities are shown in Tables D.1 and D.2, as obtained from the website of each utility company. The marginal cost, determined from utility rates without including fixed monthly fees, customer charges, or rates for lower volume usage, is the expected cost of the next unit of energy. These rates are highly variable, so further analysis would consider projections of future rates. This analysis assumes the cost difference due to variation between electric rates for primary use and supplemental use to be negligible.

As explained in Chapter 6, the NSTAR standby rate is charged to cover the cost to the utility of standing ready to meet their customer's full electric demand in case the on-site generation system is inoperative for any reason. This charge applies to all new distributed generation systems with capacity of 250 kW or more, with the exception of most renewable energy systems and those systems under 1 MW that meet 30% or less of the facility's electrical load. The office building is the only one of these sample facilities that is large enough to be charged the standby rate.

Table D.1: Marginal Electric Utility Rates of Sample Facilities

Facility	Electric Utility	Electricity, MC_E ($/kWh)	Demand, MC_D ($/kW)	Standby Charge, MC_S ($/kW)
Apartment Building	NSTAR	$0.18	$0	-
Fabricated Metals	WMECO	$0.11	$3.62	-
Food Processing	National Grid	$0.16	$4.99	-
Health Club	National Grid	$0.15	$6.72	-
Hotel	National Grid	$0.16	$4.99	-
Nursing Home	NSTAR	$0.17	$4.31	-
Office Building	NSTAR	$0.20	$19.10	$8.84

Table D.2: Marginal Natural Gas Utility Rates of Sample Facilities

Facility	Gas Utility	Natural Gas for Heating, MC_{NGH} (\$/MMBtu)	Natural Gas for CHP, MC_{NGC} (\$/MMBtu)
Apartment Building	NSTAR	\$17.25	\$18.72
Fabricated Metals	Berkshire Gas	\$12.84	\$12.84
Food Processing	Bay State Gas	\$14.98	\$14.98
Health Club	Keyspan	\$17.86	\$17.02
Hotel	NSTAR	\$16.48	\$16.13
Nursing Home	NSTAR	\$16.48	\$16.13
Office Building	Keyspan	\$16.39	\$16.09

Annual energy consumption was determined based on the number of employees at each facility or number of units in the apartment building, using the consumption per employee and consumption per unit values explained in Chapter 7 and Appendices A-C. The peak electrical demand used by the utility for billing was assumed to be 1.5 times the average demand. Tables D.3 and D.4 show the calculated energy consumption and current energy costs.

Table D.3: Current Energy Consumption of Sample Facilities

Facility	Annual Electric, E_T (kWh)	Average Demand (kW)	Peak Demand, D_T (kW)	Annual Heating Fuel, NG_T (MMBtu)
Apartment Building	879,715	152	228	8,112
Fabricated Metals	1,909,441	331	497	8,653
Food Processing	1,738,651	276	414	14,906
Health Club	401,773	66	99	851
Hotel	1,457,055	166	249	4,563
Nursing Home	596,386	68	102	2,711
Office Building	2,766,000	923	1,385	5,506

Table D.4: Current Annual Energy Costs of Sample Facilities

Facility	Electricity, AC_E	Heating, AC_H	Total, $ACOE_{original}$
Apartment Building	$157,900	$139,935	$297,835
Fabricated Metals	$227,101	$111,078	$338,179
Food Processing	$309,653	$223,343	$532,997
Health Club	$67,343	$15,195	$82,538
Hotel	$243,031	$75,215	$318,245
Nursing Home	$105,290	$44,686	$149,975
Office Building	$883,555	$90,233	$973,788

This analysis considers CHP systems that can use the thermal output to provide both heating and cooling for the commercial/institutional and residential facilities and CHP systems that provide only heating for the industrial facilities.

It was estimated, based on the Energy Guide Business Analyzer from Nexus Energy Software, that 20% of the annual electricity consumption in each of the commercial/institutional and residential facilities is used for air conditioning, so that quantity of energy was moved from the electric to the thermal load for this analysis. Similarly it was estimated that the electric demand at each facility would be reduced by 20% without the inclusion of air conditioning. Using the assumption that air conditioning is used during half of each facility's operating hours, the average cooling load was estimated by dividing 20% of annual electricity consumption by half of the operating hours. The peak cooling load was assumed to be twice the average, and the cooling load was converted to tons by assuming 0.8 kW per cooling ton. These modified values for energy consumption are shown in Table D.5.

Table D.5: Modified Current Energy Consumption of Sample Facilities

Facility	Annual Electric, E_T (kWh)	Average Demand (kW)	Peak Demand, D_T (kW)	Annual Thermal Fuel, NG_T (MMBtu)	Peak Cooling (tons)
Apartment Building	703,772	121	182	8,593	64
Fabricated Metals	1,909,441	331	497	8,653	-
Food Processing	1,738,651	276	414	14,906	-
Health Club	321,418	53	79	1,070	48
Hotel	1,165,644	133	200	5,359	106
Nursing Home	477,108	54	82	3,037	44
Office Building	2,212,800	739	1,108	7,017	454

Specifications and costs for commercially available CHP systems were obtained from the 2005 CEC report, Assessment of California CHP Market and Policy Options for Increased Penetration, as shown in Table D.6.

Table D.6: Reciprocating Engine Driven CHP Characteristics [43]

Size	Installed Cost ($/kW)	O&M Cost ($/kWh)	Power to Heat Ratio (MMBtu/MMBtu)	Heat Rate (MMBtu/kWh)
100 kW	$1,550	$0.018	0.61	0.0115
300 kW	$1,250	$0.013	0.61	0.0115
1000 kW	$1,200	$0.012	0.92	0.01035

The cost for the absorption chillers required for CHP with cooling were obtained from the Midwest CHP Application Center's MAC CHP Assessor and are shown in Table D.7.

Table D.7: Absorption Chiller Costs [44]

Size	Installed Cost ($/ton)
55 tons	$1,360
100 tons	$1,075
500 tons	$680

---

[43] Assessment of California CHP Market and Policy Options for Increased Penetration, page E-5.
[44] Midwest Combined Heat and Power Application Center, MAC CHP Assessor software program.

Table D.8 shows the chosen CHP system sizes and the calculated energy generation. The electrical capacity for each CHP system was determined by rounding the facility's average electric demand down to the nearest 25 kW increment. Chiller sizes were determined by rounding the peak cooling load up to the nearest 25 ton increment. Equipment properties from Table D.6 above were used based on the closest system size.

Table D.8: CHP System Data for Sample Facilities

Facility	Electric Capacity, KW (kW)	Absorption Chiller Capacity (tons)	Annual Electricity Generation, E_G (kWh)	Annual Useful Thermal Energy Generation, H_G (MMBtu)
Apartment Building	100	75	700,800	3,137
Fabricated Metals	325	-	1,378,000	6,168
Food Processing	275	-	1,276,000	5,711
Health Club	50	50	216,320	968
Hotel	125	125	876,000	3,921
Nursing Home	50	50	350,400	1,568
Office Building	725	475	2,262,000	6,713

The calculated operating costs with CHP are shown in Table D.9.

Table D.9: Annual Energy Costs with CHP for Sample Facilities

Facility	Operation & Maintenance, $AC_{O\&M}$	Fuel, AC_F	Supplemental Electricity, AC_{ES}	Supplemental Thermal, AC_{HS}	Standby Charges, AC_S	Sub-Total
Apartment Building	$12,614	$87,446	$533	$87,446	-	$251,454
Fabricated Metals	$17,914	$203,436	$67,995	$12,101	-	$301,446
Food Processing	$16,588	$219,861	$88,192	$116,375	-	$441,015
Health Club	$3,894	$0	$18,718	$0	-	$64,952
Hotel	$15,768	$7,377	$51,318	$7,377	-	$236,986
Nursing Home	$6,307	$17,359	$23,360	$17,359	-	$112,036
Office Building	$27,144	$0	$126,955	$0	$76,865	$607,752

The capital costs for each CHP system were calculated using the values in Tables D.6 and D.7 and are shown in Table D.10.

Table D.10: CHP Capital Costs and Total Cost of Energy for Sample Facilities

Facility	Total Capital Cost	Annual Cost of Capital, AC_C	Total Annual Cost with CHP $ACOE_{CHP}$
Apartment Building	$257,000	$41,826	$290,735
Fabricated Metals	$406,250	$66,115	$367,561
Food Processing	$343,750	$55,944	$496,959
Health Club	$145,500	$23,679	$87,963
Hotel	$328,125	$53,401	$291,798
Nursing Home	$145,500	$23,679	$134,178
Office Building	$1,446,750	$235,452	$827,829

Finally, Table D.11 shows the reduction in annual energy costs with CHP over the ten year financing period in both dollars and percentage, as well as the simple payback period for the CHP system. Where the annual benefit values are negative numbers, the costs would increase over the ten year financing period in these examples.

Table D.11: Energy Cost Savings and Simple Payback of CHP for Sample Facilities

Facility	Annual Benefit, AB$	Annual Benefit Percentage, AB%	Simple Payback Period, SP (years)
Apartment Building	$4,555	2%	5.5
Fabricated Metals	-$29,382	-9%	11
Food Processing	$36,038	7%	3.7
Health Club	-$6,094	-7%	8.3
Hotel	$27,858	9%	4.0
Nursing Home	$14,259	10%	3.8
Office Building	$130,585	13%	4.0

BIBLIOGRAPHY

Applied GIS, Inc. for New York State Energy Research and Development Authority, Geographic Location Assessment Tool Final Report, January 2003.

Bay State Gas, www.baystategas.com (accessed 2005-2006).

Berkshire Gas Company, www.berkshiregas.com (accessed 2005-2006).

Beaudoin, Heather, Combined Heat and Power In New England: Guidelines and Barriers To Implementation with Case Studies. Masters Thesis: University of Massachusetts Amherst, 2002.

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

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

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

Commonwealth of Massachusetts, www.mass.gov (accessed 2005).

Commonwealth of Massachusetts, Department of Environmental Protection, 2004 Air Quality Report. 2005.

Commonwealth of Massachusetts, Division of Energy Resources, Market Monitor 2000. 2002.

Commonwealth of Massachusetts, Office for Commonwealth Development. Massachusetts Climate Protection Plan. Spring 2004.

Dun & Bradstreet, Zapdata database, www.zapdata.com (accessed 2005-2006).

Energy and Environmental Analysis, Inc., www.eea-inc.com (accessed 2005).

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

Bruce Hedman. The Potential for Combined Heat and Power. Energy and Environmental Analysis, Inc., March 2005.

Institute for Electrical and Electronics Engineers, www.ieee.org (accessed 2005).

ISO New England, 2003 NEPOOL Marginal Emission Rate Analysis. December 2004.

ISO New England, Annual Report 2002. 2003.

ISO New England, www.iso-ne.com (accessed 2005-2006).

Keyspan, www.keyspanenergy.com (accessed 2005-2006).

Massachusetts Technology Collaborative, www.masstech.org/policy/dgcollab (accessed 2005).

Massachusetts Water Pollution Control Association, www.mwpca.org (accessed 2005).

Midwest Combined Heat and Power Application Center, MAC CHP Assessor software program, www.chpcentermw.org (accessed 2005-2006).

National Grid, www.nationalgridus.com/masselectric (accessed 2005-2006).

National Multi Housing Council, www.nmhc.org (accessed 2005).

Nexus Energy Software, Energy Guide software program, www.energyguide.com (accessed 2005-2006).

Northeast Combined Heat and Power Application Center, www.northeastchp.org (accessed 2005-2006).

Northeast States for Coordinated Air Use Management (NESCAUM), Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action. 2003.

NSTAR, www.nstaronline.com (accessed 2005-2006).

Onsite Energy Corporation & Pace Energy Project for New York State Energy Research and Development Authority, Combined Heat and Power Market Potential for New York State. October 2002.

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

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

O'Connor, Brendan, Combined Heat and Power Feasibility Study Characterization Utilizing Applicable Software Programs. Masters Thesis: University of Massachusetts Amherst, 2004.

Power Magazine. November/December 2004.

Regulatory Assistance Project, www.raponline.org (accessed 2005).

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

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

Tracey, Sharon, James Booker, Lawrence Ambs, and Hwei-ling Greeney, Identification of Northeast Regional Industries of the Future. Alfred University & University of Massachusetts Amherst, 2000.

United States Combined Heat & Power Association. www.uschpa.com (accessed 2005).

U.S. Department of Agriculture, National Agricultural Statistics Service, 2002 Census of Agriculture. June 2004.

U.S. Census Bureau, 2002 County Business Patterns. November 2004.

U.S. Census Bureau, 2003 Annual Survey of Manufactures. May 2005.

U.S. Census Bureau, www.census.gov (accessed 2005).

U.S. Department of Energy, www.energy.gov (accessed 2005).

U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2005. July 2005.

U.S. Department of Energy, Energy Information Administration, Electric Power Annual 2004. November 2005.

U.S. Department of Energy, Energy Information Administration, Commercial Buildings Energy Consumption Survey, www.eia.doe.gov/emeu/cbecs/contents.html (accessed 2005).

U.S. Department of Energy, Energy Information Administration, Manufacturing Energy Consumption Survey, www.eia.doe.gov/emeu/mecs/contents.html (accessed 2005).

U.S. Department of Energy, Energy Information Administration, Natural Gas Annual 2004. December 2005.

U.S. Department of Energy, Energy Information Administration, Residential Energy Consumption Survey, www.eia.doe.gov/emeu/recs/contents.html.

U.S. Department of Energy, Energy Information Administration, State Electricity Profiles 2002. January 2004.

U.S. Department of Housing and Urban Development, www.hud.gov (accessed 2006).

U.S. Department of Housing and Urban Development, Robert Groberg & Dianne Thompson, email communication with author. 2006.

U.S. Department of Justice, Federal Bureau of Prisons, www.bop.gov (accessed 2005).

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

U.S. Environmental Protection Agency, Emission Totals by State for 2000, www.epa.gov/cleanenergy/egrid/pdfs/state.pdf (accessed 2006).

U.S. Environmental Protection Agency. AP 42, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, www.epa.gov/ttn/chief/ap42/ (accessed 2006).

Western Massachusetts Electric Company, www.wmeco.com (accessed 2005-2006).