Market Potential of Combined Heat and Power in Massachusetts

Prepared for Massachusetts Technology Collaborative

Pursuant to June 30, 2006 Report of the DG Collaborative

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This report is available on-line at:
www.masstech.org/dg/2008-03-MA-CHP-Market-KEMA.pdf

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1. Executive Summary

The Massachusetts Distributed Generation Collaborative has been working since 2004 to address the role of distributed generation (DG) in utility company planning. In its 2006 Report to the Massachusetts Department of Public Utilities, the DG Collaborative recommended that certain economic and environmental benefits of distributed generation be explored in future work, saying "the participants in the DG Collaborative plan to ... explore the following areas of potential DG value: impact of DG on constrained areas, impact of DG on market prices, impact of DG on the environment" and "economic benefits to the customer and to the larger economy." [1]

One factor that is expected to affect the nature and extent of these benefits is the quantity of DG that is installed and operated in Massachusetts. For example, the research that was undertaken by the DG Collaborative for the 2006 Report analyzed the quantities of DG required to leverage distribution deferral benefits, but the analysis was limited to eight selected distribution areas.[2] The impacts on market prices and other potential economic benefits may be affected by the scale of DG that is developed. To provide information to address these issues, this report provides estimates of the potential for new DG, with a focus on Combined Heat and Power (CHP) as one of the largest sources of DG capacity and generation.

Significant CHP capacity has already been installed in Massachusetts, including 89 MW of CHP that is considered for purposes of this report to be the installed base on which our projections build. In the 14-year period from 1984 through 1997, an average of 3.1 MW/year of this CHP capacity was installed, increasing to 5.3 MW/year in the 10-year period from 1998 through 2007.

This report estimates the quantities of CHP that could be developed in Massachusetts under different assumptions, including what might occur naturally and what might result from supportive public policies. This study presents a model developed by KEMA to estimate CHP penetration in the next 20 years.

KEMA's penetration model estimated payback periods for typical CHP installations for different plant sizes in various commercial, institutional and industrial market segments in each of the next 20 years, through 2026. For each year, these paybacks were based on the electricity and natural gas prices expected for that year and on the costs and heat rates for various gas-fired CHP systems. The payback calculations were also based on assumptions of CHP capacity factors and rates of utilization of the thermal output for each market segment and plant size. KEMA then used market penetration curves to estimate the penetration of CHP based on the expected payback for a new CHP facility in each segment and plant size in each year.

The results are presented for a number of scenarios for the 12-year period 2009 through 2020, including a "base case" estimate of approximately 240 MW of new CHP resources in Massachusetts, and an "achievable policy" scenario of approximately 680 MW, as illustrated in Figure ES-1 below. These estimates did not include the potential for CHP in multi-family or single-family residential buildings. They also did not assume substantial increases in the use of CHP's thermal output for absorption cooling, which represents a significant possible expansion of the CHP market.

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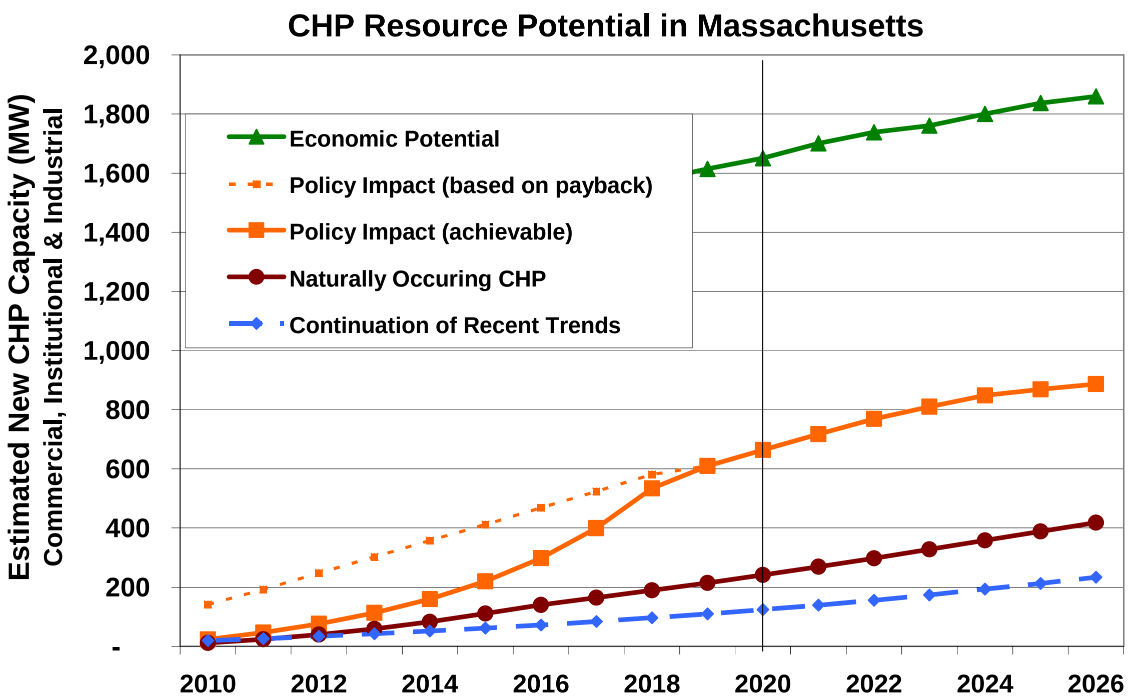
[1] Massachusetts Distributed Generation Collaborative, 2006 Report, D.T.E. 02-38-C, June 30, 2006, pages 38 and 46, available at: http://www.masstech.org/dg/02-38-C_2006-Report_DGcollab.doc#_Toc139361544.

[2] Ibid., Attachment G, "DG and Distribution Planning: An Economic Analysis for the Massachusetts DG Collaborative," available at http://www.masstech.org/dg/collab-reports.htm.

Figure ES-1



Based on this range of estimates, 750 MW was selected by the Renewable Energy Trust as a CHP policy scenario for the purpose of the development of the complementary report prepared by Synapse Energy Economics, Inc., "Impacts of Distributed Generation on Wholesale Electric Prices and Air Emissions in Massachusetts" (March 2008), which models the impacts of CHP penetration on the wholesale electricity market and estimates the economic benefits of CHP for Massachusetts electricity customers.[3]

[3] Synapse Energy Economics, Inc., "Impacts of Distributed Generation on Wholesale Electric Prices and Air Emissions in Massachusetts," for Massachusetts Technology Collaborative, March 2008, available at: http://www.masstech.org/dg/2008-03-MA-CHP-Impacts-Synapse.pdf.

2. Introduction

In its 2006 Report to the Massachusetts Department of Public Utilities,[4] the Massachusetts Distributed Generation (DG) Collaborative recommended that the impact of DG on market prices be explored in future work, saying "…end-use customers who install DG reduce their dependence on the regional market for their energy needs, which may contribute to a decrease in energy price volatility. Reductions in regional energy demand should result in lower market clearing prices that benefit all customers." The 2006 Report also stated that "…the participants in the DG Collaborative plan to undertake the following activities: ... explore the following areas of potential DG value: impact of DG on constrained areas, impact of DG on market prices, and impact of DG on the environment."

Many of these issues may depend significantly on the quantity of DG resources that can be expected to be installed in the future, so the Massachusetts Technology Collaborative (MTC) engaged KEMA, Inc. to prepare this report on the market potential of one such technology, Combined Heat and Power (CHP).

This report is a summary of the CHP Market Penetration model that was completed by KEMA, Inc. in support of the Massachusetts Technology Collaborative (MTC) Distributed Generation (DG) Policy Collaboration Initiative. Specifically, the goal of this report is to assess the future CHP market potential in the Commonwealth of Massachusetts. This document provides a description of the models, methodologies, and results of the market penetration estimates of CHP resources in the next 20 years.

KEMA's present study builds on the previous work of the DG Collaborative, and is intended to contribute to the ongoing analysis of the benefits that can be obtained through the integration of DG resources into the generation mix and to assist in the future planning and implementation of such resources.

2.1 Trends in Massachusetts CHP Growth to Date

Significant CHP capacity has already been installed in Massachusetts. The state's CHP capacity was approximately 1,850 MW at the end of 2007.[5] The largest portion of this consists of eight large combined cycle plants with cogeneration that were installed from 1984 through 1993 totaling 1,192 MW. The total of 1,857 MW also includes the 277 MW Kendall Square Station district energy facility in Cambridge. These nine plants are relatively large and were built in an earlier regulatory environment.

There are approximately another 100 CHP projects which total 388 MW of capacity.[6] These projects are summarized in the following table, with the most recent installations listed first, and are then further described below the table.

[4] DG Collaborative, 2006 Report.

[5] Primary source for this section: http://www.eea-inc.com/chpdata/States/MA.html. Additional data taken from recent reports by Massachusetts utilities, from: http://www.masstech.org/dg/ma-data.htm.

[6] For comparison, a separate survey of the existing penetration of CHP in Massachusetts found a total capacity of 375 MW at 121 sites as of 2005, with an average system size of 3.1 MW. "Technical Analysis of the Potential for Combined Heat and Power in Massachusetts," Lauren R. Mattison, Center for Energy Efficiency and Renewable

Figure 2-2
Trends in Growth of Selected Massachusetts CHP Categories[7]

	MW	#	Average kW/Project	kW / year
CHP Since Restructuring				
Reciprocating engine CHP <= 250 kW (1998-2007)	3	35	93	325
Reciprocating engine CHP >= 1 MW (2001 - 2008)	16	4	3,875	1,938
Steam turbine CHP (2003)	7	2	3,300	
Gas turbine CHP (1999, 2005)	26	4	6,400	
	51	**45**	**1,132**	
Small CHP 1984 through 1997				
Reciprocating engine CHP <= 250 kW (1984-1997)	24	30	792	1,698
Steam turbine CHP (1988-1991)	15	6	2,439	
	38	36	1,067	
Subtotal, Recent CHP	**89**	**81**	**1,103**	
Steam-Turbine CHP before 1988				
Years 1980-1987	176	5	35,200	
Years 1969-1974	103	4	25,750	
Years 1935-1956	20	6	3,333	
	299	15	19,933	
Total of above CHP capacity	**388**	**96**	**4,045**	

These projects and categories are described below.

CHP Since Restructuring. Since restructuring was implemented in 1998, 51 MW of CHP has been installed in MA. This included the following types of CHP projects:

- 25.6 MW based on combustion turbines in 4 projects in 1999 and 2005 (Wyeth Bio Pharma, Malden Mills, Biogen IDEC and Bridgewater State College);
- 6.6 MW based on steam turbines in 2 projects (University of Massachusetts Amherst and Williams College, both in 2003)
- 15.5 MW based on reciprocating engines in 4 projects sized between 1 MW and 7 MW from 2001 through 2005 (American Optical Corporation, New England Confectionary/NECCO, Garelick Farms and Boston's Madison Park High School);
- 2.9 MW based on reciprocating engines sized between 60 kW and 250 kW, in an average of 5 projects/year from 2001 through 2007, with an average size of 90 kW.

Energy, University of Massachusetts, May 2006, available at www.masstech.org/renewableenergy/public_policy/DG/resources/2006-05-UMass-CHP-Potential.pdf.

[7] This table does not include 8 larger-scale gas turbine combined cycle projects with cogeneration totaling 1,192 MW installed between 1984 and 1993, many of which were Qualifying Facility (QF) projects by independent power producers (IPPs), nor does it include the 277 MW Kendall Square Station that provides district steam.

Small CHP 1984 - 1997. During these 14 years, 30 of the CHP projects were below 250 kW in size and were based on reciprocating engines. This was the first wave of CHP projects based on this technology, with an average size of about 790 kW per project. These projects were installed at a rate of 1.7 MW/year in this period before restructuring. In addition, six CHP projects, totaling 15 MW, were installed with relatively small steam turbines in the middle of this period (1988-1991).

Steam Turbine CHP Before 1988. Existing CHP projects also include 15 steam turbine CHP projects, totaling 299 MW. These are presented in a separate category because they are relatively large, or are based on older technology or solid fuels, or are otherwise atypical of the CHP expected to be installed in Massachusetts in the future:

- 6 industrial steam turbine-based CHP projects totaling 20 MW installed from 1935 through 1956 (now burning gas, coal and oil);
- 4 steam turbine-based CHP projects totaling 103 MW installed from 1969 through 1974 (college, hospital and industrial projects burning oil and gas);
- 5 industrial steam turbine-based CHP projects totaling 176 MW installed in the 1980s (burning waste, gas and coal).

The CHP capacity of greatest relevance to this report is the 51 MW built since 1998, but the 38 additional MW of small plants built from 1984 through 1997 also represent the kind of small CHP applications that are the focus of this report. This total of 89 MW of CHP is considered for purposes of this report to be the installed base on which our projections build. In the 14-year period from 1984 through 1997, an average of 3.1 MW/year of this CHP capacity was installed, and this rate increased to 5.3 MW/year in the 10-year period from 1998 through 2007. This represents an 8% growth rate for CHP in recent years.

This report analyzes the potential for increases going forward from this base.

2.2 Types of Future CHP Potential

The process of estimating DG resources mirrors the process of estimating the market potential of energy-efficiency measures which became popular throughout the utility industry from the late 1970s through the mid-1990s. For energy-efficiency, coinciding with the advent of the so-called “least-cost” or “integrated resource planning” (IRP), these studies became one of the primary means of characterizing the resource availability and value of energy efficiency within the overall resource planning process.

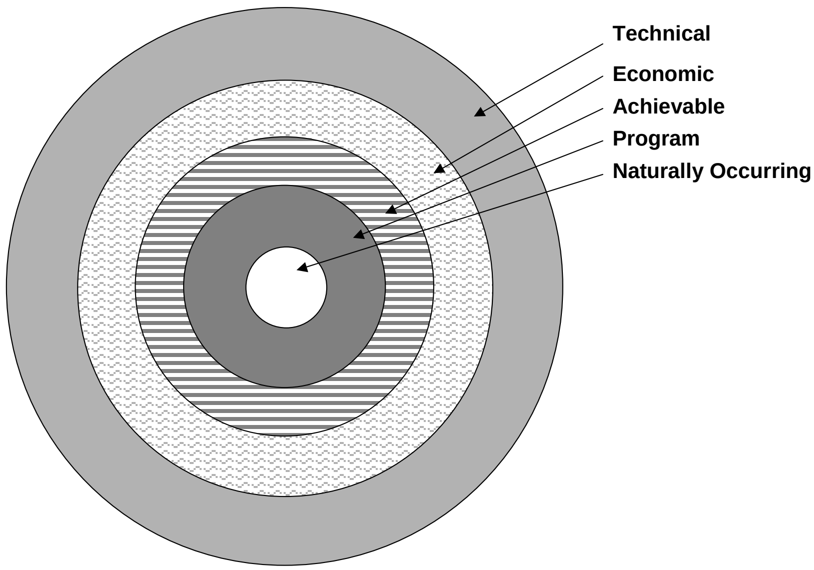
Resource studies typically define three types of potential – technical potential, economic potential, and achievable potential. In this study, potential refers to installed megawatts (MW) of CHP resources. These three types of potential are illustrated in Figure 2-1 and further described below:

***Technical* potential** assumes the *complete* penetration of all CHP resources that are considered feasible from an engineering perspective — regardless of price.

***Economic* potential** refers to the technical potential of those CHP resources that are cost-effective when compared to alternative forms of generation.

***Achievable* potential, or market penetration,** refers to resources that could actually be installed, after the economic potential has been tempered by reasonable customer uptake of the technology. Within the achievable potential, resources may in some cases be further broken down into naturally occurring potential (installations in the absence of market intervention) and program potential (installations as a result of a specific program's funding levels or incentives provided for implementation).

Figure 2-1
Conceptual Relationship of Different Definitions of DG Resource Potential



In this Report, the analysis of CHP starts with the "naturally occurring" potential. This is an indication that some level of CHP resources are expected to be economically viable over the planning horizon in the absence of new state-level incentives. Nevertheless, some of the inputs for this analysis are based on assumptions that reflect expectations of future market and policy developments at the national or global level, such as improvements in CHP technologies over time, increasing customer awareness of energy challenges and opportunities, and the effect of carbon-related markets on electricity prices, as described below. The modeling framework for this report may be used in the future to analyze the potential impact of future state-level incentives to spur further installation of CHP resources.

This report estimates the market penetration (achievable potential) of CHP resources in the Commonwealth of Massachusetts in the next 20 years. This study is not a forecast.

3. CHP Market Penetration Analysis

The market potential for CHP depends on many factors. The CHP market penetration model developed by KEMA for this report calculates CHP potential by estimating the payback of a typical CHP plant within each industry or commercial building type, and then using a market penetration curve and other assumptions to determine the penetration of CHP within that industry based on the expected payback.

In this section of the report, we first discuss the capital and operating costs of CHP technologies and CHP heat rates over time. We then discuss the number and characteristics of potential CHP host sites in Massachusetts in the commercial, industrial and institutional sectors. This report does not address the potential CHP market for single or multi-family residential markets. We also discuss the assumptions made for CHP sizes, capacity factors and thermal load utilization, three of the most important drivers of the economics of CHP, which are primarily based on the electric and thermal load profiles of the host customers. We then discuss the calculations of financial performance for different types and sizes of CHP projects, including assumptions about gas and electricity prices and rates and the calculations of payback periods that result from all the cost and performance assumptions. Finally, we discuss the approach used to estimate market penetration.

3.1 CHP Technology Costs and Heat Rates

Performance and cost data were developed for four different CHP systems - a typical reciprocating engine, a microturbine, a fuel cell, and a large gas turbine. Performance data and cost data were taken for 2007, and then projected for years 2015 and 2025 to account for technology performance improvements. Estimates of future performance were obtained from the 2003 National Renewable Energy Lab (NREL) study Gas Fired Distributed Energy Resource Technology Characterizations[8] and these estimates were confirmed and adjusted based on primary research. For reciprocating engines, projections were also obtained from the DOE Advanced Reciprocating Energy System (ARES) program. For microturbines, projections were also obtained from the DOE Advanced Microturbine Program and for fuel cells, projected future costs were gathered from the active molten carbonate fuel cell manufacturer, FuelCell Energy.

The model provides the option to select one of the four CHP systems for each industrial or commercial sector and facility size. For this analysis, the most efficient and cost effective generation options were used: the reciprocating engine data was utilized for facility sizes less than 1 MW, and for facility sizes above 1 MW the gas turbine data was utilized.

The model also includes an installation cost adjustment factor to adjust the installation costs of the CHP system based on whether an installation would be difficult, such as in a downtown city application, or simple, such as in an area that has easily accessible electric panels, gas lines, and space to install the system.

[8] Available at: http://www.masstech.org/renewableenergy/public_policy/DG/resources/2003-11_gasDER_tech-char_NREL-34783.pdf.

3.2 Number and Size of Potential CHP Host Sites

The market potential of CHP was analyzed separately for the following industrial sectors and commercial and institutional building types:

NAICS	SIC	Industrial
311	20	Food
313	22	Textiles
321	24	Lumber/Wood Products
322	26	Paper
325	28	Chemicals
326	30	Rubber
331	33	Primary Metals
332	34	Fabricated Metal Products
333	35	Machinery
334	35,36,38	Computer & Electric Products
335	36	Electrical Equipment
336	37	Transportation Equipment
337	25	Furniture

Commercial & Institutional
Car Washes
Colleges & Universities
Golf & Country Clubs
Grocery Stores
Health Clubs
Hospitals & Healthcare
Hotels & Motels
Laundries
Museums
Nursing Homes & Assisted Living
Office Buildings
Restaurants
Retail Stores
Schools
Warehouses
Water & Sewage Treatment Plants

Each of these customer categories was segmented into four size ranges for this analysis, based on the average customer electricity load for the year. The four size ranges were:

- 50 kW to 500 kW
- 500 kW to 1 MW
- 1 MW to 5 MW
- 5 MW to 20 MW.

The number of facilities in each of these sectors and size categories in Massachusetts was estimated based on a 2006 report entitled "Technical Analysis of the Potential for Combined Heat and Power in Massachusetts" by the University of Massachusetts' Center for Energy Efficiency and Renewable Energy (CEERE).[9] Facility sizes were estimated based on census and other data on the number of employees per facility, energy use per employee and other factors. This data and analysis were reviewed by KEMA and by the University of Massachusetts' Center for Energy Efficiency and Renewable Energy in 2008, and adjustments were made in capacity factors, expected CHP project sizes and other assumptions for purposes of the present report.

3.3 CHP Capacities, Capacity Factors and Thermal Load Utilization

This section addresses the following key drivers of the economic feasibility of CHP:

- CHP Size
- Capacity Factor
- Thermal Load Utilization.

This section describes the development of model inputs for these three interrelated factors for each facility size in each industry sector.

Though KEMA created the market penetration model, additional support and information was provided by three subcontractors:

- CEERE at the University of Massachusetts-Amherst,
- Synapse, Inc. and
- Endurant Energy LLC.

[9] "Technical Analysis of the Potential for Combined Heat and Power in Massachusetts," Lauren R. Mattison, Center for Energy Efficiency and Renewable Energy, University of Massachusetts, May 2006, available at www.masstech.org/renewableenergy/public_policy/DG/resources/2006-05-UMass-CHP-Potential.pdf.

CHP system size (kW): For each of the target sectors and facility size segments, CEERE had previously estimated a CHP application size primarily based on national data regarding thermal power ratios in those sectors matched to thermal power ratios of various CHP systems. For this report, each estimate was reviewed by KEMA and CEERE and compared to actual CHP installations, mostly in Massachusetts, from certain sectors and facility sizes. CHP application sizes were modified as necessary to reflect sizing that has been successful in existing projects.
For purposes of this report, for facilities that were expected to have high thermal loads, the CHP application was generally sized to account for about 50% of the total typical electrical base load of the facility. For smaller loads, the percentage was reduced, resulting in smaller CHP capacities.

The majority of the savings of a CHP application comes from the thermal offset. Therefore, the assumption was made that an application would be sized in order to maximize the amount of thermal energy that could be utilized from the CHP application. As a result, when there was an industry segment that projected a high electrical load but a low thermal load, the size of the CHP application was reduced in order to meet the thermal load rather than the electrical load. The main reason for this is that in most cases to the extent a CHP application produces electricity in excess of that which is associated with meeting its thermal load, that electricity can have a higher cost than power from the grid.

Capacity Factors and Thermal Load Utilization: Model inputs were also developed by KEMA and CEERE for CHP capacity factors and thermal utilization. The following tables show the levels of these key variables that were assumed in this study for each of the most important sectors, as well as some of the model results. These assumptions are for the base case, naturally-occurring scenario. The results of these assumptions, and changes in assumptions for the other modeling scenarios are discussed in section 4.

Table 3-1

Industrial CHP Profiles

Selected Industrial CHP Profiles (inputs)

Average Load of Facilities:	50kW - 500kW	500kW - 1000 kW	1000kW - 5000kW	5000kW - 20,000kW
Food Industry Profile				
Number of Facilities	294	19	17	0
Average CHP Size Utilized in Model	130	360	2000	0
CHP Capacity Factor	90%	90%	90%	0%
Thermal Load Utilization	100%	100%	100%	0%
Textiles Industry Profile				
Number of Facilities	69	15	6	1
Average CHP Size Utilized in Model	120	250	1100	7500
CHP Capacity Factor	70%	80%	80%	80%
Thermal Load Utilization	95%	95%	95%	95%
Paper Industry Profile				
Number of Facilities	66	42	52	2
Average CHP Size Utilized in Model	300	500	1200	5000
CHP Capacity Factor	75%	80%	80%	80%
Thermal Load Utilization	90%	90%	90%	90%
Chemicals Industry Profile				
Number of Facilities	65	31	33	13
Average CHP Size Utilized in Model	90	240	950	2400
CHP Capacity Factor	80%	85%	90%	90%
Thermal Load Utilization	85%	85%	85%	85%
Fabricated Metals Industry Profile				
Number of Facilities	697	44	18	1
Average CHP Size Utilized in Model	130	450	400	2500
CHP Capacity Factor	85%	90%	90%	90%
Thermal Load Utilization	90%	90%	90%	90%
Computer & Electronics Industry Profile				
Number of Facilities	0	105	112	29
Average CHP Size Utilized in Model	0	100	250	2300
CHP Capacity Factor	0%	90%	90%	90%
Thermal Load Utilization	0%	80%	80%	80%

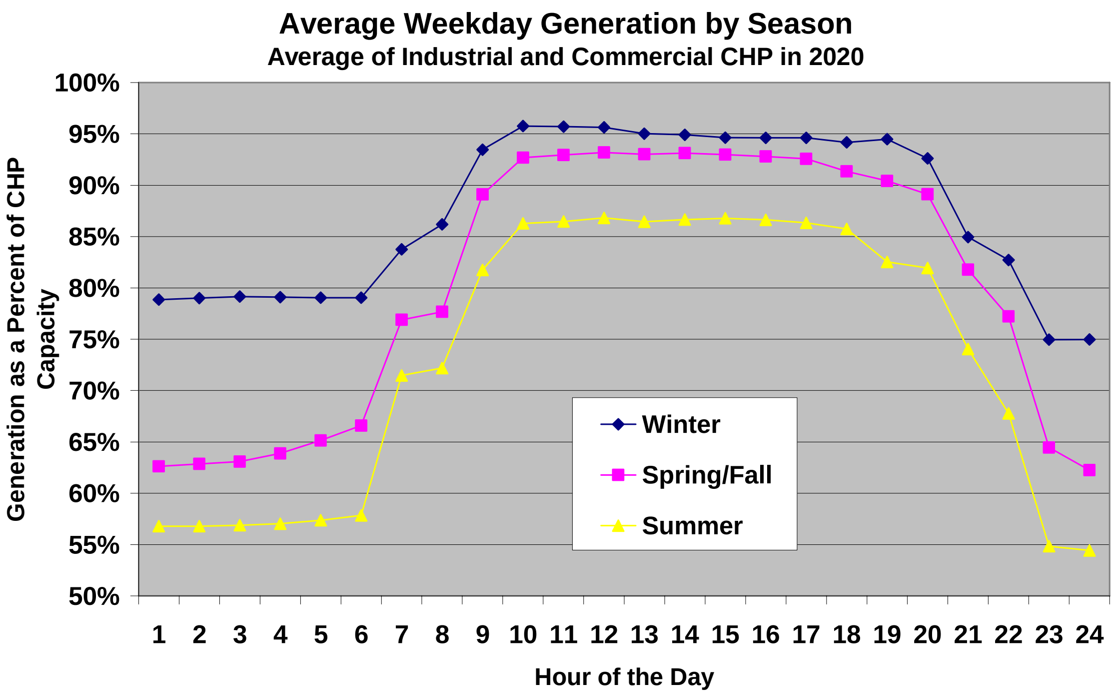
Table 3-2
Commercial CHP Profiles (Selected)

Commercial CHP Profiles

Average Load of Facilities:	50kW - 500kW	500kW - 1000 kW	1000kW - 5000kW	5000kW - 20,000kW
College & University Industry Profile				
Average CHP Size Utilized in Model	100	500	1000	7500
CHP Capacity Factor	77%	77%	77%	77%
Thermal Load Utilization	95%	95%	95%	95%
Number of Facilities: Potential	42	9	38	29
Adoption as % of Potential	10%	16%	23%	32%
Number of Facilities: CHP Adopters	4	1	9	9
MW Penetration in 2026	0	1	9	70
Grocery Store Industry Profile				
Average CHP Size Utilized in Model	75	350	600	0
CHP Capacity Factor	55%	55%	55%	0%
Thermal Load Utilization	84%	84%	84%	0%
Number of Facilities	525	248	71	0
Adoption as % of Potential	4%	0%	15%	0%
Number of Facilities: CHP Adopters	22	0	11	0
MW Penetration in 2026	2	0	6	0
Health Club Industry Profile				
Average CHP Size Utilized in Model	75	400	750	0
CHP Capacity Factor	75%	75%	75%	0%
Thermal Load Utilization	79%	79%	79%	0%
Number of Facilities	328	38	2	0
Adoption as % of Potential	7%	14%	20%	0%
Number of Facilities: CHP Adopters	24	5	0	0
MW Penetration in 2026	2	2	0	0
Hospital & Heath Care Industry Profile				
Average CHP Size Utilized in Model	150	750	1100	3000
CHP Capacity Factor	75%	75%	75%	75%
Thermal Load Utilization	95%	95%	95%	95%
Number of Facilities	26	31	63	7
Adoption as % of Potential	10%	18%	25%	29%
Number of Facilities: CHP Adopters	3	6	16	2
MW Penetration in 2026	0	4	17	6
Hotel & Motel Industry Profile				
Average CHP Size Utilized in Model	120	800	1000	0
CHP Capacity Factor	75%	75%	75%	0%
Thermal Load Utilization	89%	89%	89%	0%
Number of Facilities	334	27	23	0
Adoption as % of Potential	10%	16%	24%	0%
Number of Facilities: CHP Adopters	34	4	6	0
MW Penetration in 2026	4	4	6	0
Nursing Home & Assisted Living				
Average CHP Size Utilized in Model	100	500	900	0
CHP Capacity Factor	75%	75%	75%	0%
Thermal Load Utilization	95%	95%	95%	0%
Number of Facilities	873	39	3	0
Adoption as % of Potential	11%	17%	24%	0%
Number of Facilities: CHP Adopters	100	7	1	0
MW Penetration in 2026	10	3	1	0
Office Building Profile				
Average CHP Size Utilized in Model	60	250	400	2500
CHP Capacity Factor	50%	55%	60%	65%
Thermal Load Utilization	84%	84%	89%	89%
Number of Facilities	4,577	666	311	99
Adoption as % of Potential	5%	13%	25%	29%
Number of Facilities: CHP Adopters	248	85	77	29
MW Penetration in 2026	15	21	31	72

Based on the mix of assumed CHP capacity factors for the various segments and plant sizes, and on other information on hourly CHP operating patterns, an hourly electricity generating profile was developed for the overall mix of CHP. This profile is illustrated in Figure 3-1 below. It includes an estimate of the percentage of the total CHP resource that will be operating for each hour of a typical 7-day week for each of three seasons (winter, summer and shoulder).

Figure 3-1



The additional estimates and sources of data on which the hourly CHP profile is based are the following. The hourly electricity generating profile for the overall mix of CHP was estimated by weighting each of the following hourly profiles based on their proportion of the gWh of electricity estimated to be generated by CHP in 2020 in the Achievable Policy Scenario. The annual weighted average of this profile is approximately the same as the weighted average capacity factor for the total CHP resource in the KEMA "achievable policy" scenario.

Generic HVAC-Based CHP

- Based on CEERE projections for a 600 kW CHP at an institutional customer, to serve heating and cooling loads, with the following seasonal capacity factors:
  - winter 100%, summer 90%, other months 42%.

Industrial Market Segments

- This profile is a combination of the following 3 sources: a projection by CEERE for a 600 kW CHP at an actual Massachusetts industrial plant (weighted 70%), a 2-shift CHP operation running at 100% for 16 hrs (from 6 am to 9 pm) for 6 days (weighted 20%), and the following actual facility (weighted 10%):

- The actual facility data is from NYSERDA from November 2006 through November 2007, for a 330 kW CHP at a food processing plant, excluding outages & holidays. The plant operated primarily during daytime hours and generation appeared to vary with substantial changes in activity levels in the production process.

College
- Assumed to operate at 95% during all winter hours, and at average capacity factors of 65% during the summer and 90% during other months, with an hourly generating pattern during the day modeled after that of the "Generic HVAC-Based" profile (see above).

Grocery
- Based on an operating profile of a 60 kW CHP running at approximately 100% during winter store operating hours, and at 85%-90% during operating hours in other seasons, for a small store with a load of approximately 200 kW (plus additional summer air conditioning load).

Hospital
- This profile is a combination of two profiles weighted as follows:
  - 80% base-loaded at 100%, and
  - 20% based on actual hourly performance from a gas turbine CHP system recently installed at a hospital in Maine (EMMC), excluding outage hours.

Hotel
- Based on a primarily base-loaded operating profile of a 350 kW CHP for a hotel with a peak load of approximately 1 MW.

Nursing
- Based on a profile that is sized to run base-loaded for heating in the winter and shoulder months, but in the summer to operate 10 hours/day to serve hot water loads.

Office
- This profile is a combination of 4 sources weighted as follows:
  - 20% base-loaded at 100%,
  - 25% for CHP operating at 100% during office hours (12 hrs from 8 am to 8 pm, 5 days);
  - 30% for CHP driven by space heating and cooling (see Generic HVAC-Based);
  - 25% for the following actual facility:
- The actual facility data is from NYSERDA for a 70 kW CHP at Ten West 66th Street in New York City from November 2006 through November 2007, excluding outage hours.

Retail
- Based on an operating profile of a 300 kW CHP running at 100% during retail operating hours, and at various levels in the 2 hours before opening, for a large store with a load of approximately 500 kW (plus additional summer air conditioning load).

Other Commercial & Institutional
- This profile is a combination of the following 3 profiles weighted as follows:
  - 50% base-loaded at 100%,

- o 25% for CHP operating at 100% during 12 daytime hours (from 8 am to 8 pm) over 5 days/week,
- o 25% for CHP driven by space heating and cooling (see Generic HVAC-Based).

The hourly electricity generating profile for the overall mix of CHP, developed as described above, serves to confirm and illustrate the overall level of the capacity factors that were used as inputs to the KEMA market penetration model for the different CHP sizes and industry categories. This hourly profile was also used in the accompanying March 2008 report by Synapse Energy Economics, Inc., "Impacts of Distributed Generation on Wholesale Electric Prices and Air Emissions in Massachusetts" which models the impacts of CHP penetration on the wholesale electricity market.[10]

3.4 Gas and Electricity Prices

The key price inputs of the model are taken from the report by Synapse Energy Economics entitled *Avoided Energy Supply Costs in New England - 2007 Final Report*, August 10, 2007.[11] This 2007 AESC Study was sponsored by most of the investor-owned electric utilities, gas utilities and other energy efficiency program administrators in Massachusetts, Connecticut, Rhode Island and New Hampshire and was overseen by them and non-utility parties and their consultants, through the Avoided-Energy-Supply-Component (AESC) Study Group. These prices therefore have the benefit of having being generated through a transparent public/private process including stakeholders from most of the New England states.

The gas and electricity prices from the AESC Report were derived in an internally-consistent manner, which is important for this study because the economics of CHP depend on this "spark spread." The spark spread is essentially the difference between the market price of electrical energy and the cost of generating it, which is primarily determined in New England by natural gas prices. The electricity prices include the estimated effects of the Forward Capacity market (FCM) and some degree of carbon pricing going forward, as described in the AESC report.

The price estimates in the AESC Report represent "avoided costs," so they do not take into consideration the effects of future efficiency programs over time. For purposes of the scenarios presented in this report, the wholesale electric prices from the Synapse report were therefore reduced by 2% in all years to account for the likely reduction in market clearing prices due to the energy efficiency and CHP and other DG that will be installed in the region.[12]

The retail price paid by customers considering CHP was built up from the wholesale prices by adding 20% for all the costs associated with the retail function, and adding 5% for average distribution losses. In addition, distribution rates were estimated based on assumptions about the average load factor for the end-use facilities in each market segment, as described in the next section.

Generally, these estimates showed electricity prices escalating faster over this period than gas prices, improving the spark spread for CHP. The price trends are shown in the following chart:

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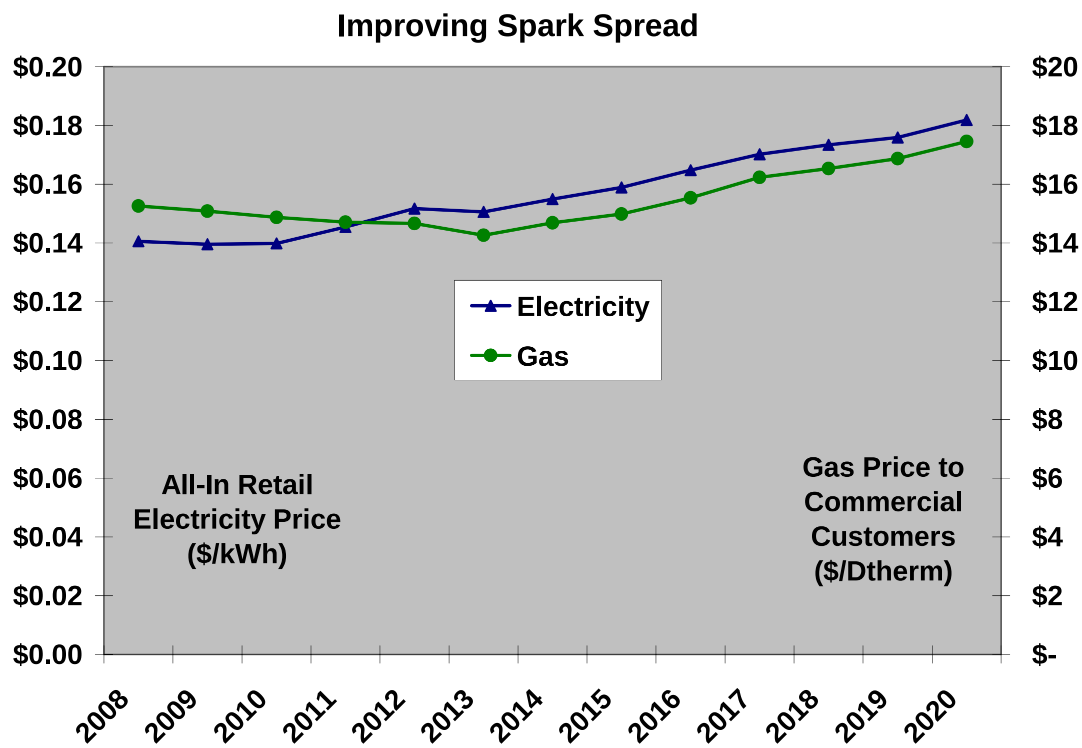
10 Synapse, Impacts of Distributed Generation.

11 See http://www.masstech.org/dg/2007-AESC-NE-avoided-costs.pdf.

12 For more information about such price reductions, see Synapse, Impacts of Distributed Generation.

Figure 3-2
Projected Gas and Electricity Prices 2008-2020



3.5 Electricity Distribution Rates

The model estimated electricity rates based on the rate structures for small and large commercial and industrial customers (equivalent to G2 and G3 rates) for Massachusetts distribution companies and estimated load factors for the CHP application size ranges. For hypothetical facilities in each of the size categories, the model determined the average cost of energy that those facilities would be paying. That cost was used in the payback analysis calculations. An example of how the electricity prices were estimated for a given facility size is shown in Table 3-3.

Table 3-3
Calculation of Average Electricity Costs for G-3 Rate Customer with 5MW CHP Application

G-3 (National Grid): General service for business customers with maximum demand >200 kW.			
Monthly Bill Analysis			
Peak Demand	**5,000**	kW	
Load Factor	55%		
Peak Coincidence	75%	66% = Level Load	
Total Usage	2,007,500	kWh	
Peak Usage	1,505,625	kWh	
Off-Peak Usage	501,875	kWh	
Levelized Cost	**$0.142**	Per kWh	
Non-generation rate subtotal	$ 0.0410		
Service Charge/Prod.&Tran.	$ 2,152.28	Fixed	$2,152.28
Distribution	$ 6.09	Per kW	$30,463.75
	$ 0.00620	Per Peak kWh (8 am to 9 pm)	$9,340.90
	$ 0.00039	Per Off-Peak kWh (9 pm to 8 am)	$194.98
Transition	$ 1.50	Per kW	$7,513.13
	$ 0.00513	Per kWh	$10,301.99
Transmission	$ 0.93	Per kW	$4,656.88
	$ 0.00577	Per kWh	$11,590.30
Demand Side Management	$ 0.00250	kWh	$5,018.75
Renewable	$ 0.00050	kWh	$1,003.75
Generation	$ 0.10122	kWh	$203,203.61
Total Monthly Bill			**$285,440.31**

The average statewide standby charge was set at 75% of the average of Distribution charges, which is approximately equivalent to 90% of the average demand charge for distribution. Although some Massachusetts distribution companies do not have standby charges in effect at present, this assumption is roughly based on the level of standby charges presently in effect for some NSTAR customer classes and for some CHP applications.

3.6 Payback Estimates for Each Year 2007 to 2026

The payback calculation reflected anticipated changes in technology costs, gas prices, and electricity prices. The following pre-tax[13] payback calculation was performed for CHP installed in each year of the analysis:

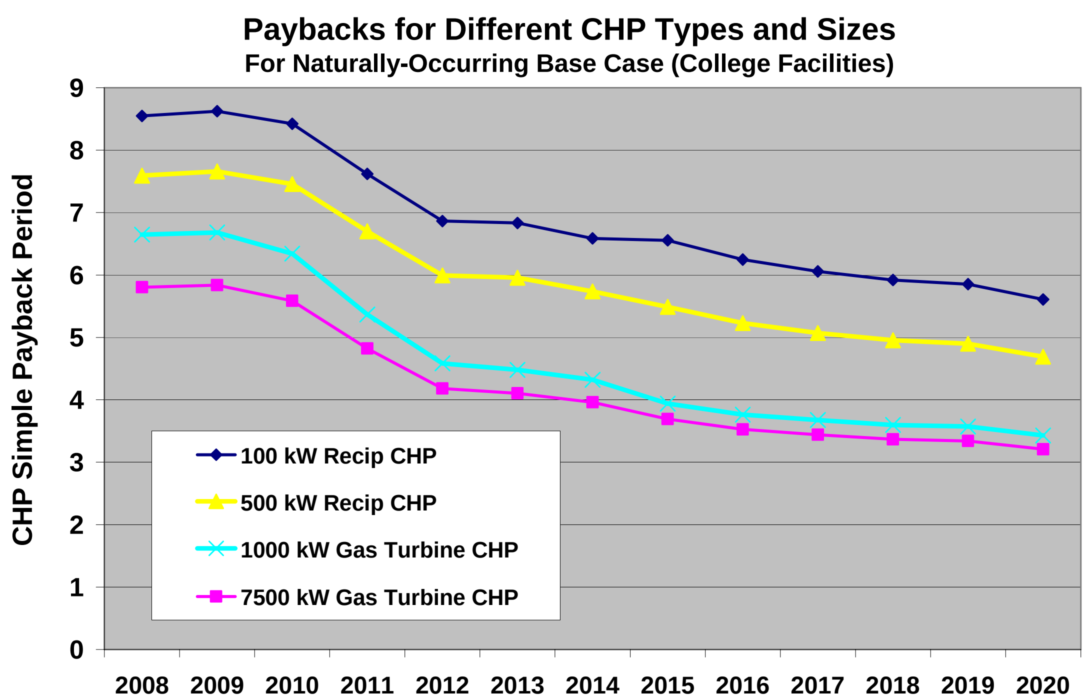
a. Calculating the thermal and electrical savings.

b. Subtracting the costs of on-site generation—the fuel and maintenance costs along with utility standby charges.

c. If net savings resulted, the capital cost of the expected application was divided by the savings in order to calculate the yearly payback.

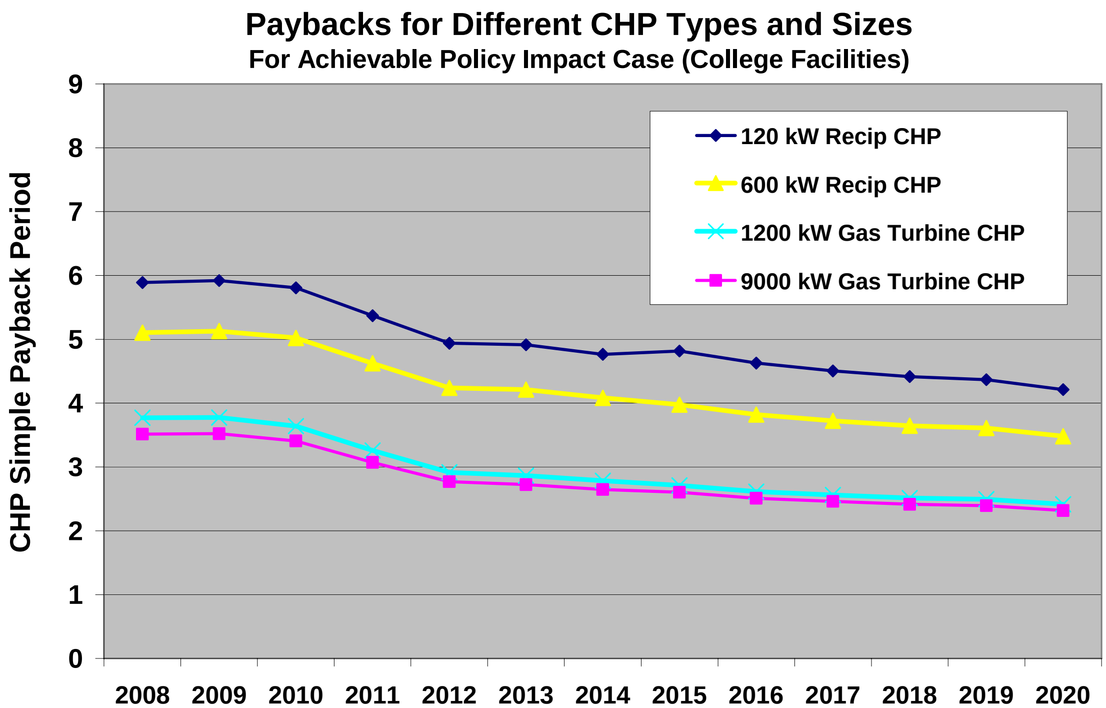
Figure 3-3 and Figure 3-3 present the payback periods estimated over time for different CHP sizes for the two key Scenarios.

Figure 3-3



[13] This analysis did not address tax costs or tax benefits of CHP.

Figure 3-4



3.7 Market Penetration Estimates

The first section below discusses the rate of eventual adoption of CHP by customers as a function of the payback period for their investment in CHP. The second section discusses the limits to CHP adoption as a result of various barriers. We then discuss how all these factors are combined to estimate the potential annual market penetration for each industry and size category.

3.7.1 Market Penetration Curves

As stated above, the market penetration over the planning horizon was estimated as a function of the simple payback of the CHP investment. In this section we describe the assumptions that were used for this analysis and the basis on which these assumptions were chosen.

One source of information was research jointly sponsored by EPRI and the California Energy Commission. The 2005 EPRI report on this study of CHP penetration in California stated that:

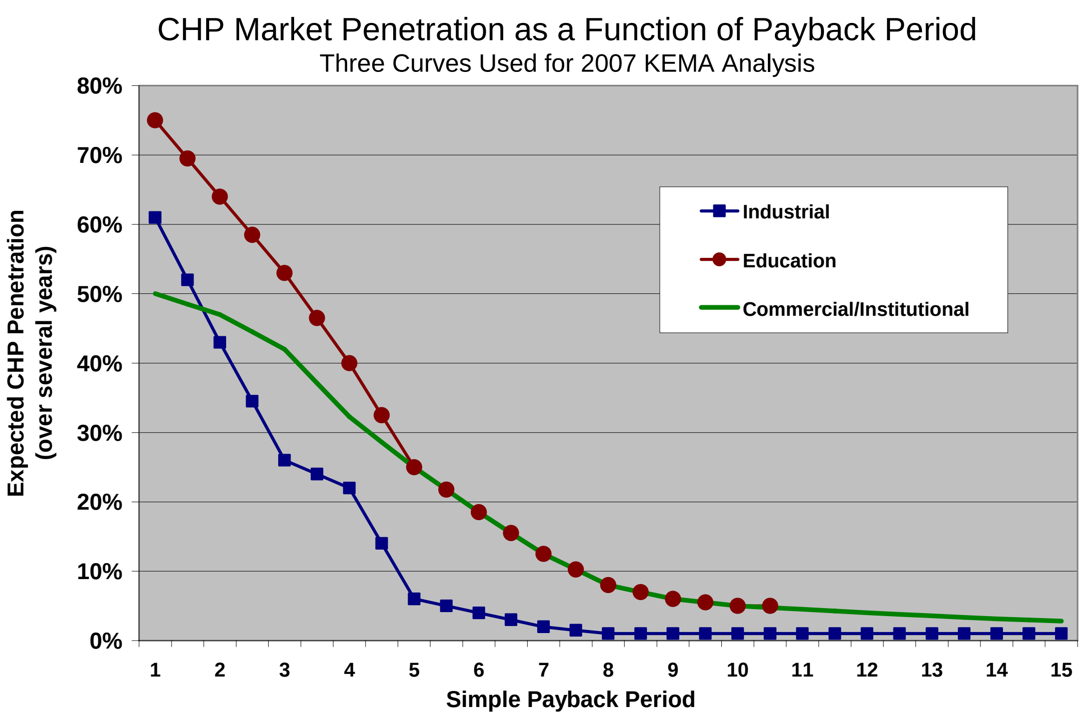
> California energy users, like those throughout the country, adopt CHP for two basic reasons. The first, and most important, is to reduce their overall cost of energy. The second is the increased power reliability that many energy users feel a CHP application will provide them. Although

> there are many factors that affect project economics, most energy users ultimately reduce the complexity of a CHP decision to a simple payback calculation. Yet, the payback threshold that California energy users apply is very demanding – less than half of all energy users would be willing to accept a payback of even two years for a CHP project....[14]

This report included penetration curves for a few different categories of potential CHP customers. KEMA applied the curve for manufacturing from this California study to all of the industrial categories in the analysis of Massachusetts market. The curve for education was applied to the college and university sector in Massachusetts.

A different curve was used for the rest of the commercial and institutional sectors in Massachusetts. The derivation of the commercial/institutional curve is described below. The three curves used for this market potential study are shown below in Figure 3-5.

Figure 3-5



[14] Assessment of California CHP Market and Policy Options for Increased Penetration, EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: July 2005 (with citations to Primen's 2003 Distributed Energy Market Survey), available at: http://www.masstech.org/renewableenergy/public_policy/DG/resources/2005-07_CEC_CHP-report_EPRI-EEA-E3.pdf

For the commercial and institutional sectors (other than education), the KEMA team worked with the MTC staff to create an appropriate curves to be utilized for this report. We started with the curve used in the recent analysis for the DG Collaborative, included in the January 2006 report by Navigant Consulting, Inc. (NCI), *Distributed Generation and Distribution Planning: An Economic Analysis for the Massachusetts DG Collaborative*. NCI's report provided quantitative models and analyses to test the contribution of DG to electric distribution planning and customer needs. The analysis was also intended to support assessment of other potential DG costs and benefits to a range of key stakeholders. NCI's analysis did support the hypothesis that DG can, in at least some realistic situations, contribute value to distribution planning while meeting customer needs. This NCI analysis was prepared under contract with MTC and through a thorough stakeholder process for the Massachusetts Distributed Generation collaborative. This process led to the 2006 Report of the DG Collaborative in which further analysis was recommended on the benefits of DG and related issues, and thereby led to the present Report.

During this stakeholder process in 2005, various market penetration curves were discussed. One curve was based on the exponential model of market penetration of CHP from the Department of Energy's (DOE) Energy Efficiency & Renewable Energy Group (EERE).[15] This curve was relatively flat, with penetration relatively less sensitive to CHP paybacks, partly because it was based on research that emphasized packaging of CHP with other energy efficiency measures by energy service companies. This EERE curve is included in the chart below, as the blue dashed line showing higher penetration for the higher payback periods.

The final curve that was used in the NCI economic analysis for the DG Collaborative is also shown in the chart below, designated as "DG Collaborative 2006." It is the orange dashed line with the triangle markers, which shows relatively high penetration for the most attractive, lower payback periods. The DG Collaborative's 2006 Report describes the methodology through which this curve was applied. For each payback period, the curve shows the level of market penetration that can be expected to be achieved over several years. The rate at which that penetration is actually achieved will vary based on various market and policy conditions, and the resulting time period required to achieve that level of penetration was assumed to vary between 5 and 10 years for that study.

Another curve that was considered was the curve presented in the EPRI California report for the retail sector.[16] It was quite close to the EERE curve in the low-payback range, and close to the DG Collaborative 2006 curve in the higher ranges.

These three curves were then combined with industry insight from the KEMA team to create a final penetration curve that was utilized in the report for most of the commercial and institutional sectors, which is the solid green line with no markers " in the chart below, designated "Commercial/Institutional CHP 2007." This final curve was developed as follows:

- The "DG Collaborative 2006" curve was used for most of the payback periods, including paybacks of 3 through 9 years.

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[15] Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume III: Energy Savings Potential, Tiax LLC, July 2002, pages 2-5; available at: http://www.eere.energy.gov/buildings/info/documents/pdfs/hvacvolume3finalreport.pdf.

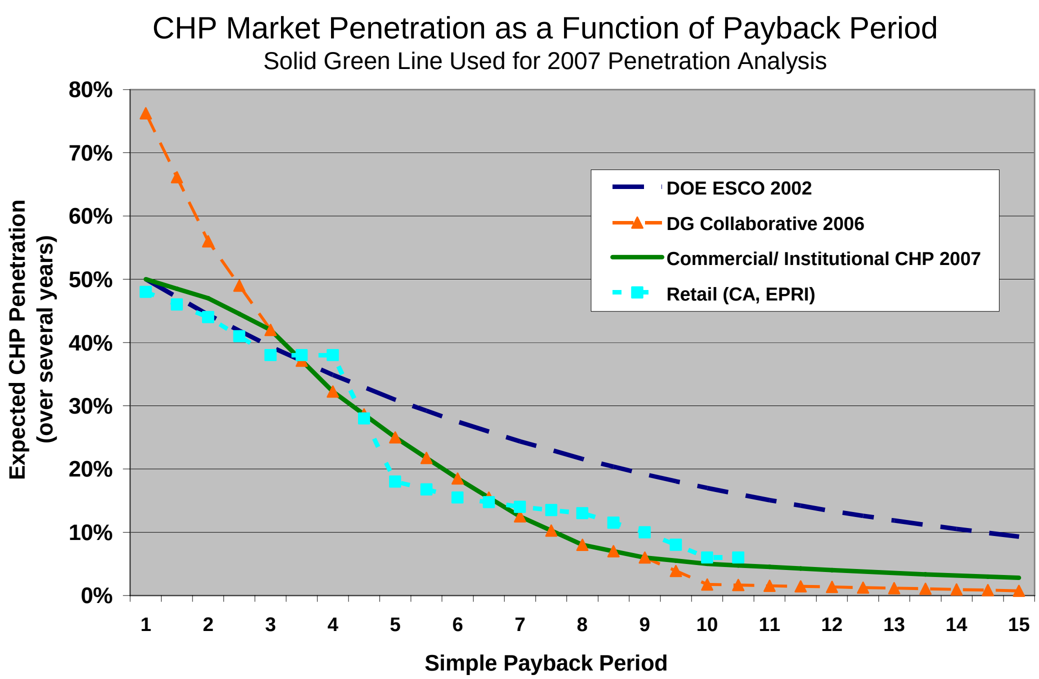
[16] EPRI, Assessment of California CHP Market, page _____.

- For payback periods of one and two years, lower penetrations were used, close to the EERE curve and the retail curve from the EPRI report.

- For payback periods of ten years and greater, higher penetrations were used than had been assumed for the 2006 DG Collaborative analysis, estimated to be 30% of the EERE curve values.

The following chart compares these curves and shows how the Commercial/Institutional CHP 2007 curve developed for this report generally falls between the other curves used as reference points.

Figure 3-6



The way in which the Commercial/Institutional CHP 2007 curve is applied in the KEMA penetration model is discussed in Section 3.7.3 below, including assumptions made for different scenarios about the number of years that will be required for these levels of penetration to be reached.

3.7.2 Barriers to Market Penetration

Not all customers will base their investment decisions on the payback period, and CHP is not technically feasible for all customers. The model input "Maximum Penetration Due To Barriers" was used to eliminate to percentages of the potential market for which CHP would not be adopted due to the following types of barriers:

- Site-specific installation barriers that would reduce CHP economics, such as space constraints, atypical interconnection costs or other requirements for expensive customization of CHP installations. For the Naturally-Occurring base case, these barriers were assumed to reduce "Maximum Penetration" as by 25 percentage points from 100% to 75%.

- Structural market barriers that are neither technical nor economic, such as uncertainty or fear over spark spread volatility and the barriers we call "mode of operation." For the base case these barriers were assumed to reduce Maximum Penetration by an additional 25 percentage points from 75% to 50%.

The result of these assumptions is that Maximum Penetration was assumed to be 50% in the Base Case. For the estimate of economic and achievable potential, it was assumed that many of the structural market barriers could be largely overcome, increasing the penetration to 65% of the maximum potential.

Though there are significant end-user, efficiency, and societal benefits to utilizing CHP as an application, and though estimated paybacks are favorable, historically there have been hurdles that have inhibited the rate of adoption of CHP systems.

These hurdles, or constraints to CHP adoption, can reside with end-users and their perception of CHP, can take the form of hassle factors such as maintaining CHP systems and regulatory rules, or simply be policies that make it difficult for an individual to adopt an application. Some of these constraints are listed below. KEMA has listed these in order to highlight that even though with today's favorable spark spread (difference between electricity and natural gas costs) and paybacks, some CHP will still not get installed. Some of these barriers may be addressed by a range of programs or regulations that can help facilitate CHP adoption.

The following are examples of "Site-Specific Installation Barriers," which are reflected in the cost and performance calculations:

- Level of customization is required at every facility. Additional cost adders are encountered for simple site conditions. These site conditions can be (1) Location of CHP system is located far away from Electric Panel, (b) Location is far away from gas line, meaning line needs to be extended at extra costs, (c) Space problems cause system to be needed to be put on the roof of a building or in undesirable location.

- Many Massachusetts installations are in the "small system" category. "Standard" issues such as interconnection equipment specification and site conditions have a larger proportional impact on small systems and can dramatically increase cost on a "$/kW" basis and reduce payback.

- In depth analysis may reveal uneven thermal usage. With Baseloaded CHP, thermal is produced at a steady rate. Uneven facility usage reduces amount of thermal consumed; hence, savings from thermal usage is decreased and leads to a negative impact on payback.

- Smaller Facilities, which are a large portion of Massachusetts potential, tend to have lower capacity factors as they are not operating 24/7, which makes economics difficult because of uneven thermal utilization. Exceptions that are more promising due to high capacity factors and thermal loads include nursing homes, metal plating companies, and some grocery stores and food processors.

In addition to taking these types of site-specific installation barriers into account in setting the cost and performance assumptions, they are reflected in the model by reducing the Maximum Penetration from 100% to 75% for the Naturally-Occurring base case.

The following are examples of "Structural Market Barriers," which can to some extent be overcome through policy interventions in the markets:

- Volatility of spark spread leads facilities owners to doubt payback estimates, as they worry that gas volatility may cause the spread to deteriorate over time.

- Mode of Operation: For small facilities, "Third Party Own & Operate" model is preferred, as potential CHP hosts tend to not have enough on site manpower to maintain and operate the machine. However, many CHP distributors may not be able to offer Own & Operate approach for CHP.

- Mode of Operation: For large facilities, owners of such facilities have manpower to maintain and monitor CHP applications and want to own systems outright. However, such facilities will have examined CHP before and may rely on a portfolio of thermal heating & cooling options (fuel oil, natural gas, CHP).

For the Naturally-Occurring base case, these barriers were assumed to reduce Maximum Penetration by an additional 25 percentage points from 75% to 50%. For the estimates of economic and achievable potential, it was assumed that many of the structural market barriers could be largely overcome, increasing the penetration to 65% of the maximum potential.

3.7.3 Market Penetration Calculations

Based on the factors described above, the general approach to estimate market penetration begins with the assumed capacity (in kW) of each CHP application, which is multiplied by the estimated number of facilities in each sector to create a CHP technical market size (in MW) for each sector. The technical market size is then multiplied by the percentage assumed for the "Maximum Market Due To Barriers", discussed in the previous section, in order to calculate the size of the "Addressable Market" in each year.

The market penetration curve determines an expected penetration percentage of the Addressable Market based on the payback. Paybacks were mapped on a market penetration curve for each targeted industrial and commercial sector and each year. Assumptions were then made for each scenarios about the number of years that will be required for these levels of penetration to be reached. Each year's expected market penetration was then calculated based on the expected penetration level divided by the number of years over which that penetration would occur.

The key output of the model is the amount of penetration in MW. For each market segment and for each CHP size range, a market penetration and cumulative market penetration was calculated for each year. Examples of how this process was applied to two industry sectors are shown in the tables below:

Table 3-4
Estimated Market Penetration of CHP in Food Industry, 2007-2012

Food Industry Technical Potential -- Capacity (MW) for Massachusetts			
Market Size Category (kW)	Number of Sites	Average Facility Size	Total MW Potential
50kW - 500kW	294	130	38.2
500kW - 1 MW	19	360	6.8
1 MW - 5 MW	17	2,000	34.0
5 MW - 20 MW	0	0	0.0
Total	330		79

Initial Market Penetration		
Market Size Range	Initial Market Share	Inital penetration (MW)
50kW - 500kW	0.0%	0.00
500kW - 1 MW	5.0%	0.34
1 MW - 5 MW	5.9%	2.00
5 MW - 20 MW	0.0%	0.00
		2.34

		2007	2008	2009	2010	2011	2012
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
50kW - 500kW	Payback Period	6.41	5.84	5.89	5.80	5.36	4.93
	EAF	**4%**	5%	5%	5%	6%	14%
	Addressable Mkt	19.11	19.35	19.60	19.84	20.08	20.31
	Mkt Penetration	0.04	0.04	0.06	0.06	0.07	0.17
	Cum. Mkt. Pen.	0.04	0.09	0.14	0.20	0.27	0.45
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
500kW - 1 MW	Payback Period	6.20	5.63	5.69	5.58	5.10	4.65
	EAF	4%	5%	5%	5%	6%	14%
	Addressable Mkt	3.57	3.62	3.67	3.71	3.75	3.80
	Mkt Penetration	0.01	0.01	0.01	0.01	0.01	0.03
	Cum. Mkt. Pen.	0.01	0.01	0.03	0.04	0.05	0.09
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1 MW - 5 MW	Payback Period	4.87	4.49	4.52	4.36	3.84	3.38
	EAF	14%	22%	14%	22%	24%	26%
	Addressable Mkt	19.20	19.35	19.43	19.54	19.54	19.52
	Mkt Penetration	0.13	0.21	0.18	0.29	0.32	0.34
	Cum. Mkt. Pen.	0.13	0.35	0.53	0.82	1.13	1.48

Table 3-5
Estimated Market Penetration of CHP in College Sector, 2007-2012

College & University Technical Potential – Capacity (MW)			
Market Size Category	Number of Sites	Average Facility Size	Total MW Potential
50kW - 500kW	42	150	4
500kW - 1 MW	9	750	5
1 MW - 5 MW	38	2,500	38
5 MW - 20 MW	29	14,224	218
Total	118		264

Initial Market Penetration		
Market Size Range	Initial Market Share	Inital penetration (MW)
50kW - 500kW	20.7%	0.87
500kW - 1 MW	19.3%	0.87
1 MW - 5 MW	20.8%	7.90
5 MW - 20 MW	3.3%	7.10
		16.74

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
50kW - 500kW	Payback Period	9.41	8.55	8.62	8.42	7.62	6.86
	EAF	6%	7%	7%	8%	10%	15.5%
	Addressable Mkt	1.67	1.69	1.71	1.73	1.74	1.76
	Mkt Penetration	0.00	0.00	0.01	0.01	0.01	0.02
	Cum. Mkt. Pen.	0.00	0.01	0.02	0.02	0.03	0.05
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
500kW - 1 MW	Payback Period	8.37	7.59	7.66	7.46	6.70	5.99
	EAF	8%	10%	10%	13%	16%	22%
	Addressable Mkt	2.00	2.00	2.01	2.03	2.04	2.06
	Mkt Penetration	0.03	0.01	0.01	0.02	0.02	0.03
	Cum. Mkt. Pen.	0.03	0.04	0.06	0.07	0.09	0.12
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1 MW - 5 MW	Payback Period	7.19	6.65	6.68	6.34	5.37	4.58
	EAF	13%	16%	16%	19%	25%	33%
	Addressable Mkt	18.06	18.23	18.37	18.51	18.56	18.53
	Mkt Penetration	0.10	0.13	0.13	0.23	0.31	0.41
	Cum. Mkt. Pen.	0.10	0.23	0.37	0.60	0.91	1.32
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
5 MW - 20 MW	Payback Period	6.29	5.80	5.84	5.59	4.82	4.18
	EAF	19%	22%	22%	22%	33%	40%
	Addressable Mkt	136.76	137.47	137.96	138.02	138.08	137.15
	Mkt Penetration	1.34	1.58	2.01	2.01	3.01	3.67
	Cum. Mkt. Pen.	1.34	2.92	4.92	6.93	9.94	13.61

4. CHP Potential Results

4.1 Context

The CHP penetration model was designed to provide flexibility with inputs and to provide an up to date assessment of CHP potential in the state of Massachusetts. The model also used available data or modified data based on the professional judgment of KEMA and CEERE in order to calculate the results. The intention of the model was not to create a detailed feasibility study for any particular facility, but rather to provide a high-level estimate of the potential of CHP in MA. For this study multiple market penetration scenarios were modeled, including a “Naturally Occurring” base case, and an “Achievable Policy Impact case.”

In the Naturally-Occurring case (also referred to as the base case), market penetration was driven by the expected prices of gas and electricity without any major program intervention, other than a continuation of federal and state activities that are already underway to provide information about the advantages of CHP and to remove barriers to CHP growth. This results in the installation of approximately 240 MW of new CHP in the 12-year period from 2009 through 2020, as illustrated in Figure 4-1 below (in the red line with circle markers).

In the Achievable Policy Impact case, the economics of CHP were assumed to be improved significantly by improving key CHP drivers such as the kW size of projects and their capacity factors, as described in greater detail below. In addition, the model inputs were adjusted to simulate faster CHP growth, by reducing the time required to reach the expected level of market penetration from 15 to 12 years. This results in the installation of approximately 660 MW of new CHP in the 12-year period from 2009 through 2020 (see the orange line with square markers in the chart below), an increase of 420 MW over the Naturally-Occurring case.

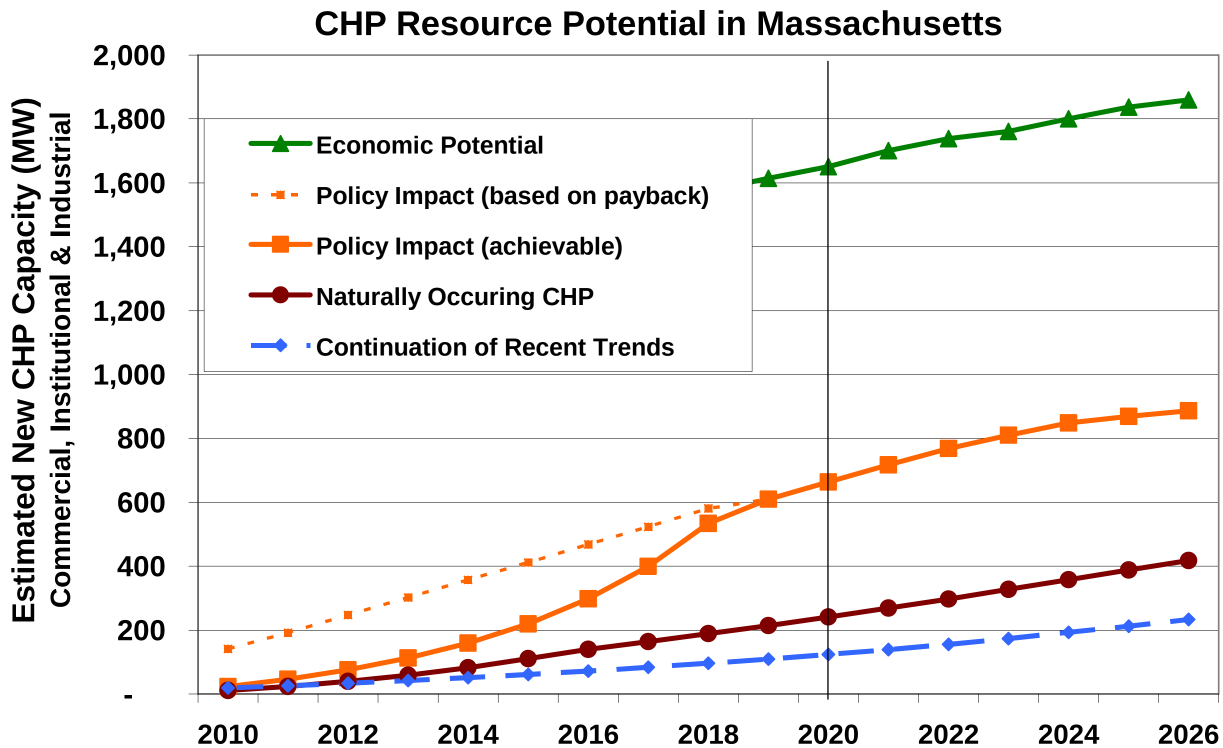
The results of these two scenarios, and the way they were modeled, are described further below.

For purposes of comparison, two additional scenarios were also developed:

- A lower-penetration case with continuation of the recent trend of approximately 8% annual growth in CHP installations in Massachusetts (dashed line), and
- A higher-penetration “Economic Potential” case in which it was assumed that all CHP with paybacks of 5 years or less would be installed, without any delay for the sales cycle or growth of the market supply chain (green line with triangle markers).

These results are presented graphically below in Figure 4-1, and are described in the sections below.

Figure 4-1



4.2 Continuation of Recent Trends

In the last few years, CHP installations have been growing at a rate of approximately 8%. The dashed line at the bottom of Figure 4-1 illustrates this trend.

4.3 Naturally Occurring Base Case

It is likely that CHP growth will improve compared with recent growth trends, due to improvement in the "spark spread" as well as a range of current outreach activities by EPA and DOE, state agencies and gas and electric utilities. The naturally-occurring CHP was modeled with a set of assumptions based on market prices for gas and electricity projected by Synapse in the AESC report. These prices have the benefit of being estimated in an internally-consistent manner through a public/private process covering all the New England states. These prices reflect a significant improvement over time in the spark spread, which accounts for a significant portion of the increase in CHP above the recent trend of about 8% annual growth. Other assumptions on which this scenario are based are discussed below.

Table 4-1 and Table 4-2, below, show the expected base case penetration of CHP by sector for the industrial and commercial/institutional sectors in 2026. This result is the base case penetration of CHP in Massachusetts through 2026 if significant new policies are not implemented to encourage CHP. This scenario reaches a penetration of approximately 300 MW by 2020 and over 500 MW by 2026. In this scenario, the average installations of CHP capacity would average approximately 20 MW per year in the period 2011 through 2015, increasing to approximately 25 MW/year in the period 2016 through 2020.

For each year, a cumulative penetration amount was calculated for each industry segment and shown below.

Table 4-1
Expected Penetration of CHP in Massachusetts (MW)

Industrial CHP (MW in 2026)	Average Customer Load				Total MW of CHP
	50-500 KW	500 kW - 1 MW	1-5 MW	5-20 MW	
Computer & Electric Products	0	2	5	17	24
Fabricated Metal Products	6	3	1	1	11
Paper	1	1	12	2	16
Food	4	1	7	0	12
Chemicals	0	0	6	2	9
Machinery	1	2	2	0	5
Textiles	0	0	1	2	3
Electrical Equipment	0	1	2	0	3
Primary Metals	0	1	2	0	3
Other	1	0	1	0	3
Total MW Industrial CHP	**13**	**12**	**41**	**23**	**89**
Percent of Total	15%	13%	46%	26%	

Commercial & Institutional CHP (MW in 2026)	Average Customer Load				Total MW of CHP
	50-500 KW	500 kW - 1 MW	1-5 MW	5-20 MW	
Office Buildings	15	21	31	72	138
Colleges & Universities	0	1	9	70	80
Hospitals & Healthcare	0	4	17	6	28
Retail Stores	16	0	3	0	19
Nursing Homes & Assisted Living	10	3	1	0	14
Restaurants	14	0	0	0	14
Water & Sewage Treatment Plants	1	2	6	6	15
Hotels & Motels	4	4	6	0	13
Laundries	5	1	1	0	6
Health Clubs	2	2	0	0	4
Grocery Stores	2	0	6	0	8
Schools	1	0	2	0	4
Other	4	1	3	0	8
Total MW Commercial CHP	**75**	**38**	**86**	**153**	**352**
Percent of Total	21%	11%	24%	44%	

The above tables have summarized base case results in terms of CHP capacity. The following table presents the corresponding number of CHP projects that would be expected to be installed, in the commercial and institutional sectors.

Table 4-2
Expected Penetration of CHP in Massachusetts, Number of C/I Plants

Number of Commercial & Institutional CHP Plants in 2026	Average Customer Load				Total MW of CHP
	50-500 KW	500 kW - 1 MW	1-5 MW	5-20 MW	
Office Buildings	248	85	77	29	439
Colleges & Universities	4	1	9	9	24
Hospitals & Healthcare	3	6	16	2	26
Retail Stores	324	0	11	0	335
Nursing Homes & Assisted Living	100	7	1	0	107
Restaurants	202	0	0	0	202
Water & Sewage Treatment Plants	11	3	6	1	21
Hotels & Motels	34	4	6	0	44
Laundries	33	1	1	0	35
Health Clubs	24	5	0	0	30
Grocery Stores	22	0	11	0	32
Schools	13	0	3	0	16
Number of Commercial CHP Plants	**1,018**	**113**	**139**	**41**	**1,311**
Average CHP Size (kW)	74	337	616	3,727	269
Total MW Commercial CHP	75	38	86	153	352

The above tables also show the average size of the CHP projects in each customer size category. For example, for customers or CHP hosts with average annual loads between 50 kW and 500 kW, the average size of CHP installations is expected to be 74 kW. At the other extreme, for customers or CHP hosts with average annual loads between 5 MW and 20 MW, the average size of CHP installations is expected to be 3.7 MW.

The other assumptions on which the naturally-occurring CHP scenario is based represent the base case modeling assumptions:

- The potential market for CHP grows at a rate of 1.5%/year as a result of load growth in existing and new customers.

- CHP adoption is limited to a maximum growth rate of 25%/year, even if the penetration curves would suggest a higher rate of adoption based on CHP paybacks.
- It is assumed for this scenario that CHP owners do not obtain all the likely economic benefit from the Forward Capacitry Market (FCM) but that the host customer only receives a net annual capacity benefit of $24/kW ($2/kw-month). This could represent a situation with modest levels of revenue received from the FCM, much of which is consumed by transaction costs and M&V costs or payments to intermediaries.
- The maximum penetration is limited to 50% of the technical potential, which means that 50% of the potential CHP opportunities are eliminated by one or more of the barriers listed in section __.
- It is assumed that it takes 15 years for the expected penetration to be achieved in the two largest size categories, with 1 additional year for category from 500 kW to 1 MW, and 2 additional years for the smallest category.

The key model assumptions for this base case, and the other cases, are presented in Table 4-3.

Table 4-3
Key Assumptions by Case

Massachusetts CHP Penetration Model	**Naturally Occuring**	**Achievable Policy Impact**	**Economic Potential**
Input Assumptions			
Growth Rate of Potential Market	1.5%	1.5%	1.5%
Maximum Growth Rate of CHP Adoption	**25%**	**35%**	unlimited
Sensitivity Adjustment of CHP Sizes (% change in kW)	100%	**120%**	**125%**
Maximum Penetration Due To Barriers	50%	**65%**	**65%**
Market Penetration Assumed for 3-year Payback	42%	42%	**100%**
Market Penetration Assumed for 6-year Payback	19%	19%	19%
Policy/Sensitivity Inputs			
Annual Capacity Benefit from FCM ($/kW)	**$24.00**	**$48.00**	**$48.00**
Capital Cost Reduction (% below standard inputs)	0%	**12%**	0%
Maximum Capital Cost Reduction ($/kW)	$0	**$200**	$0
Gas Distribution Rate Reduction (% of Margin)	0%	**20%**	0%
Maximum CHP Credit on Electric Rate ($/kWh)	$0.000	**$0.010**	$0.000
CHP Credit on Electric Rate (% below total)	0.0%	**7.5%**	0.0%
Years to Expected Market Penetration: Commercial	15	**12**	1
Years to Expected Market Penetration: Industrial	15	**12**	1
Payback period 2008 (examples)			
5-20 MW CHP: Computer & Electronics	4.6	2.6	3.6
1-5 MW CHP: Hospitals	6.3	3.2	4.7
50-500 kW CHP: Fabricated Metal Products	7.4	4.9	5.8
Payback period 2012			
5-20 MW CHP: Computer & Electronics	3.4	2.1	2.7
1-5 MW CHP: Hospitals	4.4	2.5	3.4
50-500 kW CHP: Fabricated Metal Products	6.0	4.2	4.8
Payback period 2016			
5-20 MW CHP: Computer & Electronics	2.9	2.1	2.3
1-5 MW CHP: Hospitals	3.7	2.6	2.9
50-500 kW CHP: Fabricated Metal Products	5.5	4.2	4.4
Massachusetts CHP Penetration (MW)			
Commercial & Institutional (2009-2020)	205	584	765
Industrial (2009-2020)	37	105	155
Total Increase in 18 years 2009-2020	**242**	**688**	**920**
Additional Increase in 6 years 2021-2026	177	197	209
Total 2026	**419**	**885**	**1,129**
Increase from Base Case			
Total CHP Generation in 2020 (gWh/year)	1,672	5,048	13,055
Weighted Avg Capacity Factor	70.7%	76.7%	85.5%

4.4 Achievable Policy Impact Case

This study did not attempt to specify or analyze particular CHP programs or policy options. Instead, its goal was to identify the magnitude of CHP that would be achievable if a set of multiple policies were implemented. Therefore, the modeling approach was to change several assumptions at the same time, which would have the same effect as a comprehensive set of policies, by improving CHP economics, removing barriers and reducing the time required for market penetration to occur.

Specifically, the achievable policy impact Scenario represents a case that would be made possible by the following interventions in the model:[17]

- Reducing Capital Costs by 12% or $220/kW (which could be achieved by incentives or rebates)
- Reducing Gas Rates by 20% of the Distribution Margin,[18]
- Providing a CHP Credit on the host's electric rate of $.01/kWh),
- Increasing the CHP host customer's net Annual Capacity Benefit from FCM from $24/kW to $48/kW ($4/kw-month),
- Increasing Average CHP Size by 20% over the Base Case
- Increasing CHP Capacity Factor by 10% over the Base Case
- Increasing Maximum Penetration (due to barriers) from 50% to 65%, as a way to simulate the mitigation of the "structural" or site-specific barriers described in section __ above,
- Reducing Years to Expected Market Penetration from 15 to 12 (these are the assumptions for the two largest size categories, with the smaller categories 1 or 2 years higher in each run).

This possible scenario for policy intervention reaches approximately 688 MW by 2020 and 885 MW by 2026. In this scenario, the average increase in CHP capacity would be approximately 40 MW per year in the period 2011 through 2015, increasing to approximately 100 MW/year in the period 2016 through 2020.

4.5 Economic Potential Case

The Economic Potential was modeled by making the following additional changes in assumptions from the Achievable Policy case:

- Assuming that all CHP with paybacks of 5 years or less would be included or installed, and
- Reducing the Years to Expected Market Penetration to only one year for all sectors.

On this basis, the economic potential reaches approximately 920 MW by 2020 and approximately 1,100 MW by 2026. These economic potential results are not directly comparable to the approach that is often used to estimate economic potential in energy efficiency studies. However, it provides a useful point of

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[17] While these changes were modeled as a group, none of them are analyzed as individual policy options in this report.

[18] While this study did not specify any particular approach to implement such a change to gas rates, other Northeast states, including New York and Connecticut, have recently implemented various such approaches.

comparison within this market penetration framework, by varying key assumptions on which the modeling of the other scenarios was based.

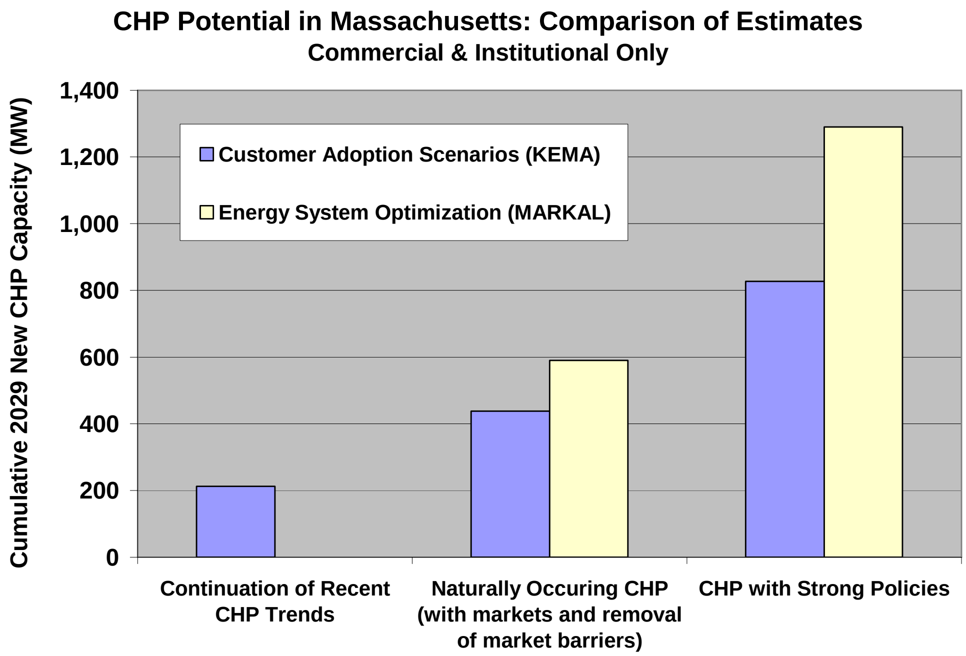
4.6 Comparison to Other studies

This section compares the results of the KEMA model with other relevant studies.

4.6.1 Comparison with NESCAUM's MARKAL Model

Contemporaneous with the KEMA study, the Northeast States for Coordinated Air Use Management (NESCAUM) has been conducting a study of commercial and institutional CHP potential.[19] NESCAUM's study, for the Kendall Foundation, utilized the MARKAL model to optimize the Massachusetts energy system, including all energy uses and supply of all fuels and electricity, as opposed to KEMA's model which emphasized adoption rates by energy users based on payback periods for potential investments in CHP. Though different logic and calculations were used in NESCAUM's study than in the KEMA model presented here, NESCAUM estimated penetration of about 600 MW through naturally occurring scenario by 2029, and over 1,200 MW penetration in a strong policy scenario, which included a carbon cap extending over the commercial sector. Figure 4-2 below, shows the comparison of results.

Figure 4-2
Comparison of Projected CHP Penetration from KEMA and NESCAUM MARKAL Models



19 The NESCAUM study is available at: _______ .

4.6.2 Comparison with projections from other states

KEMA also projected CHP penetration based on the results of projections from other, nearby, states including New York, New Jersey, and Connecticut.

In constructing its projections, KEMA reviewed the following reports:

- New York State Energy Research and Development Authority, 2002, *Combined Heat and Power Market Potential for New York State, Final Report 02-12, October 2002.* Prepared by Energy Nexus Group, Onsite Energy Corporation, and Pace Energy Project.
- Rutgers University Center for Energy, Economic, and Environmental Policy, 2004, *New Jersey Energy Efficiency and Distributed Generation Market Assessment, August 2004.* Prepared by KEMA, Inc.
- Institute for Sustainable Energy at Eastern Connecticut State University, 2004, *Distributed Generation Market Potential: 2004 Update / Connecticut and Southwest Connecticut.* Prepared by KEMA, Inc.

In addition, data on numbers of commercial and industrial customers, peak loads, retail sales and prices of electricity, and prices of natural gas were gathered from publicly available information at the DOE Energy Information Administration.

In the above referenced reports, projected installations of distributed generation in New York, New Jersey, and Connecticut were evaluated and presented in two scenarios, a “base case” and an “accelerated case”. The accelerated case anticipated market transformation policy initiatives that would provide incentives and/or reduce barriers to the installation of distributed generation. In Connecticut, the analysis was further broken down technology-based scenarios, including a “current technologies” scenario, and an “advanced technology” scenario to model the impact of technical improvements on distributed generation systems.

The New York evaluation, which served as a model for both the New Jersey and Connecticut projections, developed specific customer profiles to estimate penetration of DG into various market segments. The methodology, as described in the New York report, was to:

- Identify applications where CHP provides a reasonable fit to the electric and thermal needs of the user.
- Quantify the number and size distribution of target applications.
- Estimate CHP potential in terms of MW capacity.

The New Jersey and Connecticut evaluations used the estimated customer profiles from New York as a basis for their analysis. Those analyses therefore assumed that the breakdown of total CHP potential by application size in New York State is similar to that of CT or New Jersey.

For Massachusetts, a similar assumption was made. To estimate projected DG installations in Massachusetts, the projections from New York, New Jersey, and Connecticut were scaled up or down based on the ratios of total customers from Massachusetts to the other states. Estimates were also constructed using the ratios of total retail energy sales for commercial and industrial customers from Massachusetts to the other states. The resulting estimates, in turn, were averaged to determine projected installations of DG in Massachusetts. This was done for both the base and accelerated cases; from Connecticut the analysis only used the current technologies scenario.

In addition, KEMA reviewed the DG penetration curves from New York, New Jersey, and Connecticut to estimate penetrations for a single year (2015). For New York, this involved extending the projected penetration curve in that report by 3 years. For Connecticut, it was extended by one year, and for New Jersey, 2015 was within the 20 year estimations that were included.

The resulting projections suggested that DG installations in MA are likely to be between 400MW (base case) and 1400 MW (accelerated policy case) by 2015, which would represent between 4% to 13% of summer peak load. These projections are roughly similar to the results suggested by both NESCAUM's and KEMA's current studies.