APPENDIX 10

Combined Heat and Power Market Assessment for Delmarva Power

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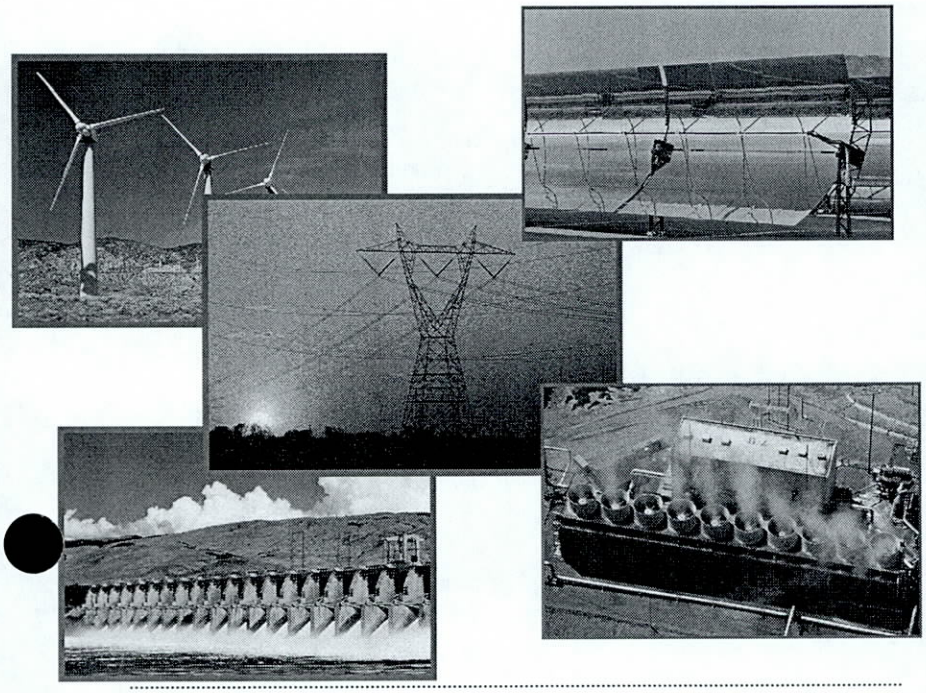

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1. Introduction

Combined heat and power (CHP), also known as cogeneration, is an efficient and clean approach to generating electricity or mechanical power and useful thermal energy from a single fuel source at the point of use. Instead of purchasing electricity and then burning fuel in an on-site furnace or boiler to produce thermal energy, an industrial or commercial facility can use CHP to provide these energy services in one energy-efficient step. As a result, CHP can provide significant energy efficiency and environmental advantages over separate heat and power. For optimal efficiency, CHP systems typically are designed and sized to meet the users' thermal baseload demand.

CHP technology can be deployed quickly, cost-effectively, and with few geographic limitations. CHP systems are located at or near end-users, and therefore defer or reduce construction of new transmission and distribution (T&D) infrastructure. While the traditional method of producing separate heat and power has a typical combined efficiency of 45 percent, CHP systems can operate at efficiency levels as high as 80 percent.

Changing energy markets and climate change policies are driving greater interest in energy efficiency and clean energy technologies. CHP offers significant environmental benefits compared to separately purchased electricity and onsite-generated thermal energy. CHP's high efficiency results in less fuel use and lower levels of greenhouse gases emissions. CHP in the United States today avoids more than 1.9 Quadrillion Btus of fuel consumption and 248 million metric tons of CO_2 emissions compared to traditional separate production of electricity and heat[1]. This CO_2 reduction is the equivalent of removing more than 45 million cars from the road.

The size of CHP systems can range from 1 kW (the demand of a single-family home) to several hundred MW (the demand of a large petroleum-refining complex). Due to this size flexibility, CHP can be utilized in a variety of applications. Eighty-eight percent of U.S. CHP capacity is found in industrial applications, providing power and steam to large industries such as chemicals, paper, refining, food processing, and metals manufacturing. CHP in commercial and institutional applications is currently 12 percent of existing capacity, providing power, heating, and cooling to hospitals, schools, campuses, nursing homes, hotels, and office and apartment complexes[2].

In July 2009, the Energy Conservation and Efficiency Act of 2009, was signed into law in Delaware designating energy efficiency as a priority energy resource in the state that should be considered before other new supply-side resources are obtained. The legislation creates an Energy Efficiency Resource Standard (EERS) that requires a 15 percent reduction in electricity consumption and peak demand by 2015 through demand side management programs that could include Combined Heat and Power initiatives. Compliance is met by state electric distribution companies, and the percentage savings are measured as a percentage of total retail sales.

This report presents an analysis of CHP potential in the Delmarva service territory of Delaware. The amount of the 15 percent electricity savings goal that can be met through CHP installations by 2015 is intended for Delmarva's use in their Integrated Resource Plan (IRP) detailing the demand side management programs to be employed in meeting the 15 percent goal.

The CHP market assessment presented in this report is based on the *ICF CHP Market Model* that estimates cumulative CHP market penetration as a function of competing CHP system

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[1] Oak Ridge National Laboratory. "Combined Heat and Power: Effective Energy Solutions for a Sustainable Future." December 2008.
[2] CHP Installation Database. Maintained by ICF International for US Department of Energy. 2010. http://www.eea-inc.com/chpdata/index.html

specifications, current and future energy prices, and electric and thermal load characteristics for target markets. The CHP analysis includes the following four steps:

- Estimate of CHP Technical Market Potential – An estimate of the technically suitable CHP applications by size and by industry. This estimate is derived from the screening of customer data based on application and size characteristics that are used to estimate groups of facilities with appropriate electric and thermal load characteristics conducive to CHP.
- CHP Technology Characterization – For each market size range, a set of applicable CHP technologies is selected for evaluation. These technologies are characterized in terms of their capital cost, heat rate, non-fuel operating and maintenance costs, and available thermal energy for process use on-site
- Estimate of Energy Price Projections – Present and future fuel and electricity prices are estimated to provide inputs into the CHP net cost calculation.
- Estimate of CHP Market Penetration – Within each market size, the competition among applicable CHP technologies is evaluated. Based on this competition, the economic market potential is estimated and shared among competing CHP technologies. The rate of market penetration by technology is then estimated using a market diffusion model.

This report is organized into the following sections:

- **Existing CHP in Delmarva Territory** – A review of existing CHP facilities in Delmarva Power's service territory
- **CHP Technical Potential** – An estimate of the overall size of the CHP market including the size and types of targeted applications.
- **CHP Technology Cost and Performance** – A summary of the cost and performance of applicable CHP technologies used in the analysis
- **Market Penetration Model** – A description of the *ICF CHP Market Model* that estimates cumulative CHP market penetration as a function of competing CHP system specifications, current and future energy prices, and electric and thermal load characteristics for target markets. This section includes a summary of critical assumptions used in the analysis including fuel and electricity price projections
- **CHP Market Penetration Results** – A summary of the CHP penetration results for a base case and incentive scenario

2. Existing CHP in Delmarva Power Service Territory

Delaware currently has 40.5 MW of CHP installed at three facilities in the state. All of this capacity is located in industrial facilities, which have traditionally had thermal and electric loads conducive to CHP. One of these three installations is located in Delmarva Power's service territory:

- DuPont De Nemours / Invista Seaford Plant – an 18 MW boiler/steam turbine system providing thermal energy for DuPont's nylon production plant in Seaford. DuPont spun off the nylon fibers business in 2004 to a wholly owned subsidiary named Invista.

Until recently, the Valero-owned Delaware City Refinery operated a 202 MW CHP system that provided thermal energy to the refinery. This refinery was shut down in November 2009 due to cost cutting measures by Valero Energy Corporation, however if another company decides to buy the refinery, this site may represent a significant source of CHP capacity in the future.

The market penetration of CHP in Delaware, and therefore Delmarva's service territory, has not been as high as other areas of the east coast. The neighboring states of Pennsylvania and New Jersey have much higher rates of CHP penetration. The following table lists the three CHP systems currently operating in Delaware.

Table 1 Existing CHP Systems Operating in Delaware

Facility Name	City	Technology	Capacity (MW)	Application	Installation Year
Kraft Cogeneration Facility	Dover	Boiler/Steam Turb	18	Food Processing	1985
General Chemical Corporation	Claymont	Boiler/Steam Turb	4.5	Chemicals	1952
Du Pont De Nemours / Invista	Seaford	Boiler/Steam Turb	18	Textiles	1939
		Total =	**40.5**		

3. CHP Technical Potential

This section provides an estimate of the technical market potential for combined heat and power in the industrial, commercial/institutional, and multi-family residential market sectors in Delmarva's service territory. The CHP technical potential is an estimation of market size constrained only by technological limits – the ability of CHP technologies to fit customer energy needs. CHP technical potential is calculated in terms of CHP electrical capacity that could be installed at existing and new facilities based on the estimated electric and thermal needs of the site. The technical market potential does not consider screening for economic rate of return, or other factors such as ability to retrofit, owner interest in applying CHP, capital availability, natural gas availability, and variation of energy consumption within customer application/size class. The technical potential as outlined is useful in understanding the potential size and distribution of the target CHP market in the area. Identifying the technical market potential is a preliminary step in the assessment of actual economic market size and ultimate market penetration.

CHP is best applied at facilities that have significant and concurrent electric and thermal demands. In the industrial sector, CHP thermal output has traditionally been in the form of steam used for process heating and for space heating. For commercial and institutional users. thermal output has traditionally been steam or hot water for space heating and domestic hot water heating, and more recently for providing space cooling through the use of absorption chillers. Two different types of CHP markets were included in this evaluation of technical potential: 1) traditional power and heat CHP, and 2) combined cooling heating and power (CCHP). Both of these markets were further disaggregated by high load factor and low load factor applications resulting in the analysis of four distinct market segments.

3.0.1 Traditional CHP

This market represents CHP systems where the electrical output is produced to meet all or a portion of the base load for a facility and the thermal energy is used to provide steam or hot

water. The most efficient sizing for CHP is to match thermal output to baseload thermal demand at the site. Depending on the type of facility, the appropriate sizing could be either electric or thermal limited. Industrial facilities often have "excess" thermal load compared to their on-site electric load (meaning the CHP system will generate more power than can be used on-site if sized to match the thermal load). Commercial facilities almost always have excess electric load compared to their thermal load. Two sub-categories were considered:

- *High load factor applications:* This market provides for continuous or nearly continuous operation. It includes all industrial applications and round-the-clock commercial/institutional operations such colleges, hospitals, hotels, and prisons.
- *Low load factor applications:* Some commercial and institutional markets provide an opportunity for coincident electric/thermal loads for a period of 3,500 to 5,000 hours per year. This sector includes applications such as office buildings, schools, and laundries.

3.0.2 Combined Cooling Heating and Power (CCHP)

All or a portion of the thermal output of a CHP system can be converted to air conditioning or refrigeration with the addition of a thermally activated cooling system. This type of system can potentially open up the benefits of CHP to facilities that do not have the year-round heating load to support a traditional CHP system. A typical system would provide the annual hot water load, a portion of the space heating load in the winter months and a portion of the cooling load during the summer months. Two sub-categories were considered:

- *Incremental high load factor applications:* These markets represent round-the-clock commercial/institutional facilities that could support traditional CHP, but with consideration of cooling as an output, could support additional CHP capacity while maintaining a high level of utilization of the thermal energy from the CHP system.
- *Low load factor applications.* These represent markets that otherwise could not support traditional CHP due to a lack of thermal load.

3.1 Technical Potential Methodology

The determination of technical market potential consists of the following elements:

- Identify applications where CHP provides a reasonable fit to the electric and thermal needs of the user. Target applications are identified based on reviewing the electric and thermal energy consumption data for various building types and industrial facilities.
- Quantify the number and size distribution of target applications. Delmarva electric customer data was used to identify the number of target application facilities by sector and by size that meet the thermal and electric load requirements for CHP.
- Estimate CHP potential in terms of megawatt (MW) capacity. Total CHP potential is then derived for each target application based on the number of target facilities in each size category and CHP sizing criteria appropriate for each sector.
- Subtract existing CHP from the identified sites to determine the remaining technical market potential.

3.1.1 CHP Target Applications

In general, the most efficient and economic CHP operation is achieved when: 1) the system operates at full-load most of the time (high load factor application), 2) the thermal output can be fully utilized by the site, and 3) the recovered heat displaces fuel or electricity purchases.

There are a number of commercial and industrial applications that characteristically have sufficient and coincident thermal and electric loads for CHP. Examples of these applications include food processing, pulp and paper plants, laundries and health clubs. Most commercial and light industrial applications have low base thermal loads relative to the electric load, but have high thermal loads in the cooler months for heating. Such applications include hotels, hospitals, nursing homes, college campuses, correctional facilities, and light manufacturing.

In order to identify a complete list of applications where CHP provides a reasonable fit to the electric and thermal needs of the user, ICF reviewed electric and thermal energy (heating and cooling) consumption data for various building types and industrial facilities. Data sources included the DOE EIA *Commercial Buildings Energy Consumption Survey (CBECS),* the DOE *Manufacturing Energy Consumption Survey (MECS)* and various market summaries developed by DOE, Gas Technology Institute (GRI), and the American Gas Association. Existing CHP installations in the commercial/institutional and industrial sectors were also reviewed to understand the required profile for CHP applications and to identify target applications.

There are two fundamental approaches to sizing CHP systems for a given application based on what the thermal energy will be used for:

- Traditional CHP - Size the CHP system for the base thermal load (domestic hot water, pool heating, showers, laundries, kitchens) which usually results in a system sized below the base electric load.
- Combined Cooling Heating and Power (CCHP) - Size the CHP system to include thermally activated cooling to create additional thermal use during the cooling months that when combined with space heating justifies a larger CHP system that better matches the electric demand.

The following two tables show the applications that were identified in these two categories as well as their assumed load profiles. Applications with a high load factor were assumed to operate for 7,500 hours a year, whereas applications with a low load factor were assumed to operate for 5,000 hours a year. The category and load profile combinations make up the four markets that were defined at the beginning of this section. Each application is shown with both the corresponding NAICS code and SIC code.

Table 2 Traditional CHP Target Applications

NAICS	SIC	Application	Application Type	Load Factor
311 - 312	20	Food Processing	Industrial	High
313	22	Textiles	Industrial	High
321	24	Lumber and Wood	Industrial	High
337	25	Furniture	Industrial	High
322	26	Paper	Industrial	High
325	28	Chemicals	Industrial	High
324	29	Petroleum Refining	Industrial	High
326	30	Rubber/Misc Plastics	Industrial	High
331	33	Primary Metals	Industrial	High
332	34	Fabricated Metals	Industrial	High
333	35	Machinery/Computer Equip	Industrial	High
336	37	Transportation Equip.	Industrial	High
335	38	Instruments	Industrial	High
339	39	Misc. Manufacturing	Industrial	High
2213	4941	Water Treatment/Sanitary	Commercial/Institutional	High
92214	9223	Prisons	Commercial/Institutional	High
8123, 8213	7211	Laundries	Commercial/Institutional	Low
71394	7991	Health Clubs	Commercial/Institutional	Low
71391	7992	Golf/Country Clubs	Commercial/Institutional	Low
8111	7542	Carwashes	Commercial/Institutional	Low

Table 3 Combined Cooling Heating and Power Target Applications

NAICS	SIC	Application	Application Type	Load Factor
531	6513	Apartments	Commercial/Institutional	High
721	7011	Hotels	Commercial/Institutional	High
623	8051	Nursing Homes	Commercial/Institutional	High
622	8062	Hospitals	Commercial/Institutional	High
6113	8221	Colleges/Universities	Commercial/Institutional	High
518	7374	Data Centers	Commercial/Institutional	High
531	6512	Comm. Office Buildings	Commercial/Institutional	Low
6111	8211	Schools	Commercial/Institutional	Low
612	8412	Museums	Commercial/Institutional	Low
491	43	Post Offices	Commercial/Institutional	Low
452	50	Big Box Retail	Commercial/Institutional	Low
48811	4581	Airport Facilities	Commercial/Institutional	Low
445	5411	Food Sales	Commercial/Institutional	Low
722	5812	Restaurants	Commercial/Institutional	Low
512131	7832	Movie Theaters	Commercial/Institutional	Low
92	9100	Government Buildings	Commercial/Institutional	Low

3.1.2 Quantification of Target Facilities based on Delmarva Customer Data

Delmarva customer data was used to identify the number of target application facilities by sector and by size (electric demand) that meet the thermal and electric load requirements for CHP. Delmarva provided data on the annual electricity use and peak demand for customers that were active as of January 2010 and had a metered demand level between 50 kW and 20,000 kW for 2009. Delmarva may have more large customers with electric demand over 20,000 kW that are candidates for CHP, however they were not included in this analysis. The demand level

analyzed encompasses small commercial facilities up to medium-sized industrial plants. The complete dataset contained 3,264 customer records, 2,178 of which fell into target CHP applications.

3.1.3 Estimate Electric and Thermal Loads and CHP System Sizing

To calculate the total technical potential for CHP in Delmarva's customer base, each of the 2,178 potential facilities needs to have a hypothetical CHP system sized to its electrical and thermal loads. The sum of all the individual CHP system potentials would then result in the overall total CHP potential for the region.

It was assumed that the CHP systems would be sized to meet the base thermal loads (heating and cooling) unless the CHP system sizing exceeded the average facility electric demand. In this case, the CHP system size would be limited to the site's average electric demand. The average electric load of each facility in the dataset was estimated by dividing the total kWh electricity consumption by the assumed operating hours corresponding with the application's load factor (7,500 hours a year for high load factor, 5,000 hours a year for low load factor).

After the average electric demand was calculated for each facility, the thermal load was estimated to properly size the CHP system for high thermal utilization and to determine whether the thermal load would limit the CHP system size. In previous studies, ICF has used information on thermal loads for the target CHP applications derived from data in DOE's *Commercial Buildings Energy Consumption Survey (CBECS),* and *Manufacturing Energy Consumption Survey (MECS)*, the *Major Industrial Plant Database (MIPD*), and *Commercial Energy Profile Database (CEPD*), as well as studies of industrial electric and thermal profiles developed by DOE, Gas Technology Institute (GRI), and the American Gas Association. These data sources provided information on the end use of energy in commercial and industrial facilities, so that an average power-to-heat ratio for each target application could be developed. This electric and thermal data was used to develop thermal factors for each application that are used to estimate the CHP system size as a function of average electric demand. The thermal factor is based on both the power-to-heat ratio (P/H) of the application as well as the P/H ratio of a typical CHP system for that application.

After the process of sizing a potential CHP system to each of the 2,178 Delmarva customers in target CHP applications, 861 customers showed the potential for CHP systems over 50 kW in capacity. The technical potential at these 861 facilities is the focus of this analysis.

3.1.4 Target Application Growth Projections to 2030

The CHP technical market potential was estimated for both 2010 and 2015. The 2010 estimate is based on the specific facility data included in the Delmarva customer dataset. The 2015 estimate includes economic growth projections for each application between 2010 and 2015. The growth factors used in the analysis for growth between 2010 and 2015 by individual sector are shown below. The growth projections are based on a sector-specific growth forecast for Delaware from Moody's Economy.com[3]. These growth rates are used in this analysis as an estimate of the growth in new facilities or capacity additions at existing facilities. In cases where

[3] Moody's Economy.com. State Forecast Database – Delaware. 2010. http://www.economy.com/home/products/databases.asp?pid=30-00006-00&src=serviceOverview#30-00006-00

an economic sector is declining, it was assumed that no new facilities would be added to the technical potential for CHP.

Table 4 CHP Target Application Growth Projections for Delaware

SIC Code	Market Sector	2010-2015 Real Growth
20	Food	10.57%
22	Textiles	4.17%
24	Lumber and Wood	4.17%
25	Furniture	20.36%
26	Paper	4.17%
27	Printing/Publishing	4.17%
28	Chemicals	0.00%
29	Petroleum Refining	0.00%
30	Rubber/Misc. Plastics	0.00%
32	Stone/Clay/Glass	6.75%
33	Primary Metals	24.20%
34	Fabricated Metals	24.20%
35	Machinery/Computer Equip	0.00%
37	Transportation Equip.	0.00%
38	Instruments	0.00%
39	Misc. Manufacturing	6.75%
43	Post Offices	11.36%
4581	Airports	15.01%
6512	Office Buildings	11.86%
6513	Apartments	11.86%
7542	Carwashes	11.86%
7832	Movie Theaters	33.03%
8412	Museums	33.03%
4222, 5142	Warehouses	21.86%
4941, 4952	Water Treatment/Sanitary	11.36%
52,53,56,57	Big Box Retail	24.46%
5411, 5421, 5451, 5461, 5499	Food Sales	24.46%
5812, 00, 01, 03, 05, 07, 08	Restaurants	33.03%
7011, 7041	Hotels	33.03%
7211, 7213, 7218	Laundries	11.86%
7374	Data Centers	20.38%
7991, 00, 01	Health Clubs	33.03%
7992, 7997-9904, 7997-9906	Golf/Country Clubs	33.03%
8051, 8052, 8059	Nursing Homes	18.95%
8062, 8063, 8069	Hospitals	18.95%
8211, 8243, 8249, 8299	Schools	18.95%
8221, 8222	Colleges/Universities	18.95%
9100	Government Buildings	10.73%
9223	Prisons	11.36%

3.2 Technical Potential Results

This section provides the CHP technical potential estimates by application and size range. The estimates are divided into CHP technical potential that serves on-site electric demands at target facilities and additional CHP technical potential that is available if the facilities are allowed to export electricity to the grid. Accordingly, the on-site tables do not include any CHP capacity that is over the facility average electric demand. Excess CHP capacity that is available in certain applications is presented in the export tables.

3.2.1 2010 Technical Potential

Table 5 Industrial On-site Technical Potential - 2010

SICs	Application	50-500 kW Sites	50-500 kW MW	500-1 MW Sites	500-1 MW (MW)	1-5 MW Sites	1-5 MW (MW)	5-20 MW Sites	5-20 MW (MW)	Total Sites	Total MW
20	Food	11	1.9	3	2.1	7	17.7	1	7.9	22	29.7
22	Textiles	2	0.2	0	0.0	1	3.6	0	0.0	3	3.8
24	Lumber and Wood	2	0.1	0	0.0	0	0.0	0	0.0	2	0.1
25	Furniture	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
26	Paper	1	0.1	1	0.6	1	4.2	0	0.0	3	4.9
27	Printing	2	0.4	1	0.6	0	0.0	0	0.0	3	1.0
28	Chemicals	18	4.0	4	2.6	15	35.2	6	43.3	43	85.1
29	Petroleum Refining	7	0.9	1	0.7	0	0.0	0	0.0	8	1.6
30	Rubber/Misc Plastics	12	2.4	0	0.0	0	0.0	0	0.0	12	2.4
32	Stone/Clay/Glass	1	0.2	0	0.0	0	0.0	0	0.0	1	0.2
33	Primary Metals	2	0.4	0	0.0	0	0.0	0	0.0	2	0.4
34	Fabricated Metals	4	0.6	0	0.0	0	0.0	0	0.0	4	0.6
35	Machinery/Computer Equip	1	0.1	0	0.0	0	0.0	0	0.0	1	0.1
37	Trasportation Equip.	1	0.1	1	0.6	0	0.0	0	0.0	2	0.7
38	Instruments	3	0.9	0	0.0	2	2.1	0	0.0	5	3.1
39	Misc. Manufacturing	2	0.2	1	0.7	0	0.0	0	0.0	3	0.8
	Total	69	12.5	12	7.9	26	62.8	7	51.2	114	134.4

Table 6 Commercial On-site Technical Potential - 2010

SICs	Application	50-500 kW Sites	50-500 kW MW	500-1 MW Sites	500-1 MW (MW)	1-5 MW Sites	1-5 MW (MW)	5-20 MW Sites	5-20 MW (MW)	Total Sites	Total MW
43	Post Office	0	0.0	0	0.0	1	1.1	0	0.0	1	1.1
52	Big Box Retail	62	8.7	0	0.0	2	2.6	0	0.0	64	11.3
4222	Refridgerated Warehouses	5	1.2	4	2.5	3	3.8	0	0.0	12	7.6
4581	Airports	5	0.4	1	0.6	1	1.1	0	0.0	7	2.0
4952	Water Treatment/Sanitary	8	0.7	1	0.8	1	2.4	0	0.0	10	4.0
5411	Food Sales	46	4.6	0	0.0	0	0.0	0	0.0	46	4.6
5812	Restaurants	54	3.9	0	0.0	0	0.0	0	0.0	54	3.9
6512	Commercial Buildings	103	16.1	11	7.6	18	28.0	3	31.2	135	82.8
6513	Apartments	31	3.5	0	0.0	0	0.0	0	0.0	31	3.5
7011	Hotels	36	4.1	0	0.0	0	0.0	0	0.0	36	4.1
7211	Laundries	2	0.4	0	0.0	0	0.0	0	0.0	2	0.4
7374	Data Centers	1	0.4	1	0.5	1	1.4	1	6.3	4	8.6
7542	Carwashes	5	0.4	0	0.0	0	0.0	0	0.0	5	0.4
7832	Movie Theaters	3	0.3	0	0.0	0	0.0	0	0.0	3	0.3
7991	Health Clubs	4	0.4	0	0.0	0	0.0	0	0.0	4	0.4
7997	Golf/Country Clubs	21	3.7	0	0.0	0	0.0	0	0.0	21	3.7
8051	Nursing Homes	34	5.3	1	0.8	1	1.0	0	0.0	36	7.1
8060	Hospitals	14	2.6	2	1.3	4	7.5	2	13.2	22	24.6
8211	Schools	144	18.7	0	0.0	0	0.0	0	0.0	144	18.7
8220	Colleges/Universities	9	1.7	3	2.1	0	0.0	0	0.0	12	3.8
8412	Museums	5	0.9	0	0.0	1	1.3	0	0.0	6	2.2
9100	Government	51	7.4	4	2.9	0	0.0	0	0.0	55	10.3
9223	Prisons	4	0.6	2	1.1	1	1.2	0	0.0	7	2.9
	Total	647	86.2	30	20.2	34	51.4	6	50.6	717	208.5

Table 7 Export Technical Potential - 2010

SICs	Application	50-500 kW Sites	50-500 kW MW	500-1 MW Sites	500-1 MW (MW)	1-5 MW Sites	1-5 MW (MW)	5-20 MW Sites	5-20 MW (MW)	Total Sites	Total MW
20	Food	0	0	0	0	7	1.77	1	5.47	8	7.2
22	Textiles	0	0	0	0	0	0	0	0	0	0.0
24	Lumber and Wood	0	0	0	0	0	0	0	0	0	0.0
25	Furniture	0	0	0	0	0	0	0	0	0	0.0
26	Paper	0	0	0	0	0	0	1	5.75	1	5.8
27	Printing	0	0	0	0	0	0	0	0	0	0.0
28	Chemicals	0	0	0	0	13	7.51	8	45.1	21	52.6
29	Petroleum Refining	0	0	0	0	0	0	0	0	0	0.0
30	Rubber/Misc Plastics	0	0	0	0	0	0	0	0	0	0.0
32	Stone/Clay/Glass	0	0	0	0	0	0	0	0	0	0.0
33	Primary Metals	0	0	0	0	0	0	0	0	0	0.0
34	Fabricated Metals	0	0	0	0	0	0	0	0	0	0.0
35	Machinery/Computer Equip	0	0	0	0	0	0	0	0	0	0.0
37	Trasportation Equip.	0	0	0	0	0	0	0	0	0	0.0
38	Instruments	0	0	0	0	0	0	0	0	0	0.0
39	Misc. Manufacturing	0	0	0	0	0	0	0	0	0	0.0
	Total	0	0.0	0	0.0	20	9.3	10	56.3	30	65.6

Table 8 Total 2010 Technical Potential by Market Sector

Application Type	50-500 kW Sites	50-500 kW MW	500-1 MW Sites	500-1 MW (MW)	1-5 MW Sites	1-5 MW (MW)	5-20 MW Sites	5-20 MW (MW)	Total Sites	Total MW
Industrial - Onsite	69	12.5	12	7.9	26	62.8	7	51.2	114	134.4
Commercial - Onsite	647	86.2	30	20.2	34	51.4	6	50.6	717	208.5
Export	0	0.0	0	0.0	0	9.3	0	56.3	0	65.6
Total	716	98.7	42	28.1	60	123.5	13	158.1	831	408.5

3.2.2 2015 Technical Potential

Table 9 Industrial Technical Potential – Projected Growth to 2015

SICs	Application	50-500 kW MW	500-1 MW (MW)	1-5 MW (MW)	5-20 MW (MW)	Total MW
20	Food	0.2	0.2	1.9	0.8	3.1
22	Textiles	0.0	0.0	0.1	0.0	0.2
24	Lumber and Wood	0.0	0.0	0.0	0.0	0.0
25	Furniture	0.0	0.0	0.0	0.0	0.0
26	Paper	0.0	0.0	0.2	0.0	0.2
27	Printing	0.0	0.0	0.0	0.0	0.0
28	Chemicals	0.0	0.0	0.0	0.0	0.0
29	Petroleum Refining	0.0	0.0	0.0	0.0	0.0
30	Rubber/Misc Plastics	0.0	0.0	0.0	0.0	0.0
32	Stone/Clay/Glass	0.0	0.0	0.0	0.0	0.0
33	Primary Metals	0.1	0.0	0.0	0.0	0.1
34	Fabricated Metals	0.2	0.0	0.0	0.0	0.2
35	Machinery/Computer Equip	0.0	0.0	0.0	0.0	0.0
37	Trasportation Equip.	0.0	0.0	0.0	0.0	0.0
38	Instruments	0.0	0.0	0.0	0.0	0.0
39	Misc. Manufacturing	0.0	0.0	0.0	0.0	0.1
	Total	0.5	0.3	2.2	0.8	3.9

Table 10 Commercial Technical Potential – Projected Growth to 2015

SICs	Application	50-500 kW MW	500-1 MW (MW)	1-5 MW (MW)	5-20 MW (MW)	Total MW
43	Post Office	0.0	0.0	0.1	0.0	0.1
52	Big Box Retail	2.1	0.0	0.6	0.0	2.8
4222	Refridgerated Warehouses	0.3	0.6	0.8	0.0	1.7
4581	Airports	0.1	0.1	0.2	0.0	0.3
4952	Water Treatment/Sanitary	0.1	0.1	0.3	0.0	0.5
5411	Food Sales	1.1	0.0	0.0	0.0	1.1
5812	Restaurants	1.3	0.0	0.0	0.0	1.3
6512	Commercial Buildings	1.9	0.9	3.3	3.7	9.8
6513	Apartments	0.4	0.0	0.0	0.0	0.4
7011	Hotels	1.4	0.0	0.0	0.0	1.4
7211	Laundries	0.0	0.0	0.0	0.0	0.0
7374	Data Centers	0.1	0.1	0.3	1.3	1.8
7542	Carwashes	0.1	0.0	0.0	0.0	0.1
7832	Movie Theaters	0.1	0.0	0.0	0.0	0.1
7991	Health Clubs	0.1	0.0	0.0	0.0	0.1
7997	Golf/Country Clubs	1.2	0.0	0.0	0.0	1.2
8051	Nursing Homes	1.0	0.2	0.2	0.0	1.3
8060	Hospitals	0.5	0.2	1.4	2.5	4.7
8211	Schools	3.5	0.0	0.0	0.0	3.5
8220	Colleges/Universities	0.3	0.4	0.0	0.0	0.7
8412	Museums	0.3	0.0	0.4	0.0	0.7
9100	Government	0.8	0.3	0.0	0.0	1.1
9223	Prisons	0.1	0.1	0.1	0.0	0.3
	Total	16.8	3.0	7.8	7.5	35.1

Table 11 Export Technical Potential – Projected Growth to 2015

SICs	Application	50-500 kW MW	500-1 MW (MW)	1-5 MW (MW)	5-20 MW (MW)	Total MW
20	Food	0.0	0.0	0.0	0.6	0.6
22	Textiles	0.0	0.0	0.0	0.0	0.0
24	Lumber and Wood	0.0	0.0	0.0	0.0	0.0
25	Furniture	0.0	0.0	0.0	0.0	0.0
26	Paper	0.0	0.0	0.0	0.4	0.4
27	Printing	0.0	0.0	0.0	0.0	0.0
28	Chemicals	0.0	0.0	0.0	0.0	0.0
29	Petroleum Refining	0.0	0.0	0.0	0.0	0.0
30	Rubber/Misc Plastics	0.0	0.0	0.0	0.0	0.0
32	Stone/Clay/Glass	0.0	0.0	0.0	0.0	0.0
33	Primary Metals	0.0	0.0	0.0	0.0	0.0
34	Fabricated Metals	0.0	0.0	0.0	0.0	0.0
35	Machinery/Computer Equip	0.0	0.0	0.0	0.0	0.0
37	Trasportation Equip.	0.0	0.0	0.0	0.0	0.0
38	Instruments	0.0	0.0	0.0	0.0	0.0
39	Misc. Manufacturing	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.0	1.0	1.0

Table 12 Total Technical Potential by Market Sector – Projected Growth to 2015

Application	50-500 kW MW	500-1 MW (MW)	1-5 MW (MW)	5-20 MW (MW)	Total MW
Industrial - Onsite	0.5	0.3	2.2	0.8	3.9
Commercial - Onsite	16.8	3.0	7.8	7.5	35.1
Export	0.0	0.0	0.0	1.0	1.0
Total	17.3	3.3	10.0	9.3	39.9

4. CHP Technology Cost and Performance

The CHP system itself is the engine that drives the economic savings. The cost and performance characteristics of CHP systems determine the economics of meeting the site's electric and thermal loads. Most notable technology options available today for CHP include industrial and aero-derivative gas turbines, reciprocating engines, microturbines and fuel cells. A primary fuel option for these technologies is natural gas because of its availability, cost and emission qualities, therefore this analysis assumes the CHP systems will run on natural gas. Other fuel sources include landfill gas, digester gas, industrial waste fuel streams, propane, and diesel fuel. However, diesel fuel and propane can be prohibitively expensive for CHP. Furthermore, diesel gensets can have trouble getting environmental permits. Landfill and digester gas, in sufficient quantities, are generally economical with or without heat recovery (CHP).

Of the inventory of operating CHP capacity in the U.S., gas turbines and combined cycle units (gas turbines incorporating a steam turbine bottoming cycle) account for a majority of the capacity, while reciprocating engines dominate the number of installations. The competitive size span for the various CHP technology classes is depicted in the figure below. Also noted are the market dominant technologies by size class.

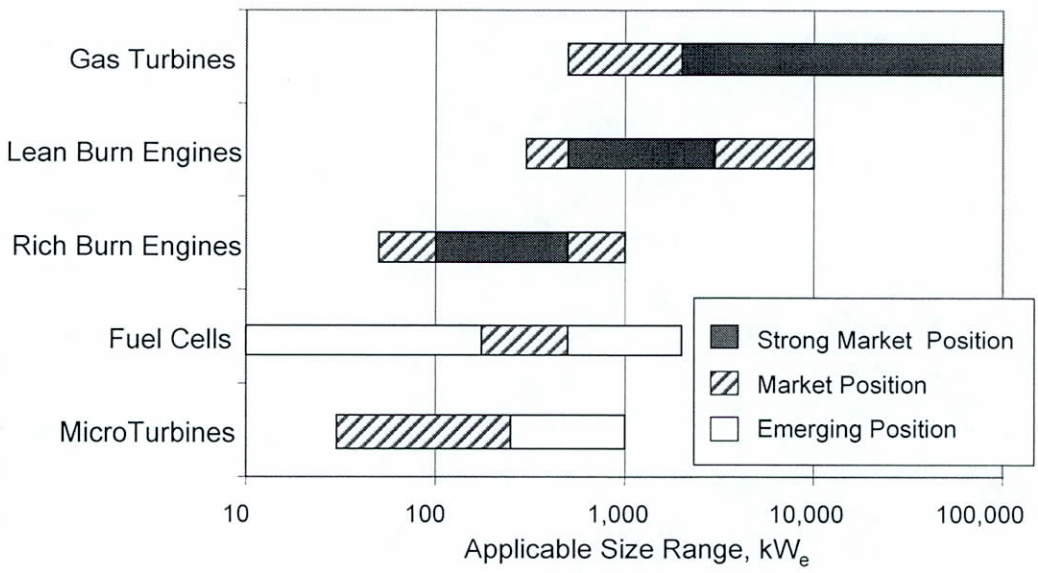


Figure 1 Technology Size Coverage

A representative sample of commercially and emerging CHP systems was selected to profile performance and cost characteristics in CHP applications. The selected systems range in capacity from approximately 100 – 40,000 kW. The technologies include gas-fired reciprocating engines, gas turbines, microturbines and fuel cells. The appropriate technologies were allowed to compete for market share in the penetration model. In the smaller market sizes, reciprocating engines competed with microturbines and fuel cells. In intermediate sizes (1 to 20 MW), reciprocating engines competed with gas turbines.

Cost and performance estimates for the CHP systems were based on work undertaken for the EPA.[4] The foundation for these updates is based on work previously conducted for NYSERDA[5], on peer-reviewed technology characterizations that Energy and Environmental Analysis (EEA) developed for the National Renewable Energy Laboratory[6] and on follow-on work conducted by DE Solutions for Oak Ridge National Laboratory.[7] Additional emissions characteristics and cost and performance estimates for emissions control technologies were based on work ICF conducted for EPRI.[8] Data is presented for a range of sizes that include basic electrical performance characteristics, CHP performance characteristics (power to heat ratio), equipment cost estimates, maintenance cost estimates, emission profiles with and without after-treatment control, and emissions control cost estimates. The technology characteristics are presented for three years: 2009, 2014, 2019. The 2009 estimates are based on current commercially available and emerging technologies. The cost and performance estimates for 2014 and 2019 reflect current technology development paths and currently planned government and industry funding. These projections were based on estimates included in the references listed above. NOx emissions estimates in lb/MWh are presented for each technology both with and without aftertreatment control (AT).

4.1 Reciprocating Engines

Table 13 Reciprocating Engine Technology Cost and Performance Characteristics

CHP System	Characteristic/Year Available	2009	2014	2019
100 kW-Rich Burn with 3 way catalyst	Installed Costs, $/kW	2,210	1,925	1,568
	Heat Rate, Btu/kWh	12,000	10,830	10,500
	Electric Efficiency, %	28.4	31.5	32.5
	Thermal Output, Btu/kWh	6100	5093	4874
	Overall Efficiency, %	79.3	78.5	78.9
	Power to Heat	0.56	0.67	0.70
	O&M Costs, $/kWh	0.02	0.016	0.012
	NO_x Emissions, lbs/MWh (w/ AT)	0.15	0.15	0.15
	NO_x Emissions, lbs/MWh (w/AT) CHP Credit	0.05	0.06	0.06
	After-treatment Cost, $/kW	incl.	incl.	incl.

[4] EPA CHP Partnership Program, Technology Characterizations, December 2007.
[5] *Combined Heat and Power Potential for New York State*, Energy Nexus Group (later became part of EEA), for NYSERDA, May 2002.
[6] "Gas-Fired Distributed Energy Resource Technology Characterizations", NREL, November 2003, http://www.osti.gov/bridge
[7] "Clean Distributed Generation Performance and Cost Analysis", DE Solutions for ORNL. April 2004.
[8] "Assessment of Emerging Low-Emissions Technologies for Distributed Resource Generators", EPRI, January 2005.

CHP System	Characteristic/Year Available	2009	2014	2019
800 kW-Lean Burn	Installed Costs, $/kW	1,640	1,443	1,246
	Heat Rate, Btu/kWh	9,760	9,750	9,225
	Electric Efficiency, %	35	35	37
	Thermal Output, Btu/kWh	4299	4300	3800
	Overall Efficiency, %	79	79.1	78.2
	Power to Heat	0.79	0.79	0.9
	O&M Costs, $/kWh	0.016	0.013	0.011
	NO_x Emissions, gm/bhp (w/o AT)	0.7	0.4	0.25
	NO_x Emissions, lbs/MWh (w/o AT)	2.17	1.24	0.775
	NO_x Emissions, lbs/MWh (w/AT)	0.11	0.12	0.08
	NO_x Emissions, lbs/MWh (w/AT) CHP Credit	0.05	0.05	0.04
	After-treatment Cost, $/kW	300	190	140
3000 kW-Lean Burn	Installed Costs, $/kW	1,130	1,100	1,041
	Heat Rate, Btu/kWh	9,492	8,750	8,325
	Electric Efficiency, %	35.9	39	41
	Thermal Output, Btu/kWh	3510	3189	2900
	Overall Efficiency, %	72.9	75.4	75.8
	Power to Heat	0.97	1.07	1.18
	O&M Costs, $/kWh	0.014	0.012	0.01
	NO_x Emissions, gm/bhp (w/o AT)	0.7	0.4	0.25
	NO_x Emissions, lbs/MWh (w/o AT)	2.17	1.24	0.775
	NO_x Emissions, lbs/MWh (w/AT)	0.11	0.12	0.08
	NO_x Emissions, lbs/MWh (w/AT) CHP Credit	0.05	0.06	0.04
	After-treatment Cost, $/kW	200	130	100
5000 kW-Lean Burn	Installed Costs, $/kW	1,130	1,099	1,038
	Heat Rate, Btu/kWh	8,758	8,325	7,935
	Electric Efficiency, %	39	41	43
	Thermal Output, Btu/kWh	3046	2797	2605
	Overall Efficiency, %	73.7	74.6	75.8
	Power to Heat	1.12	1.22	1.31
	O&M Costs, $/kWh	0.011	0.01	0.009
	NO_x Emissions, gm/bhp (w/o AT)	0.5	0.4	0.25
	NO_x Emissions, lbs/MWh (w/o AT)	1.55	1.24	0.775
	NO_x Emissions, lbs/MWh (w/AT)	0.11	0.12	0.08
	NO_x Emissions, lbs/MWh (w/AT) CHP Credit	0.06	0.07	0.04
	After-treatment Cost, $/kW	150	115	80

4.2 Gas Turbines

Table 14 Gas Turbine Technology Cost and Performance Characteristics

CHP System	Characteristic/Year Available	2009	2014	2019
3000 KW GT	Installed Costs, $/kW	1,690	1,560	1,300
	Heat Rate, Btu/kWh	13,100	12,650	11,500
	Electric Efficiency, %	26	27	29.7
	Thermal Output, Btu/kWh	5018	4750	4062
	Overall Efficiency, %	64.4	64.5	65
	Power to Heat	0.68	0.72	0.84
	O&M Costs, $/kWh	0.0074	0.0065	0.006
	NO_x Emissions, ppm (w/o AT)	15	9	5
	NO_x Emissions, lbs/MWh (w/o AT)	0.68	0.38	0.2
	NO_x Emission, lb/MWh (w/AT)	0.07	0.07	0.07
	After-treatment Cost, $/kW	210	175	150
10 MW GT	Installed Costs, $/kW	1,298	1,278	1,200
	Heat Rate, Btu/kWh	11,765	10,800	9,950
	Electric Efficiency, %	29	31.6	34.3
	Thermal Output, Btu/kWh	4674	4062	3630
	Overall Efficiency, %	68.7	69.2	70.8
	Power to Heat	0.73	0.84	0.94
	O&M Costs, $/kWh	0.007	0.006	0.005
	NO_x Emissions, ppm (w/o AT)	15	9	5
	NO_x Emissions, lbs/MWh (w/o AT)	0.68	0.38	0.2
	NO_x Emission, lb/MWh (w/AT)	0.07	0.07	0.07
	After-treatment Cost, $/kW	140	125	100
40 MW GT	Installed Costs, $/kW	972	944	916
	Heat Rate, Btu/kWh	9,220	8,865	8,595
	Electric Efficiency, %	37	38.5	39.7
	Thermal Output, Btu/kWh	3189	3019	2892
	Overall Efficiency, %	71.6	72.5	73.3
	Power to Heat	1.07	1.13	1.18
	O&M Costs, $/kWh	0.004	0.004	0.004
	NO_x Emissions, ppm (w/o AT)	15	5	3
	NO_x Emissions, lbs/MWh (w/o AT)	0.55	0.2	0.1
	NO_x Emission, lb/MWh (w/AT)	0.06	0.06	0.06
	After-treatment Cost, $/kW	90	75	40

4.3 Microturbines

Table 15 Microturbine Technology Cost and Performance Characteristics

CHP System	Characteristic/Year Available	2009	2014	2019
65 kW	Installed Costs, $/kW	2,739	2,037	1,743
	Heat Rate, Btu/kWh	13,542	12,500	11,375
	Electric Efficiency, %	25.2	27.3	30
	Thermal Output, Btu/kWh	6277	5350	4500
	Overall Efficiency, %	71.5	70.1	69.6
	Power to Heat	0.54	0.64	0.76
	O&M Costs, $/kWh	0.022	0.016	0.012
	NO_x Emissions, lbs/MWh (w/o AT)	0.17	0.14	0.13
	NO_x Emissions, lbs/MWh (w/o AT) CHP After-treatment Cost, $/kW	0.06	0.05	0.06
250 KW-use multiple units	Installed Costs, $/kW	2,684	2,147	1,610
	Heat Rate, Btu/kWh	12,290	11,750	10,825
	Electric Efficiency, %	27.8	29	31.5
	Thermal Output, Btu/kWh	4800	4300	3700
	Overall Efficiency, %	66.8	65.6	65.7
	Power to Heat	0.71	0.79	0.92
	O&M Costs, $/kWh	0.015	0.013	0.012
	NO_x Emissions, lbs/MWh (w/o AT)	0.14	0.13	0.13
	NO_x Emissions, lbs/MWh (w/o AT) CHP After-treatment Cost, $/kW	0.06	0.06	0.06

4.4 Fuel Cells

Table 16 Fuel Cell Technology Cost and Performance Characteristics

CHP System	Characteristic/Year Available	2009	2014	2019
200/400 kW PAFC (assumes all high grade and 50% low grade thermal utilized)	Installed Costs, $/kW	6,310	4,782	3,587
	Heat Rate, Btu/kWh	9,475	9,475	9,000
	Electric Efficiency, %	36	36	37.9
	Thermal Output, Btu/kWh	2923	2923	2800
	Overall Efficiency, %	66.9	66.9	69
	Power to Heat	1.17	1.17	1.22
	O&M Costs, $/kWh	0.038	0.017	0.015
	NO_x Emissions, lbs/MWh (w/o AT)	0.04	0.035	0.035
	After-treatment Cost, $/kW	n.a.	n.a.	n.a.
300 kW MCFC	Installed Costs, $/kW	5,580	4,699	3,671
	Heat Rate, Btu/kWh	8,022	7,700	7,300
	Electric Efficiency, %	42.5	44.3	46.7
	Thermal Output, Btu/kWh	1600	1500	1300
	Overall Efficiency, %	62.5	63.8	64.5
	Power to Heat	2.13	2.27	2.62
	O&M Costs, $/kWh	0.035	0.02	0.015
	NO_x Emissions, lbs/MWh (w/o AT)	0.01	0.01	0.01
	After-treatment Cost, $/kW	n.a.	n.a.	n.a.
1500 kW MCFC	Installed Costs, $/kW	5,250	4,523	3,554
	Heat Rate, Btu/kWh	8,022	7,500	6,820
	Electric Efficiency, %	42.5	45.5	50
	Thermal Output, Btu/kWh	1583	1400	1100
	Overall Efficiency, %	62.3	64.2	66.2
	Power to Heat	2.15	2.44	3.1
	O&M Costs, $/kWh	0.032	0.019	0.015
	NO_x Emissions, lbs/MWh (w/o AT)	0.01	0.01	0.01
	After-treatment Cost, $/kW	n.a.	n.a.	n.a.

4.5 Absorption Chillers

In the cooling markets, an additional cost was added to reflect the costs of adding chiller capacity to the CHP system. These costs are a function of the size of the absorption chiller which in turn depends on the amount of usable waste heat that the CHP system produces. A curve fitting approach was used and the values by CHP system size bins are as follows:

CHP System Size	Additional Cost for Absorption Chiller
50 - 500 kW	$390 - 530/kW
500 -1,000 kW	$275 - 500/kW
1 - 5 MW	$110 - 270/kW
5 - 20 MW	$65 - 110/kW
>20 MW	$45/kW

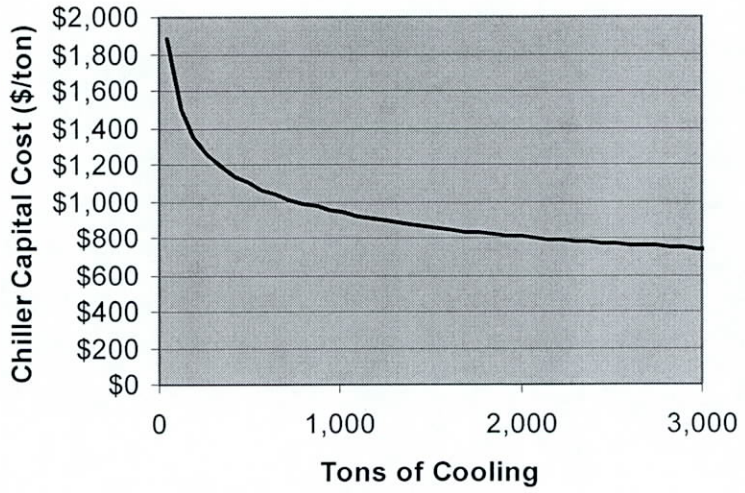


Figure 2 Absorption Chiller Capital Costs

5. Market Penetration Model

The *ICF CHP Market Model* estimates cumulative CHP market penetration as a function of the competing CHP system specifications, current and future energy prices, and site electric and thermal load characteristics. There are five markets defined by application type. Within each application type, there are five size bins. Each market application and size is defined in terms of the CHP operating load factor and the degree and type of thermal energy utilization.

The CHP Technical Potential by application SIC code is grouped into five market sectors as described below:

1. High load factor markets are applications that have electric and thermal load around the clock such as industrial facilities.
2. Low load factor markets are applications that have more daily load variation and are generally not considered to be 24-hour facilities like car washes, health clubs, and laundries.

3. High load factor heating and cooling markets are 24/7 facilities that require a constant amount of baseload electricity and can utilize available thermal energy in a combination of heating and cooling applications such as nursing homes, colleges, and hospitals.

4. Low load factor heating and cooling markets are facilities with shorter operating hours that need to operate a CHP system intermittently using available thermal energy for both heating and cooling. Representative applications in this category include schools, post offices, and office buildings.

5. Export markets are high load factor applications that can size CHP to on-site thermal loads and have enough power to cover on-site use with additional power to sell back to the utility. This market consists of process industries that typically have high thermal loads in comparison to their electric loads. The market is considered separately in the model because power sold back to the utility is at a different price than the avoided cost of power used on-site. This market is just the incremental portion of CHP at facilities that contain both on-site and export power.

Within each of these five market segments, CHP economic competition is considered in five size bins as shown in **Table 17**. Each size bin has its own assumptions about load factor and degree of thermal energy used. In addition, each size bin has the CHP technology characterized that is appropriate for that size range.

Table 17 Electric load, thermal utilization, and Technology Assumptions by Size Bin

CHP Market Size	Equivalent Full Load Hours of Use	Thermal Utilization	Competing CHP Technologies
50-500 kW	HiLF = 7,008 LoLF = 4,500	H only Markets 80% H / 0% C H/C Markets 40% H / 40% C	100 kW ICE 65 kW MT 200 kW PAFC
500-1,000 kW	HiLF = 7,008 LoLF = 4,500	H only Markets 80% H / 0% C H/C Markets 40% H / 40% C	800 kW ICE 250 kW MT x 3 300 kW MCFC x 2
1-5 MW	HiLF = 7,008 LoLF = 4,500	H only Markets 80% H / 0% C H/C Markets 40% H / 40% C	3000 kW ICE 3000 kW GT 1500 kW MCFC
5-20 MW	HiLF = 7,446 LoLF = 4,500	H only Markets 90% H / 0% C H/C Markets 45% H / 45% C	5 MW ICE 10 MW GT
>20 MW	HiLF = 8059 LoLF = 4,500	H only Markets 100% H / 0% C H/C Markets 50% H / 50% C	40 MW GT

Abbreviations

Load Factor:	HiLF = High load factor, LoLF = Low load factor
Thermal	H = heating (boiler replacement)
	C = cooling (electric AC replacement)
Technology	ICE = Internal combustion engine
	MT = Microturbine
	PAFC = phosphroic acid fuel cell
	MCFC = molten carbonate fuel cell
	GT = gas turbine

The cumulative market penetration is forecast in 5-year increments. For this analysis, the forecast periods are 2010, 2015, 2020, and 2025.

5.1 Major Market Model Input Assumptions

CHP Technology Cost and Performance

The individual technologies that compete for market share within the economic calculation in the model were summarized above in Table 17 and described in detail in *Section 4.*. The CHP costs are adjusted as applicable for the following factors:

- Early market cost adders are included in the early years to reflect additional costs for siting, packaging, and engineering. These factors range from 5-20% and are gradually reduced to nothing by the end of the forecast period. These cost adders are highest in the small "packaged" CHP sizes and lowest in the large systems that are already well established.
- The federal CHP investment tax credit for CHP is included in the first 10 years of the forecast period

Energy Prices

The expected future relationship between purchased natural gas and electricity prices, called the *spark spread* in this context, is one major determinant of the ability of a facility with electric and thermal energy requirements to cost-effectively utilize CHP.

For the electric prices, specific bill calculations for customers with and without CHP were undertaken for three load shapes: baseload (95% load factor), low load factor (51% load factor), and air conditioning (23% load factor.). The difference between the electric bills divided by the reduction in electric energy purchased determined the average avoided power cost for the CHP economic calculation within the ICF CHP Market Model. These calculations were done for large general service rates that apply to customers with loads larger than 300 kW for both secondary (LGS-S) and primary (LGS-P) voltage service. These two rates were used to characterize the CHP market with potential CHP customers below 1 MW assumed to be on the secondary rate and customers above 1 MW assumed to be on the primary rate. **Table 18** shows the charges for the two voltage levels, and **Table 19** shows the average rates and the average avoided costs by load category.

The long term real change in electric costs to customers was based on these current rates escalated at the same rate as the U.S. Energy Information Administration, *2010 Annual Energy Outlook*, *Reference Case* forecast for the Mid-Atlantic Area Council region of their Electric Market Model. These prices were aggregated into 5-year averages corresponding to the four 5-year forecast periods in the CHP Market Model. These estimates are shown in **Table 20**.

City gate natural gas prices are based on the electric generation price from EIA AEO 2010 Reference Case forecast for MAAC with industrial markups derived from the DPL gas delivery tariffs. Gas delivery costs are about $0.30/MMBtu for baseload operation and about $0.50/MMBtu for low load factor operation. The regional natural gas forecast before the final delivery markups is shown in **Figure 3.** There is no special rate for natural gas commodity or delivery for CHP customers. Therefore, the CHP system fuel and the avoided boiler fuel were evaluated at the same price.

Table 18 Proposed Standard Offer Service Rates Effective June 1, 2010

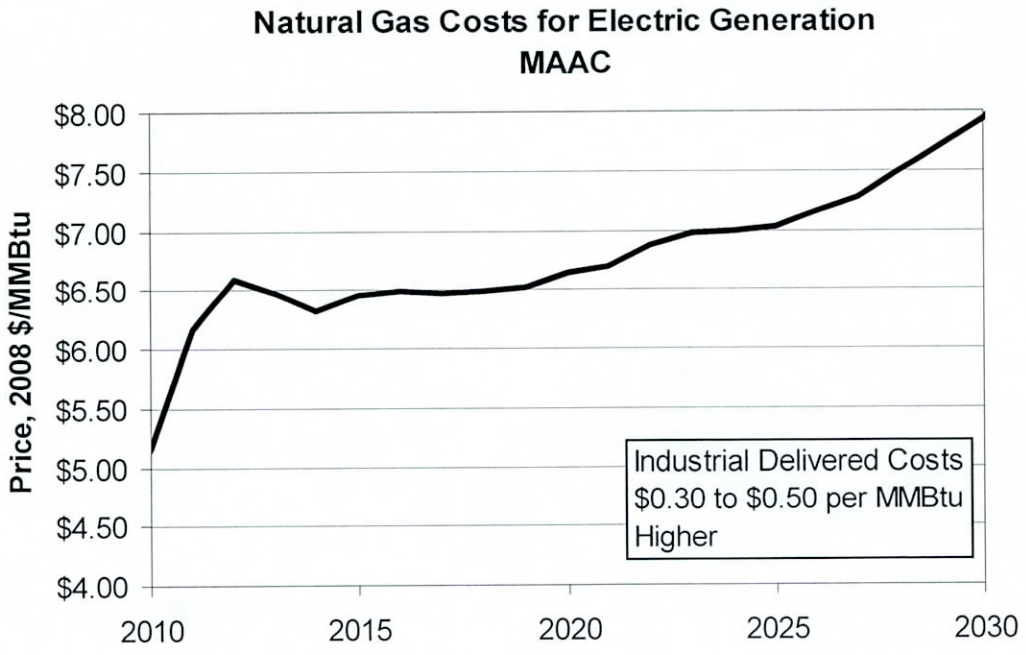
Rate Category	Large General Service	
Voltage Level	Secondary	Primary
Customer Charge, $/month	$162.38	$239.49
Delivery Service Charges		
Distribution Demand, $/kW	$2.448584	$2.670143
On Peak $/kWh	$0.002157	
Off Peak, $/kWh	$0.002157	
Environmental and Low Income Funds, $/kWh	$0.000451	$0.000451
Supply Service Charges		
Transmission Demand, $/kW	$1.272484	$1.272484
SOS Demand, $/kW	$10.829130	$9.865965
SOS On Peak Energy, $/kWh	$0.075778	$0.054027
SOS Off Peak Energy, $/kWh	$0.055111	$0.040386
Public Utility Tax, %	5%	5%

Table 19 Average DPL Electric Rates for Large General Service Customers and Average Costs Avoided by CHP

CHP Customer Load Category	Large General Service -- Secondary		Large General Service -- Primary	
	Average Rate	Average Cost Avoided	Average Rate	Average Cost Avoided
	$/kWh			
High Load Factor (95% LF)	$0.0894	$0.0826	$0.0691	$0.0627
Low Load Factor (51% LF)	$0.1195	$0.1063	$0.0957	$0.0831
Avoided Air Conditioning (22% LF)	$0.1378	$0.1378	$0.1148	$0.1148

Table 20 Long Term Electric Price Assumptions by Size and Load Shape

CHP Customer Load Category	Average Avoided Electricity Costs			
	2010-2014	2015-2019	2020-2024	2025-2029
CHP Customers up to 1 MW (LGS-S)				
High Load Factor (95% LF)	$0.0826	$0.0826	$0.0845	$0.0885
Low Load Factor (51% LF)	$0.1063	$0.1063	$0.1087	$0.1139
Avoided Air Conditioning (22% LF)	$0.1378	$0.1378	$0.1409	$0.1476
CHP Customers over 1 MW (LGS-P)				
High Load Factor (95% LF)	$0.0627	$0.0627	$0.0640	$0.0671
Low Load Factor (51% LF)	$0.0831	$0.0831	$0.0850	$0.0890
Avoided Air Conditioning (22% LF)	$0.1148	$0.1148	$0.1173	$0.1230



Source: EIA AEO 2010,

Figure 3 Regional Natural Gas Price Forecast,

5.2 Economic Competitiveness of CHP and Market Acceptance

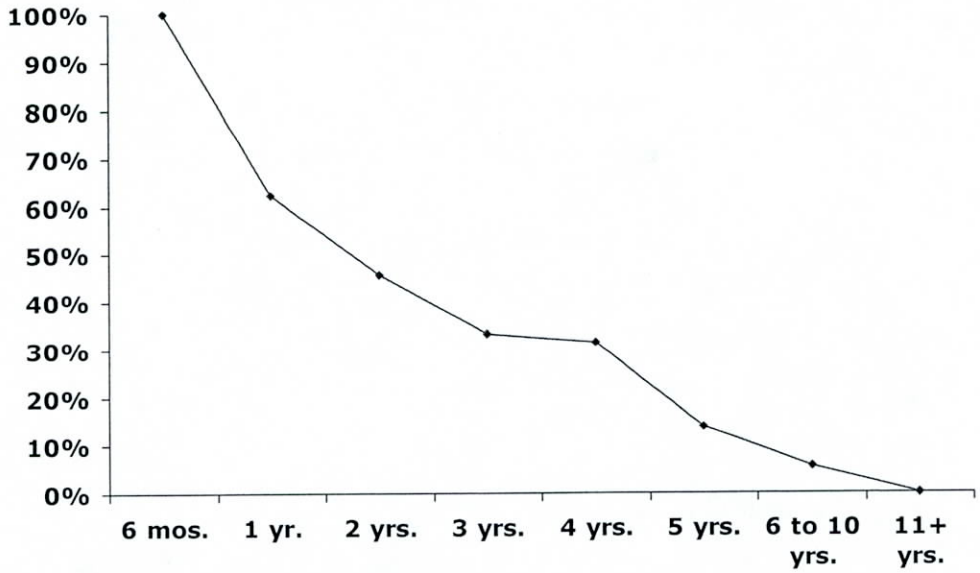
The economic competitiveness calculation within the ICF CHP Market Model is a simple pay-back calculation. The annual cost of operating the CHP system is compared to the avoided thermal and electric energy cost savings, allowing the number of years it would take for this annual savings to repay the initial capital investment to be calculated. This is a very common form of screening to identify potentially economic investments of any type, and it is used by facility operators and CHP developers in the early stages of identifying economic CHP projects.

The annual savings calculation consists of the following components:

- CHP operating cost (on a per kW basis) is a function of the system heat rate, the CHP natural gas rate, and the assumed equivalent full load hours of operation per year.
- Avoided electric cost is a function of the CHP hours of operation and the avoided CHP electric costs.
- Avoided thermal energy is a function of the share of avoided boiler use and avoided air conditioning use. In cooling applications the share is assumed to be 50/50. In non cooling applications all thermal energy is assumed to be from avoided boiler fuel.
    - Avoided boiler use depends on the thermal energy per kWh produced by the CHP system, the assumed percentage of thermal energy utilized, the boiler fuel price, and the boiler efficiency
    - Avoided air conditioning use depends on the CHP thermal energy produced, the assumed efficiency of the absorption chiller, the assumed efficiency of the electric chiller (0.68 kW/ton used) and the avoided air conditioning electric rate.

The payback period is calculated for each competing technology in the size bin. The CHP technology with the lowest payback period is assumed to define the market acceptance rate which is calculated based on a survey of business facilities that could potentially implement CHP.[9] **Figure 4** shows the percentage of the market that would accept a given payback period and move forward with a CHP investment. As can be seen from the figure, more than 30% of customers would reject a project that promised to return their initial investment in just one year. A little more than half would reject a project with a payback of 2 years. This type of payback translates into a project with an ROI of between 49-100%.

[9] Primen. Distributed Energy Market Survey. 2003.



Source: *Primen's 2003 Distributed Energy Market Survey*

Figure 4 CHP Market Acceptance as a Function of Payback Period

Potential explanations for rejecting a project with such high returns is that the average customer does not believe that the results are real and is protecting himself from this perceived risk by requiring very high projected returns before a project would be accepted, or that the facility is very capital limited and is rationing its capital raising capability for higher priority projects (market expansion, product improvement, etc.). There are many arguments that could be made that these acceptance rates should be much higher, but they are used in the model to reflect actual expected customer behavior in the absence of any change in perceptions regarding the risk of investing in CHP.

The rate of market penetration is based on *Bass diffusion curves* with allowance for growth in the maximum market. This function determines cumulative market penetration for each 5-year period. Smaller size systems are assumed to take a longer time to reach maximum market penetration than larger systems. Cumulative market penetration using a Bass diffusion curve takes a typical S-shaped curve. In the generalized form used in this analysis, growth in the number of ultimate adopters is allowed. The curves shape is determined by an initial market penetration estimate, growth rate of the technical market potential, and two factors described as *internal market influence* and *external market influence*.

The cumulative market penetration factors reflect the economic potential multiplied by the non-economic screening factor (maximum market potential) and by the Bass model market cumulative market penetration estimate.

6. CHP Market Penetration Results

CHP market penetration was analyzed for two sets of input assumptions:

- Base Case – existing federal incentives for CHP with no assumed state or utility provided incentives
- Incentive Case – a 20% reduction in the capital cost was assumed in addition to existing federal tax credits

Both cases are based on the same assumptions for CHP technology cost (before incentives) and performance and on the electric and gas prices described in the previous section.

6.1 Base Case

The Base Case results are shown in **Table 21** and **Table 22.** The output measures shown are as follows:

- Economic Potential – the capacity (MW) of CHP for which the CHP payback meets the economic acceptance criteria. This and other capacity measures are cumulative.
- Cumulative Market Penetration – This represents the additional installed CHP capacity. The cumulative market penetration is a subset of the economic potential representing the economic capacity that has penetrated the market up to that point. Not all economic capacity enters the market at once. However, by the end of the forecast period, the cumulative market penetration approaches the economic potential.
- Avoided cooling represents the electric air conditioning capacity that is avoided due to CHP systems with thermally activated cooling (absorption chillers.)
- Potential Number of Systems – This represents the range of CHP systems that would be installed to meet the capacity shown in the cumulative market penetration rows.
- Annual Electric Energy (MWh) – represents the annual output of the cumulative installed capacity.
- Incremental Onsite Fuel -- represents the net increase in annual natural gas consumption or the fuel required for the CHP prime movers minus the boiler fuel avoided by using the CHP thermal energy.
- Cumulative Investment – represents the net capital cost of the equipment after incentives. In the base case there are no utility or state incentives. However, the federal tax credits are already taken out.
- Cumulative Incentive Payments – represents the state or utility payments to the CHP customers. Again, in the base case there are no such incentives; in the incentive case this represents 20% of the CHP capital costs before incentives.
- The dollar value of the electricity avoided and the incremental fuel added is shown.

There are also a number of calculated unit measures including:

- The average capital cost equal to the net capital investment divided by the CHP cumulative electric generation capacity, and the average incentive value on the same basis. The sum of the capital cost and the incentive equal the total average unit capital cost for CHP.

- The incentive was modeled as a capital cost reduction. This capital cost incentive is converted to an equivalent annual operating cost to show what that would be if the incentive were provided in that form. This does not represent an additional incentive, only an alternative valuation the equivalency of a capital cost incentive compared to an operating cost incentive.
- The average electric and gas costs calculated.
- The average net heat rate shows the efficiency of the CHP systems after the avoided boiler fuel is subtracted from the fuel required to operate the CHP system.

Table 21 Market Penetration Results for Base Case

CHP Measurement	2010	2015	2020	2025
Economic Potential, MW	36.5	39.5	57.7	85.8
Cumulative Market Penetration (MW)				
Industrial	1.1	8.0	18.8	24.8
Commercial/Institutional	1.0	7.6	20.0	30.7
Total	2.1	15.6	38.9	55.4
Avoided Cooling	0.1	1.0	2.4	3.6
Scenario Grand Total	2.3	16.6	41.2	59.1
Potential Number of Systems	1 - 3	2 - 5	4 - 10	6 - 14
Annual Electric Energy (MWh)				
Industrial	8,246	58,150	135,609	178,037
Commercial/Institutional	7,195	53,828	141,513	216,786
Total	15,442	111,978	277,122	394,823
Avoided Cooling	527	3,457	7,415	10,545
Scenario Grand Total	15,969	115,436	284,537	405,368
Incremental Onsite Fuel (billion Btu/year)				
Industrial	47.9	333.1	762.6	1000.6
Commercial/Institutional	55.2	399.2	1005.2	1525.7
Total	103.1	732.3	1767.8	2526.3
Cumulative Investment (million 2010 $)	3.2	23.2	57.1	82.1
Cumulative Incentive Payments (Million 2010 $)	0.0	0.0	0.0	0.0
Annual Electric Energy (Million 2010 $)				
Industrial	0.6	4.5	10.9	15.0
Commercial/Institutional	0.7	5.2	14.1	22.3
Total	1.3	9.8	25.0	37.2
Avoided Cooling	0.1	0.4	0.6	0.3
Scenario Grand Total	1.4	10.2	25.6	37.5
Incremental Onsite Fuel (million 2010 $)				
Industrial	0.3	2.2	5.2	7.1
Commercial/Institutional	0.3	2.6	6.8	10.9
Total	0.7	4.7	12.0	18.1

Table 22 Cost and Performance Characteristics of Projected Base Case CHP

Calculated Averages	2010	2015	2020	2025
Average CHP Capital Cost $/kW	$1,501.05	$1,485.52	$1,469.71	$1,480.48
Average Cost including Avoided Cooling ($/kW)	$1,404.87	$1,395.76	$1,385.36	$1,389.31
Average Electric Cost Saved ($/kW)	$0.0873	$0.0885	$0.0901	$0.0925
Average Incremental Gas Cost ($/MMBtu)	$6.32	$6.48	$6.77	$7.15
Average Incremental Heat Rate (Btu/kWh HHV)	6,455	6,343	6,213	6,232

6.2 CHP Incentive Case – 20% Capital Cost Reduction

An incentive scenario representing a 20% capital cost reduction for CHP was evaluated to measure the increase in market penetration. This is a potential incentive program that Delmarva could put in place to increase the adoption of CHP in its service territory. The gas and electric pricing and all other assumptions are the same as the *Base Case* assumptions.

Table 23 Market Penetration Results for 20% Capital Cost Reduction Incentive

CHP Measurement	2010	2015	2020	2025
Economic Potential, MW	58.7	62.9	85.7	114.5
Cumulative Market Penetration (MW)				
Industrial	2.0	13.5	29.8	37.9
Commercial/Institutional	1.5	11.6	30.3	44.3
Total	3.5	25.0	60.1	82.2
Avoided Cooling	0.2	1.4	3.5	5.2
Scenario Grand Total	3.7	26.5	63.6	87.4
Potential Number of Systems	1 - 3	3 - 7	6 - 12	9 - 16
Annual Electric Energy (MWh)				
Industrial	14,355	97,643	214,566	272,983
Commercial/Institutional	10,922	82,447	215,048	313,921
Total	25,278	180,089	429,614	586,904
Avoided Cooling	736	4,958	10,962	15,163
Scenario Grand Total	26,014	185,047	440,576	602,068
Incremental Onsite Fuel (billion Btu/year)				
Industrial	82.7	556.6	1204.8	1534.0
Commercial/Institutional	81.9	601.0	1515.3	2203.2
Total	164.6	1157.6	2720.1	3737.2
Cumulative Investment (million 2010 $)	4.1	29.0	69.6	96.5
Cumulative Incentive Payments (Million 2010 $)	1.1	8.1	19.2	25.9
Annual Electric Energy (Million 2010 $)				
Industrial	1.1	7.4	16.9	22.5
Commercial/Institutional	1.0	7.9	21.0	31.6
Total	2.1	15.3	37.9	54.2
Avoided Cooling	0.1	0.6	0.9	0.4
Scenario Grand Total	2.2	15.9	38.8	54.6
Incremental Onsite Fuel (million 2010 $)				
Industrial	0.5	3.6	8.1	11.0
Commercial/Institutional	0.5	3.9	10.3	15.8

Total	1.0	7.5	18.4	26.7

Table 24 Cost and Performance Characteristics of Projected Incentive Case CHP

Calculated Averages (2010 $)	2010	2015	2020	2025
Average CHP Capital Cost $/kW	$1,160.12	$1,157.03	$1,157.82	$1,173.39
Average Cost including Avoided Cooling ($/kW)	$1,096.02	$1,094.03	$1,094.15	$1,103.25
Average Incentive Rate $/kW	$326.76	$324.42	$319.94	$315.63
Equivalent Operating Incentive, $/kWh	$0.0058	$0.0058	$0.0057	$0.0057
Average Electric Cost Saved ($/kW)	$0.0845	$0.0860	$0.0881	$0.0907
Average Incremental Gas Cost ($/MMBtu)	$6.32	$6.48	$6.77	$7.15
Average Incremental Heat Rate (Btu/kWh HHV)	6,329	6,256	6,174	6,207

6.3 Key Results

In the Base Case the projected CHP market penetration in the next five years is 16.6 MW out of an economic potential of 39.5 MW. Addition of the 20% capital cost reduction incentive increases the five year market penetration to 26.5 MW out of an economic potential of 62.9 MW.

By 2025, the cumulative market penetration in the Base Case is 59.1 MW. The 20% capital cost reduction increases this market by 28.4 MW to a total of 87.4 MW – a 48% increase in the market size.

The cumulative costs of the incentives for the incentive case are $8.1 million by 2015 and $26.0 million of the program continued to 2025. The equivalent value of these incentives if they were applied as an operating credit – paid annually for CHP electric output and avoided electric cooling – is about 5.8 mills/kWh. Market penetration with an operating credit would be similar but not exactly the same as with the capital cost reduction credit. The operating credit would provide greater stimulus to the high load factor applications and less to the low load factor and air conditioning loads.

Appendix A – CHP Potential in Agricultural Operations

This report describes the market size and potential market penetration of natural gas fueled CHP in Delmarva Power's service territory. Natural gas-based CHP systems are primarily topping cycles in which the input fuel, natural gas, is used in a prime mover such as a gas turbine, reciprocating engine, microturbine, or fuel cell, for electricity production and a portion of the heat normally wasted is recovered to supply thermal needs such as process steam or space cooling at the site. Natural gas is by far the predominant fuel used for CHP throughout the country, representing 71% of the 84 GW of installed CHP capacity in the US. Natural gas is the fuel of choice for most CHP applications because of its competitive price, ease of use, reliability of supply, relatively low criteria pollutant emissions, and, increasingly, its low carbon content in comparison to coal and oil. If properly designed and operated, natural gas CHP can provide significant benefits to Delmarva in terms of demand reduction and reduced CO_2 emissions.

In addition to natural gas-fired CHP, Delmarva has the potential for CHP development in the agriculture industry, specifically in poultry farms which are very common in the state of Delaware. Delmarva's service territory encompasses many poultry farms, especially in Sussex County, the top producing county of chickens in the US. It produces almost twice the amount of chickens as the second largest poultry producing county in the US, and is home to the headquarters of three of the top 20 broiler producing companies in the country[10].

Animal production operations use anaerobic digestion to reduce the solids content of manure and to improve its quality. Digesters are increasingly used to reduce the volume of manure waste, reduce odor, lower disposal traffic and costs, reduce spreading disposal costs, enhance pathogen control and destruction, and protect the groundwater. Along with biogas, the byproducts of the digester system also include a high-quality compost that can be used for crop fertilizer. Digesters are most suitable for operations that handle large amounts of manure as a liquid, slurry, or semi-solid with little or no bedding added. The type of digester is typically matched to the type, design, and manure characteristics of the operation. There are three types of digester systems: covered lagoon (used to treat liquid manure), complete mix digester (heated engineered tanks for scraped and flushed manure), and plug flow (treated scraped dairy manure in the 11 to 13% solids range). Biogas from a manure digester typically contains 60 to 70% methane, depending on the type of animal and the manure collection system. The balance of the biogas is composed of carbon dioxide and trace amounts of hydrogen sulfide.

The energy content of bio-gas produced from swine, beef, and poultry operations is presented in the table below.

[10] Sussex County Online. Sussex County's Poultry Industry. http://www.sussexcountyonline.com/business/poultry.html

Table 25 Energy Content of Bio-gas from Agricultural Operations[11]

	Swine (per head)	Beef (per head)	Poultry (per bird)
Design Criteria			
Animal Weight (lbs)	135	800	4
Total fresh manure & urine (gal/day)	1.35	6.1	0.032
Total waste volume after dilution (gal/day)	2	12	0.1
Volatile solids production (VS lbs/day)	1	5	0.038
Digester volume (ft3/head)	5	19	0.3
Retention time (days)	20	13	22.5
Probable VS destruction (%)	50	45	60
Anticipated Gas Yield			
Yield (ft3/head/day)	4	28	0.29
Gross energy content (Btu/head/day)	2,300	16,600	180
Net energy content (Btu/head/day) (uses 35% of gross to operate digester)	1,500	10,700	110

The following table shows the amount of farms and livestock animals that are present in the state of Delaware. It was not possible to narrow down these figures for solely the Delmarva service territory, however the overall figures may provide a framework within which to estimate Delmarva's share of the agricultural CHP potential.

Table 26 Delaware Livestock Inventory and CHP Potential

Livestock Type	# Farms	Delaware Livestock Inventory	Biogas Production (MMBtu)	CHP Potential (kW)
Broilers and other meat-type chickens	778	51,092,495	2,051,364	25,759.3
Cattle and calves	399	20,994	81,992	1,029.6
Hogs and pigs	84	8,955	4,903	61.6

The table above shows that the primary opportunity for manure biogas CHP in Delaware is in the poultry industry, with a potential of over 25 MW if the manure from all of the chickens in the state were anaerobically digested. Within the poultry industry, the target farms with potential for the use of biogas CHP are those with a flock size over 100,000. This corresponds to a CHP system of about 50 kW. However, it should be noted that the use of manure biogas CHP is limited to farms that have the animals and manure management to accommodate anaerobic digestion. Operations that produce electricity from biogas may sell much of the electricity back to the grid. Thermal energy is used to heat the digesters and for process use at the facility. As digester system size increases, the unit costs for construction and operation decrease significantly.

[11] National Sustainable Agriculture Information Service. "Anaerobic Digestion of Animal Wastes: Factors to Consider." 2006. http://attra.ncat.org/attra-pub/PDF/anaerobic.pdf

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