MINNESOTA DEPARTMENT OF COMMERCE

DIVISION OF ENERGY RESOURCES

Assessment of the Technical and Economic Potential for CHP in Minnesota

Conservation Applied Research & Development (CARD)
FINAL REPORT

Prepared for: Minnesota Department of Commerce
Division of Energy Resources

Prepared by: FVB Energy Inc. and ICF International

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Preface

This study was funded by the Conservation and Applied Research & Development (CARD) program of the Minnesota Department of Commerce to assess alternative approaches to potential changes in Minnesota policies and programs to increase implementation of combined heat and power (CHP). This report provides detailed analysis that was incorporated into a related CARD-funded study (FVB Energy Inc., Minnesota Combined Heat and Power Policies and Potential, July 2014).

The report is organized as follows.

- **Existing CHP Capacity** describes the extent and characteristics of existing CHP system in Minnesota.
- **Technical Potential** provides an estimation of market size constrained only by technological limits — the ability of CHP technologies to fit customer energy needs.
- **Economic Potential** assesses the potential for CHP based on the economics of a range of CHP technologies. The economic potential is estimated based on business as usual (or "base case"), i.e., assuming no new policies. Economic potential is then calculated with a range of Policy Options.
- **Conclusions** summarizes the results of the estimates of the technical and economic potential.

Appendix A provides detailed tables and graphs of the results of the economic potential estimated under each Policy Option.

References used in the development of this report are listed at the conclusion of the report. These references are noted in the report in parentheses in the body of the report or after figure or table captions. Footnotes are used only where additional explanation was deemed appropriate.

Executive Summary

This report presents the results of a CHP market assessment undertaken for the Minnesota Department of Commerce, Division of Energy Resources, to identify the technical and economic potential for CHP given the current market and regulatory atmosphere as well as under a series of potential policy scenarios. Key results from this report were incorporated into a related study (FVB Energy Inc., Minnesota Combined Heat and Power Policies and Potential, July 2014) which assesses alternative approaches to, and develops recommendations for, potential changes in Minnesota policies and programs to increase the implementation of CHP.

Existing CHP

There are currently 961.5 MW of operating CHP in Minnesota at 52 sites. About 83 percent of the existing CHP capacity in Minnesota resides in large systems with site capacities greater than 20 MW, and the largest share of active CHP capacity is located in the industrial sector, particularly in chemicals and paper processing.

Technical Potential

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 potable hot water heating. More recently, CHP has included the provision of space cooling through the use of absorption chillers.

Four different types of CHP markets were included in the evaluation of CHP technical potential:

- Traditional power and heat CHP
  - High load factor applications (operating at the equivalent of full load for 7,500 hours annually)
  - Low load factor applications (operating at the equivalent of full load for 5,000 hours annually)
- Combined cooling, heating and power (CCHP)
  - High load factor applications
  - Low load factor applications

In addition, the potential for waste heat to power (WHP) was estimated. With WHP electricity is generated using exhaust heat from industrial processes.

The projections for natural gas CHP were prepared by ICF by first using various commercial and industrial facility databases to identify the number of target application facilities in Minnesota by sector and by size (electric demand) that meet the thermal and electric load requirements for CHP. This analysis used a set of data consisting of facilities in Minnesota that have more than five employees and are in the target applications specified above. The determination of technical CHP 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. Various regional data sources are 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.
- Estimate CHP potential in terms of MW electric capacity. Total CHP potential is derived for each target application based on the number of target facilities in each size category and CHP sizing criteria appropriate for each application sector.
- Subtract existing CHP from the identified sites to determine the remaining technical potential.

FVB developed an alternative methodology to estimate CHP potential using Minnesota Pollution Control Agency data on fuel use in larger energy users. This alternative methodology was used as a check on the ICF model for larger gas-fired CHP, and to estimate the potential for biomass CHP.

There is a further potential opportunity for CHP that cannot be easily analyzed: conversion of existing power plants to recover currently wasted heat for distribution to buildings and industry through district energy systems.

Economic Potential

The economic potential for CHP was quantified using simple payback for CHP systems. Payback is defined as the amount of time (i.e. number of years) before a system can recoup its initial investment. For each site included in the technical potential analysis, an economic payback is calculated based on the appropriate CHP system cost and performance characteristics and energy rates for that system size and application.

Based on the calculated economic potential, a market diffusion model is used to determine the cumulative CHP market penetration over the analysis timeframe. The market penetration represents an estimate of CHP capacity that will actually enter the market between 2014 and 2040. This value discounts the economic potential to reflect non-economic screening factors and the rate that CHP is likely to actually enter the market.

Rather than use a single yearly payback value as the sole determinant of economic potential, the market acceptance rate has also been included. Three market acceptance curves were analyzed: “average” acceptance, “strong prospects”, and “utility” acceptance. These curves indicate the assumed level of payback required to consider installing CHP.

Of the 3,049 MW of existing CHP/WHP technical potential in Minnesota, 984 MW has economic potential with a payback of less than 10 years. The 984 MW of economic potential is located mostly in the high load factor markets in Xcel and Minnesota Power territories, with smaller amounts present in Alliant and municipal/coop territory. Generally, calculated payback is lower for larger customers, stemming from lower CHP system costs as a result of economies of scale, better CHP system performance characteristics, and lower natural gas prices.

The 984 MW of CHP economic potential with a payback of less than 10 years is then pared down to CHP market penetration. Additional CHP of 213 MW and 252 MW are projected to be implemented by 2030 and 2040, respectively, without new policies (Base Case). In addition, a Base Case market penetration of 50 MW is estimated for Waste Heat to Power. This capacity is almost all in Xcel service territory with some in Minnesota Power and Alliant territory.

Policy Options

Projections of CHP economic potential under a range of policy options were analyzed primarily using ICF International's model for natural-gas fired CHP market penetration. In addition, analysis of Minnesota Pollution Control Agency fuel consumption data was used to check and augment the ICF model on gas-fired CHP and to estimate the potential market penetration of biomass CHP.

CIP incentives (either capital or operating incentives) for customer investment in CHP, at levels consistent with recent levels of CIP expenditures per unit of electricity or natural gas saved, are estimated to result in approximately 100 to 240 MW of additional CHP beyond the Base Case. More substantial CIP incentives (combining capital and operating incentives) for customer investment in CHP, are estimated to result in approximately 250 to 500 MW of additional CHP beyond the Base Case.

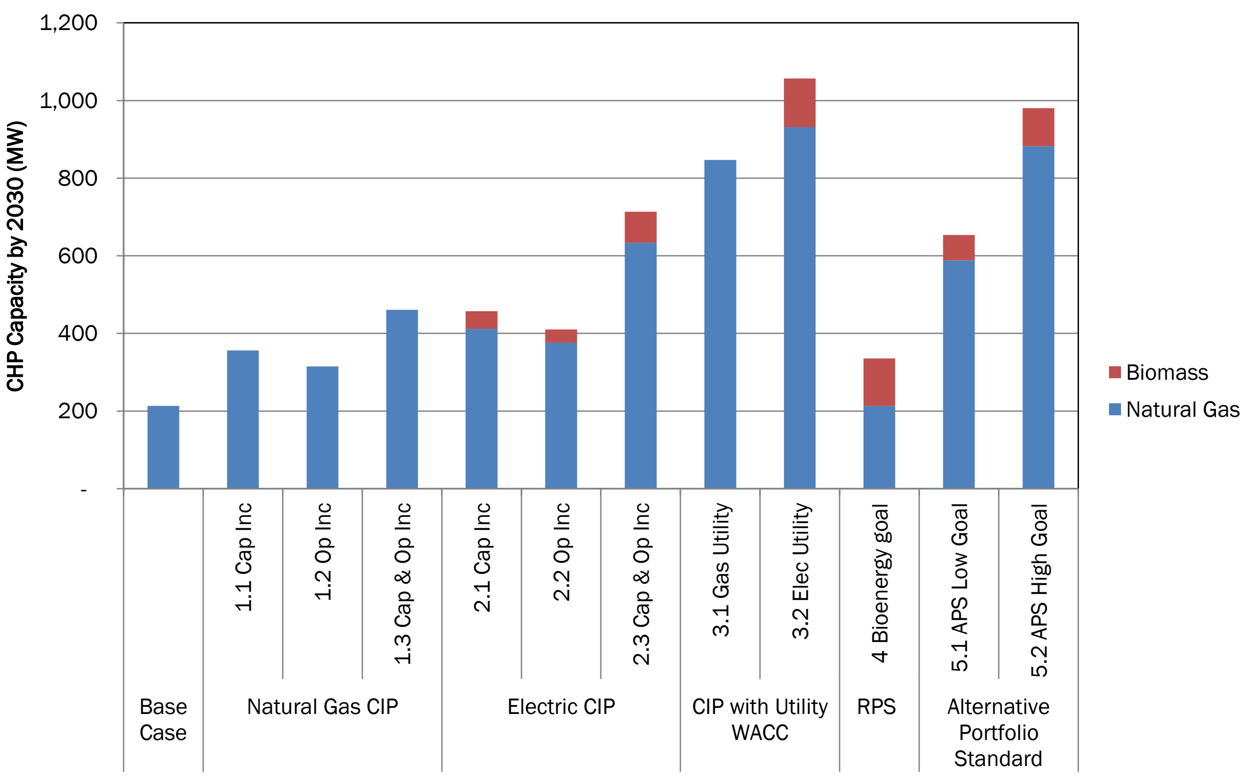
Deploying the relatively low Weighted Average Cost of Capital (WACC) of utilities to build CHP can significantly enhance CHP economics. Utility investment in CHP is estimated to result in approximately 630 to 840 MW of additional CHP beyond the Base Case. At the high end of this range, CHP would more than double by 2030.

The economic viability of bioenergy CHP is dependent on range of site-specific factors, in particular cost-effective access to biofuel, making it difficult to project on a statewide basis. The technical potential for bioenergy CHP among current energy users in Minnesota is about 230 MW. Little or no market penetration of biomass CHP is expected in the Base Case. With the range of policy options evaluated, 35 to 125 MW of new biomass CHP is projected.

An Alternative Portfolio Standard is estimated to result in approximately 440 to 770 MW of additional CHP beyond the Base Case (for Low and High APS targets). At the high end of this range, CHP would more than double by 2030.

Estimated 2030 CHP market penetration under the Base Case (Business as Usual) and with the Policy Options is summarized in Figure 1.

Figure 1. Summary of Estimated 2030 CHP Market Penetration with Policy Options



Introduction

Combined Heat and Power (CHP), also known as cogeneration, produces electricity and useful thermal energy in an integrated system. CHP systems can range in size from hundreds of megawatts - such as those being operated at refineries and in enhanced oil recovery fields down to a few kilowatts that are used in small commercial and even residential applications. Combining electricity and thermal energy generation into a single process can save up to 35 percent of the energy required to perform these tasks separately.

This report presents the results of a CHP market assessment undertaken for the Minnesota Department of Commerce, Division of Energy Resources, to identify the technical and economic potential for CHP given the current market and regulatory atmosphere as well as under a series of potential policy scenarios. Key results from this report were incorporated into a related study ("Minnesota Combined Heat and Power Policies and Potential") which assesses alternative approaches to, and develops recommendations for, potential changes in Minnesota policies and programs to increase the implementation of CHP.

Existing CHP Capacity

The existing CHP in Minnesota was characterized as part of this assessment to evaluate CHP implementation in Minnesota and assess the technical and economic market potential for new CHP deployment. There are currently 961.5 MW of operating CHP in Minnesota at 52 sites.

ICF's CHP Installation Database[1] includes data on CHP systems throughout the country across all size ranges. The database is compiled from a variety of sources including the EIA electricity forms, the Department of Energy (DOE) Technical Assistance Partnerships (TAPs), Environmental Protection Agency's (EPA) CHP Partnership, utility lists, developer lists, incentive program awardees, industry publications, press releases, and other sources.

Minnesota Pollution Control Agency (MPCA) data (discussed below under "Technical Potential") was compared to the ICF CHP Installation Database and to ICF's CHP Technical Potential Database to ensure that all existing CHP and technical potential was identified.

Figure 2 shows a breakdown of the existing CHP capacity in Minnesota by application class. The largest share of active CHP capacity is located in the industrial sector, particularly in chemicals and paper processing. The commercial/institutional market sector represents 30 percent of total CHP capacity in Minnesota with the vast majority of the sector's capacity being located at district energy facilities, hospitals, and colleges and universities.

About 83 percent of the existing CHP capacity in Minnesota resides in large systems with site capacities greater than 20 MW. However, these large systems make up only 23 percent of the number of installations. Figure 3 shows the number of CHP sites in each application class.

Figure 4 and Figure 5 show the breakdown of CHP in the industrial and commercial/institutional sectors.

[1] ICF CHP Installation Database. Maintained by ICF International for Oak Ridge National Laboratory. 2014. http://www.eea-inc.com/chpdata/index.html. Hereafter, this source will be noted in the text, tables and figures as "ICF CHP Installation Database".

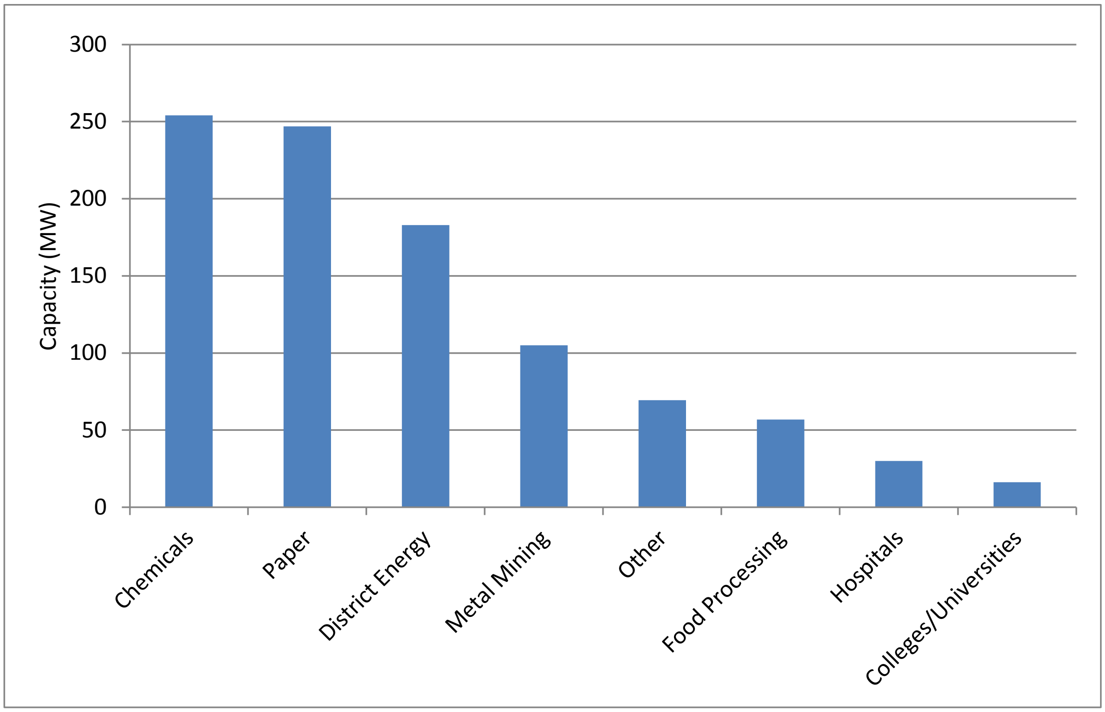


Figure 2. Existing CHP Capacity in Each Application Class (MW Capacity)

Source: ICF CHP Installation Database

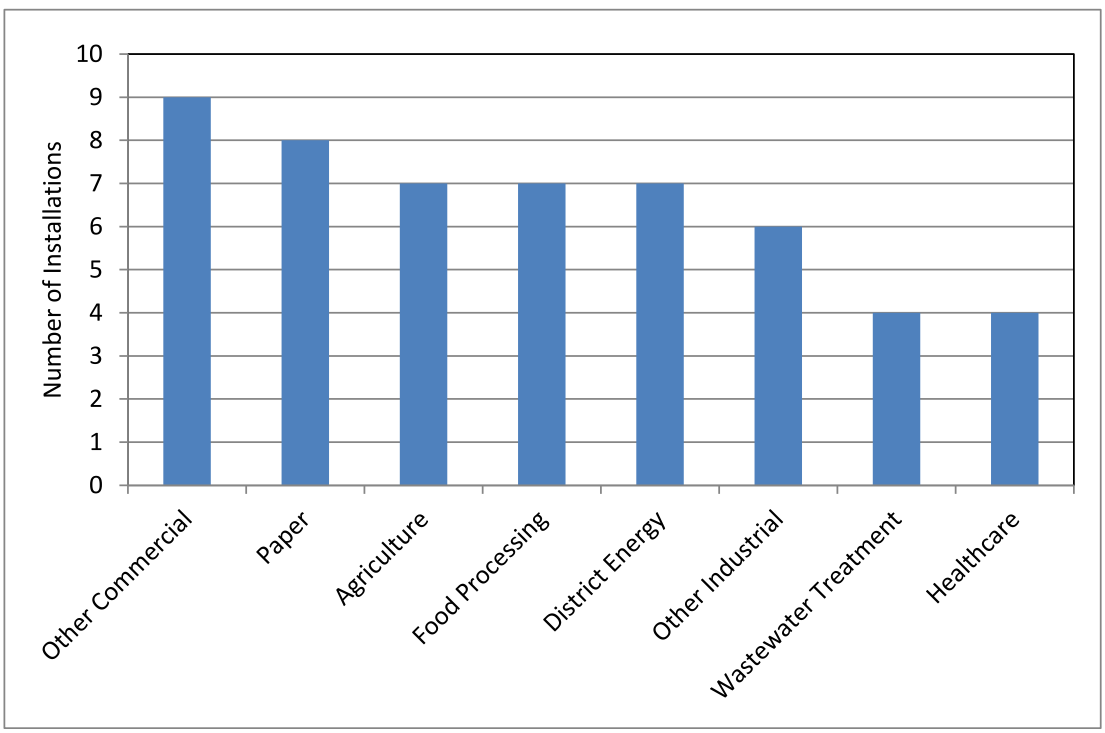


Figure 3. Existing CHP Capacity in Each Application Class (Number of Sites)

Source: ICF CHP Installation Database

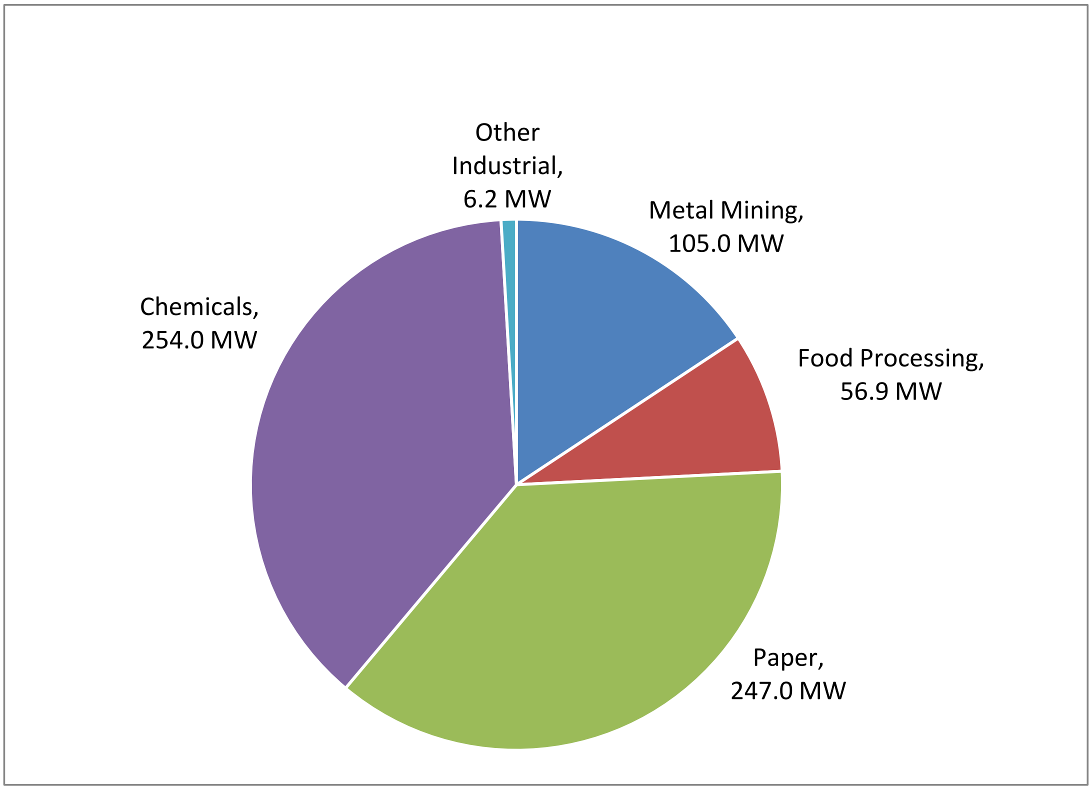


Figure 4. Industrial CHP Capacity in Minnesota (669.1 MW)

Source: ICF CHP Installation Database

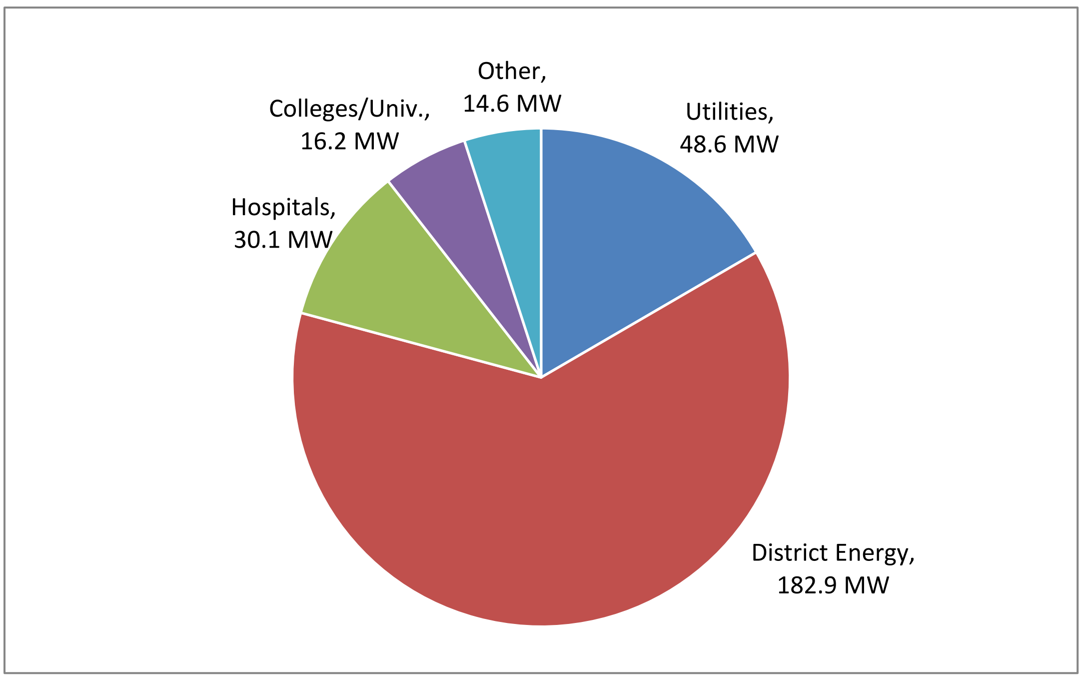


Figure 5. Commercial/Institutional CHP Capacity in Minnesota (292.4 MW)

Source: ICF CHP Installation Database

The geographic location of CHP systems in Minnesota is spread across all major utility territories. Xcel Energy has the largest share of CHP capacity in its service area due to its customer base in Minneapolis and St. Paul. Figure 6 shows the distribution of CHP by utility service area. There are currently 125 municipal electric utilities in the state that serve approximately 357,000 customers (Minnesota Municipal Utilities Association). Within these service areas, 78.3 MW of CHP capacity is currently installed.

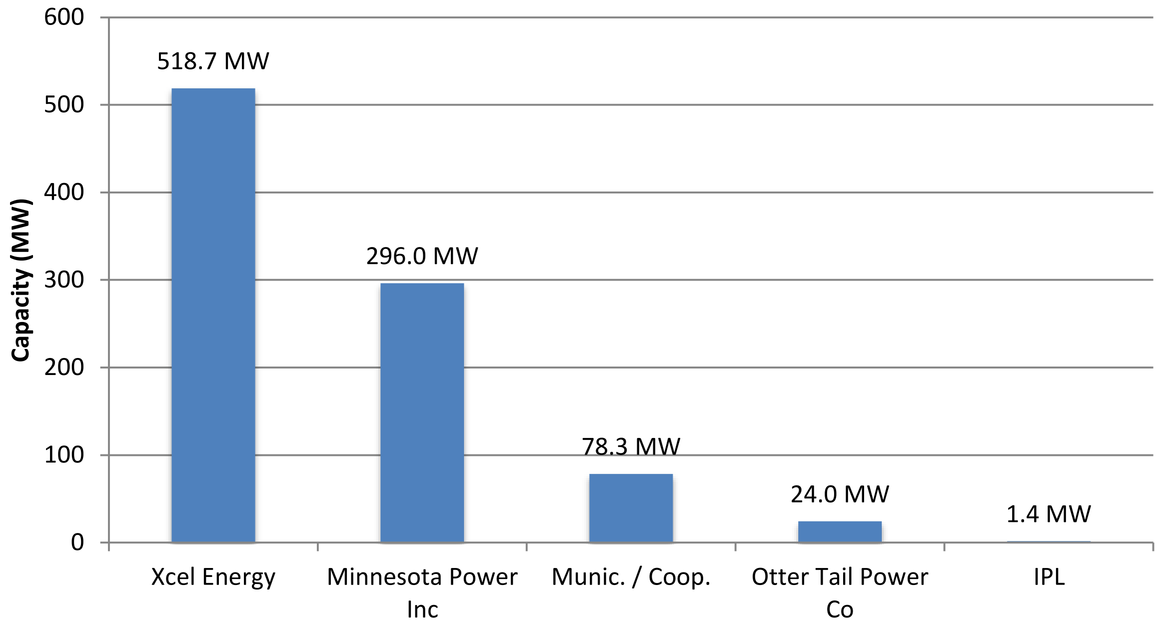


Figure 6. Installed CHP in Minnesota by Utility Service Area

Source: ICF CHP Installation Database

The existing CHP installations can also be characterized in terms of the size of the facility (Figure 7), the primary fuel utilized (Figure 8), and the type of prime mover (Figure 9).

Systems smaller than 5 MW represent only 3 percent of total existing CHP capacity in Minnesota, while systems larger than 100 MW represent nearly 48 percent of the total existing capacity. However, as will be shown later, the market saturation of CHP in large facilities is much higher than for smaller sites. Recent growth trends in installations show that larger numbers of smaller systems have been installed in recent years. From 2005 to the present, CHP systems with capacity of 5 MW and smaller have accounted for 46 percent of capacity growth.

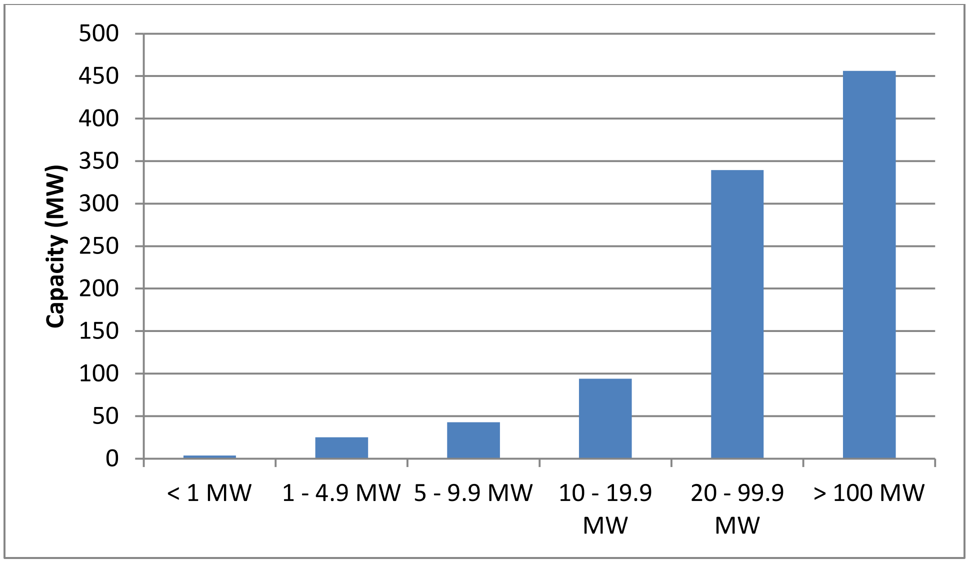


Figure 7. Existing CHP Capacity in Minnesota by Size Range

Source: ICF CHP Installation Database

Figure 8 shows that both coal and natural gas provide an approximately equal share of CHP fuel in Minnesota, accounting for 34% and 38% of CHP fuel respectively. Coal and oil fired systems are becoming increasingly rare with only 11 coal-fired CHP plants, and just 1 oil-fired plant making up less than one-half of 1 percent of capacity. The last new coal or oil-fired CHP system to be installed was in 1990. Wood and biomass fuels make up 20.5 percent of the total capacity with the bulk of this capacity in food and beverage production, and chemicals. Waste fuels (blast furnace gas, coke oven gas, municipal solid waste, and other industrial process wastes) make up the remaining 7.1 percent of systems.

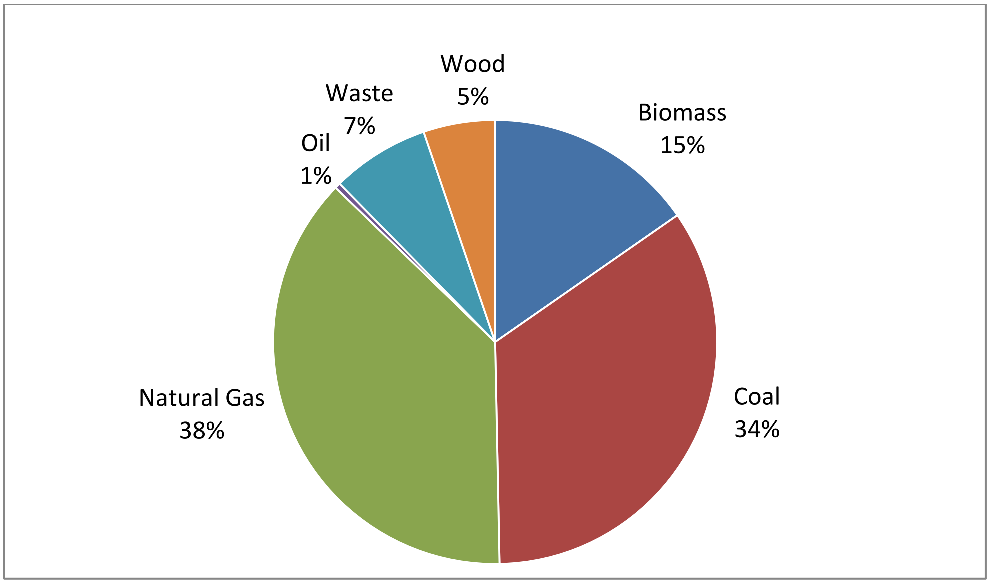


Figure 8. Existing CHP Capacity in Minnesota by Fuel

Source: ICF CHP Installation Database

The prime movers accounting for the most capacity are steam turbines with 674.7 MW, or 70 percent of the total. Steam turbines are also the most common prime mover type with 27 installations. Combined cycle turbines represent the second largest prime mover in terms of total capacity with 264 MW, or 28 percent of the total. Microturbines make up a small fraction of systems with less than 1 percent of capacity. While reciprocating engines represent only 1 percent of installed capacity, they account for 19 percent of the total in terms of the number of installations. Waste heat to power systems make up less than 1 percent of total installed capacity and number of installations.

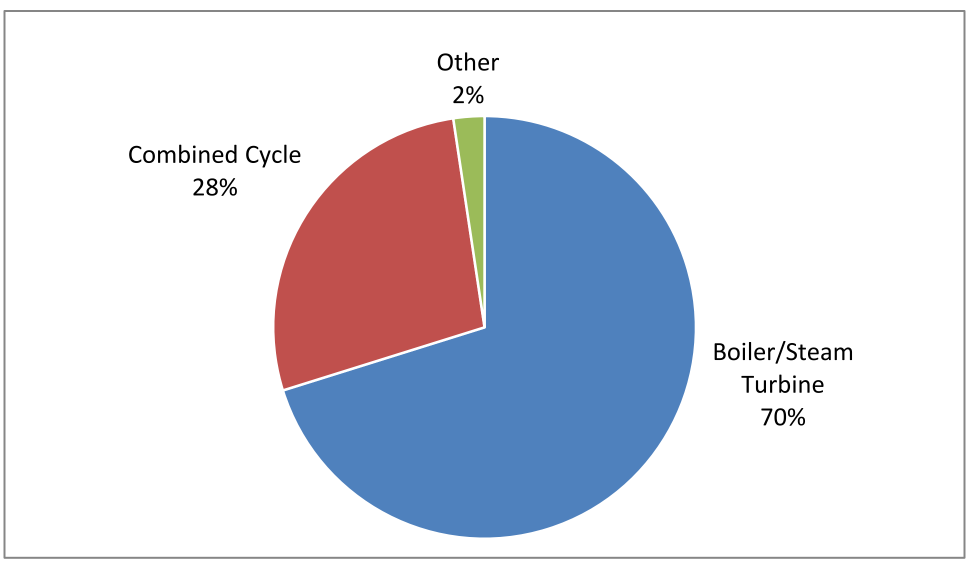


Figure 9. Existing CHP Capacity in Minnesota by Prime Mover

Source: ICF CHP Installation Database

The majority of installed CHP capacity in Minnesota is located within industrial applications, representing 69.5 percent of total capacity or 669.1 MW, while commercial and institutional applications represent 30.4 percent. Figure 10 below shows a timeline of these capacity additions from when the first industrial CHP system came online in 1948 through more recent additions in 2013. Most capacity, representing 59.1 percent, was installed before 1990 while 40.9 percent has been installed since. Over half of newer capacity, and over a quarter of total capacity in Minnesota, is at one facility that was installed in 1997.

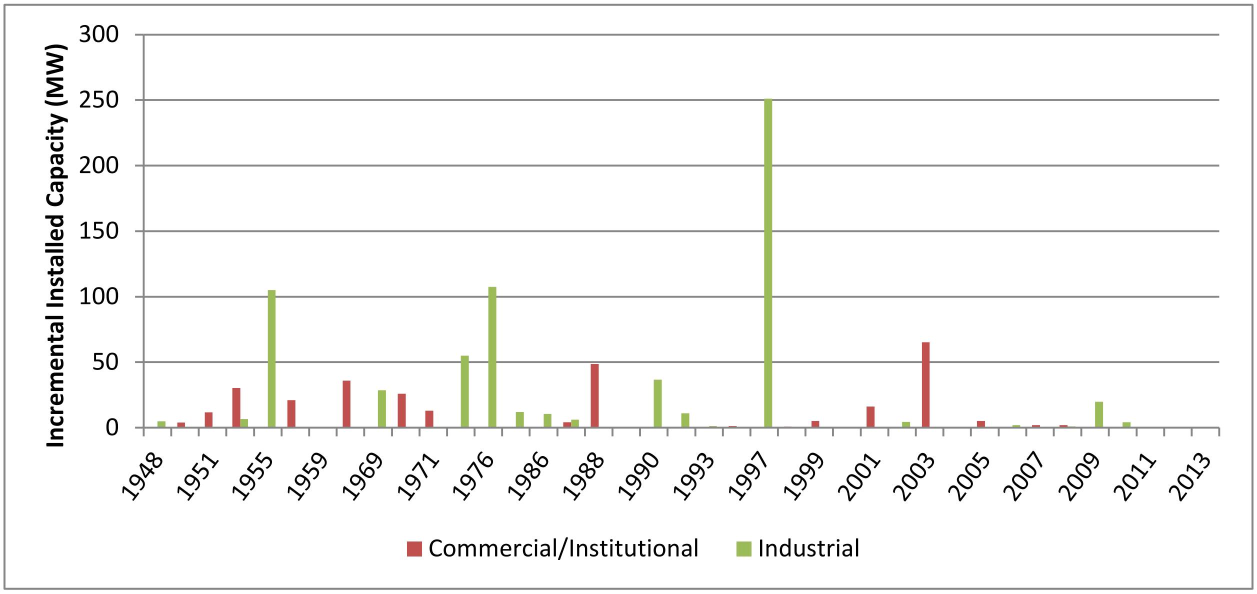


Figure 10. Incremental CHP Capacity by Sector (MW)

Minnesota, like many parts of the country, also experienced the retirement of some existing CHP facilities over the last several years. Overall, there have been over 280 MW of CHP in Minnesota that have ceased to operate because the host facility shut down. The vast majority of this capacity was located at one facility that was operated by Minnesota Power and the LTV Steel Company. The 225 MW coal fueled CHP facility was retired in 2001.

To estimate future CHP development trends, ICF maintains data on CHP systems in the proposed, planning, and construction stages of development. Since CHP systems can take years to install, depending on the system size and host application, tracking systems in development can provide a picture of where the CHP market is heading. Two CHP projects are currently under development in Minnesota: a 50 MW gas turbine facility at the Flint Hills Pine Bend refinery; and a gas turbine project at the University of Minnesota with a planned capacity of about 25 MW.

Technical Potential

This section provides an estimate of the technical market potential for CHP in the industrial, commercial/institutional, and multi-family residential market sectors in Minnesota. The 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 industrial and commercial 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, or variation of energy consumption within customer application/size class.

The technical potential is useful in understanding the potential size and distribution of the target CHP market in the region. 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 potable hot water heating. More recently, CHP has included the provision of space cooling through the use of absorption chillers.

CHP Markets

Traditional CHP

This market represents CHP applications where the electrical output is used 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, which means 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 of the CHP system. It includes all industrial applications and round-the-clock commercial/institutional operations such colleges, hospitals, 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, health clubs, and laundries.

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 CHP system in these applications 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 such as hospitals, nursing homes, and hotels 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 such as big box retail, restaurants, and food sales that otherwise could not support traditional CHP due to a lack of thermal load.

Power Plant Retrofit for CHP

The Minnesota Pollution Control Agency (MPCA) provided detailed data on 2011 fuel consumption at facilities in Minnesota including the site name, identification number, NAICS/SIC code, unit name, fuel type, and fuel consumption in physical units (tons, gallons etc.). This data was converted to million Btu (MMBtu) and was consolidated by site and sorted according to NAICS/SIC code. Data on power plant fuel use is summarized in Table 1

GHG emissions were estimated for each plant based on the quantity and type of fuel used, as shown in Table 2. It is notable that 90 percent of the total 34 million metric tonnes of estimated Minnesota power plant GHG emissions came from only five plants. Waste heat potential was roughly estimated assuming that 65 percent of the fuel use becomes waste heat. The magnitude of building space that could be heated with the waste heat was estimated using a factor of 50,000 MMBtu per year of heat required per one million square feet. Although analysis of technical and economic potential for recovering and distributing this waste heat is beyond the scope of this study, such an investigation could uncover additional CHP opportunity in Minnesota.

		Fuel consumption (MMBtu/year)				
City	**Facility Name**	**Coal**	**Natural Gas**	**Wood**	**Other**	**Total**
Becker	Xcel Energy - Sherburne Generating Plant	164,364,753	-	-	100,074	164,464,827
Cohasset	Minnesota Power Inc - Boswell Energy Ctr	90,261,948	160,825	-	205	90,422,978
Bayport	Xcel Energy - Allen S King Generating	39,595,290	37,984	-	399	39,633,673
Burnsville	Xcel Energy - Black Dog	16,224,684	2,674,245	-	-	18,898,929
Schroeder	Minnesota Power - Tac Harbor Energy Ctr	14,350,350	-	-	20,809	14,371,159
Benson	Fibrominn Biomass Power Plant	-	-	11,517,507	37,548	11,555,055
Fergus Falls	Otter Tail Power Co - Hoot Lake Plant	10,202,703	-	-	6,757	10,209,460
Hoyt Lakes	Minnesota Power - Laskin Energy Center	7,021,875	22,079	-	0	7,043,954
St. Paul	Xcel Energy - High Bridge	-	5,720,974	-	-	5,720,974
Minneapolis	Xcel Energy - Riverside	-	4,508,423	-	-	4,508,423
Virginia	Virginia Department of Public Utilities	1,737,645	232,123	1,841,324	-	3,811,092
Hibbing	Hibbing Public Utilities Commission	1,881,348	-	1,895,889	9	3,777,246
Mankato	Mankato Energy Center LLC	-	2,703,251	-	-	2,703,251
Shakopee	Koda Energy LLC	-	177,120	2,450,461	-	2,627,581
Faribault	Faribault Energy Park	-	2,268,031	-	-	2,268,031
Trimont	Great River Energy - Lakefield Junction	-	1,236,346	-	-	1,236,346
Cannon Falls	Cannon Falls Energy Center	-	1,065,097	-	-	1,065,097
Shakopee	Xcel Energy - Blue Lake	-	1,018,565	-	-	1,018,565
Austin	Great River Energy - Pleasant Valley	-	856,352	-	-	856,352
Willmar	Willmar Municipal Utilities	706,937	69,443	-	0	776,381
Rochester	Rochester Public Utilities - Silver Lake	545,229	185,991	-	(0)	731,220
Cambridge	Great River Energy - Cambridge	-	588,220	-	-	588,220
Inver Grove Hts.	Xcel Energy - Inver Hills Generating Plt	-	439,489	-	-	439,489
Sherburn	Interstate Power & Light - Fox Lake	-	378,225	-	-	378,225
Solway	Otter Tail Power Co - Solway	-	345,839	-	-	345,839
New Ulm	New Ulm Public Utilities	-	319,032	-	-	319,032
Austin	Austin Utilities - NE Power Station	147,549	18,709	-	-	166,258
Burnsville	WM Renewable Energy LLC - Burnsville	-	-	-	144,465	144,465
Hutchinson	Hutchinson Utilities Commission -Plant 2	-	104,499	-	-	104,499
Rochester	Rochester Public Utilities Cascade Creek	-	54,576	-	-	54,576
Red Wing	Xcel Energy - Red Wing Generating Plant	-	27,794	10,927	-	38,721
St. Paul	United & Children's Hospital	-	38,101	-	44	38,145
Mankato	Xcel Energy - Key City/Wilmarth	-	36,750	-	-	36,750
Monticello	Xcel Energy - Monticello Generating Plt	-	-	-	33,755	33,755
Owatonna	Owatonna Public Utilities	-	26,623	-	-	26,623
Chaska	MMPA - Minnesota River Station	-	20,106	-	-	20,106
Golden Valley	United HealthCare Services Inc	-	16,149	-	-	16,149
Fairmont	Fairmont Power Plant	-	14,996	-	-	14,996
Spring Valley	Spring Valley Utilities	-	13,511	-	-	13,511
New Prague	New Prague Utilities Commission	-	11,196	-	-	11,196
	Plants consuming less than 10,000 MMBtu/yr					53,888
	Total	347,040,312	25,390,661	17,716,108	344,065	390,545,033

Table 1. Minnesota Power Plant Fuel Consumption, 2011

Source: FVB Energy analysis of MPCA Fuel Consumption Data 2011

City	Facility Name	GHG emissions (MTCO2e)	GHG emissions (MMTCO2e)	Building floor space potentially heated (MSF)
Becker	Xcel Energy - Sherburne Generating Plant	15,369,942	15.370	2,138
Cohasset	Minnesota Power Inc - Boswell Energy Ctr	8,445,087	8.445	1,175
Bayport	Xcel Energy - Allen S King Generating	3,702,893	3.703	515
Burnsville	Xcel Energy - Black Dog	1,659,640	1.660	246
Schroeder	Minnesota Power - Tac Harbor Energy Ctr	1,342,805	1.343	187
Benson	Fibrominn Biomass Power Plant	2,760	0.003	150
Fergus Falls	Otter Tail Power Co - Hoot Lake Plant	954,107	0.954	133
Hoyt Lakes	Minnesota Power - Laskin Energy Center	657,492	0.657	92
St. Paul	Xcel Energy - High Bridge	306,295	0.306	74
Minneapolis	Xcel Energy - Riverside	241,377	0.241	59
Virginia	Virginia Department of Public Utilities	174,839	0.175	50
Hibbing	Hibbing Public Utilities Commission	175,844	0.176	49
Mankato	Mankato Energy Center LLC	144,729	0.145	35
Shakopee	Koda Energy LLC	9,483	0.009	34
Faribault	Faribault Energy Park	121,428	0.121	29
Trimont	Great River Energy - Lakefield Junction	66,193	0.066	16
Cannon Falls	Cannon Falls Energy Center	57,024	0.057	14
Shakopee	Xcel Energy - Blue Lake	54,533	0.055	13
Austin	Great River Energy - Pleasant Valley	45,848	0.046	11
Willmar	Willmar Municipal Utilities	69,793	0.070	10
Rochester	Rochester Public Utilities - Silver Lake	60,918	0.061	10
Cambridge	Great River Energy - Cambridge	31,493	0.031	7.6
Inver Grove Hts.	Xcel Energy - Inver Hills Generating Plt	23,530	0.024	5.7
Sherburn	Interstate Power & Light - Fox Lake	20,250	0.020	4.9
Solway	Otter Tail Power Co - Solway	18,516	0.019	4.5
New Ulm	New Ulm Public Utilities	17,081	0.017	4.1
Austin	Austin Utilities - NE Power Station	14,793	0.015	2.2
Burnsville	WM Renewable Energy LLC - Burnsville	-	-	1.9
Hutchinson	Hutchinson Utilities Commission -Plant 2	5,595	0.006	1.4
Rochester	Rochester Public Utilities Cascade Creek	2,922	0.003	0.7
Red Wing	Xcel Energy - Red Wing Generating Plant	1,488	0.001	0.5
St. Paul	United & Children's Hospital	2,043	0.002	0.5
Mankato	Xcel Energy - Key City/Wilmarth	1,968	0.002	0.5
Monticello	Xcel Energy - Monticello Generating Plt	2,481	0.002	0.4
Owatonna	Owatonna Public Utilities	1,425	0.001	0.3
Chaska	MMPA - Minnesota River Station	1,076	0.001	0.3
Golden Valley	United HealthCare Services Inc	865	0.001	0.2
Fairmont	Fairmont Power Plant	803	0.001	0.2
Spring Valley	Spring Valley Utilities	723	0.001	0.2
New Prague	New Prague Utilities Commission	599	0.001	0.1
	Plants consuming less than 10,000 MMBtu/yr	2,906	0.003	0.7
	Total	33,813,585	34	5,077

Table 2. Minnesota Power Plant Estimated GHG Emissions and Waste Heat Potential

Source: FVB Energy analysis of MPCA Fuel Consumption Data 2011

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. Various regional data sources are 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.
- Estimate CHP potential in terms of MW electric capacity. Total CHP potential is derived for each target application based on the number of target facilities in each size category and CHP sizing criteria appropriate for each application sector.
- Subtract existing CHP from the identified sites to determine the remaining technical potential.

Target Markets

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.

Table 3 and Table 4 show the CHP market applications classified by these 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 North American Industry Classification System (NAICS) code and Standard Industrial Classification (SIC) code. The data in the tables was sorted by application type/load factor, then lowest to highest SIC code

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	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. Traditional CHP Target Applications
Source: ICF International

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

Table 4. Combined Cooling Heating and Power Target Applications
Source: ICF International

Target CHP Facilities

The projections for natural gas CHP were prepared by ICF by first using various commercial and industrial facility databases[2] to identify the number of target application facilities in Minnesota by sector and by size (electric demand) that meet the thermal and electric load requirements for CHP. This analysis used a set of data consisting of facilities in Minnesota that have more than five employees and are in the target applications specified above. The site data includes information on:

- Company name
- Facility location (street address, county, latitude/longitude)
- Line of business (primary SIC code and primary NAICS code)
- Number of employees (at total company and at individual site)
- Annual sales
- Facility size (in square-feet)

FVB developed an alternative methodology to estimate CHP potential using the aforementioned MPCA fuel use data. Detailed data on fuel use by fuel-using unit (boiler, furnace, etc.) were converted to common energy units (MMBtu) and were then consolidated by facility site. Power plants were eliminated. Of the remaining 1,110 facilities, CHP units were identified and the portion of fuel use attributable to CHP was subtracted. Annual thermal energy requirements and annual electricity requirements were calculated based on NAICS code, using EIA data (EIA Industrial End Use Data). For each site, a CHP unit was sized to supply 80 percent of the estimated annual heating energy load or to supply the estimated electricity requirement, whichever is less. Based on the adjusted thermal and electricity requirements, the most cost-competitive CHP technology type was selected.

As discussed below, this alternative methodology was used as a check on the ICF model for larger[3] gas-fired CHP, and to estimate the potential for biomass CHP.

Technical Potential Results

Estimates for CHP technical market potential were developed using the methodology described above for existing facilities. This section profiles the CHP technical potential estimates by application and size range for the entire state and for each utility region. The total technical market potential (onsite) for CHP equals 3,049 MW in 2014.

Technical Potential—2014

Table 5 shows the breakdown of onsite gas-fired CHP technical potential by utility territory. The two regions with the largest amount of technical potential are Xcel Energy and Minnesota Power. This is primarily due to the large geographic areas covered by these two utilities. Since Xcel Energy also has the largest amount of existing CHP installations, it is not surprising that the utility has the most

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[2] The primary data source to identify potential targets for CHP installations in Minnesota was the Dun & Bradstreet (D&B) Hoovers Database (http://www.hoovers.com/), which was supplemented by the Manufacturer's News database (https://www.manufacturersnews.com/), industry association directories, and government data lists.

[3] The MPCA data does not capture many small, unpermitted fuel users.

remaining CHP potential. Minnesota Power also has a significant amount of remaining potential in the northern region of the state where the utility's service area is located.

Figure 11 and Figure 12 illustrate gas-fired CHP technical potential by megawatt capacity and number of sites in each utility territory based on the ICF model. Total potential greater than 5 MW is 1,407 MW in 72 sites with the ICF model. With the FVB methodology, potential greater than 5 MW is 1,083 MW in 74 sites. Given the methodological differences, this difference in results is not surprising.

For estimating technical potential, the ICF estimates of natural gas CHP provide the high end of the potential. As discussed later under Economic Potential, FVB identified a modest amount of biomass CHP potential (230 MW) based on estimated thermal and electricity requirements. However, for any given site, gas-fired CHP using combustion turbines or engines will provide a higher CHP potential in terms of MW of electricity output because those technologies have a higher Power-to-Heat Ratio than the steam turbine CHP technology used when biomass is the fuel.

Utility	50-500 kW	500-1 MW	1-5 MW	5-20 MW	>20 MW	Total
Northern States (Xcel)	409.0	354.3	431.3	389.0	483.4	2,067.0
MN Power	49.9	32.7	50.8	70.4	266.6	470.3
Alliant	11.9	11.3	45.6	52.0	25.1	145.9
Otter Tail	24.2	33.6	28.9	19.8	0.0	106.5
Muni/Co-op	50.1	49.3	59.8	31.2	69.1	259.4
Total	545.1	481.1	616.3	562.4	844.2	3,049.1

Table 5. Onsite CHP Technical Potential (MW) by Utility Territory in 2014

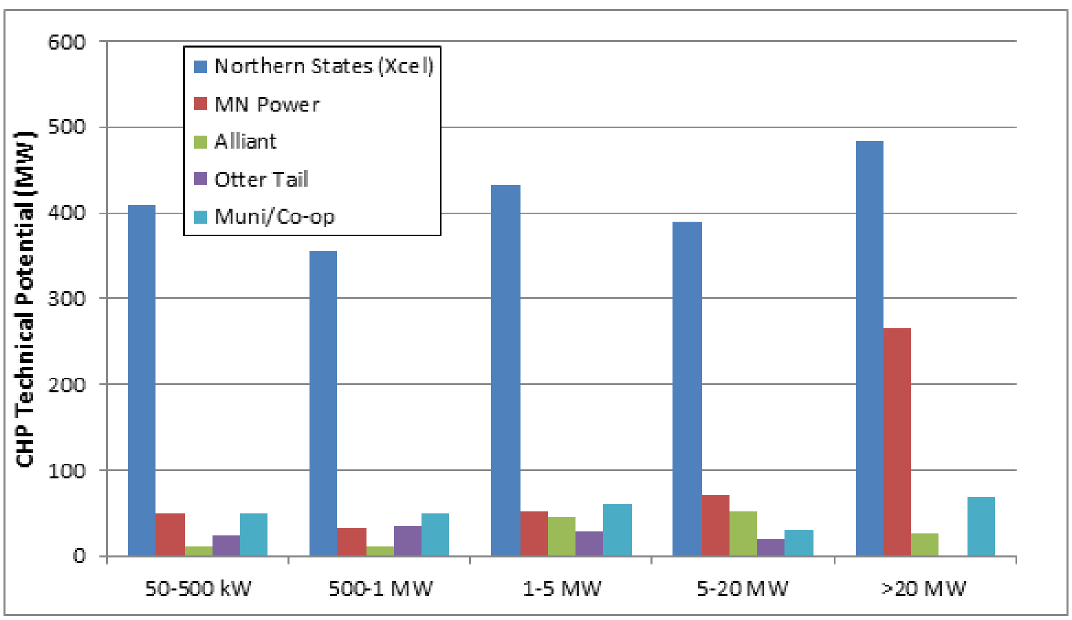

Figure 11. Minnesota CHP Technical Potential (MW) by Electric Utility

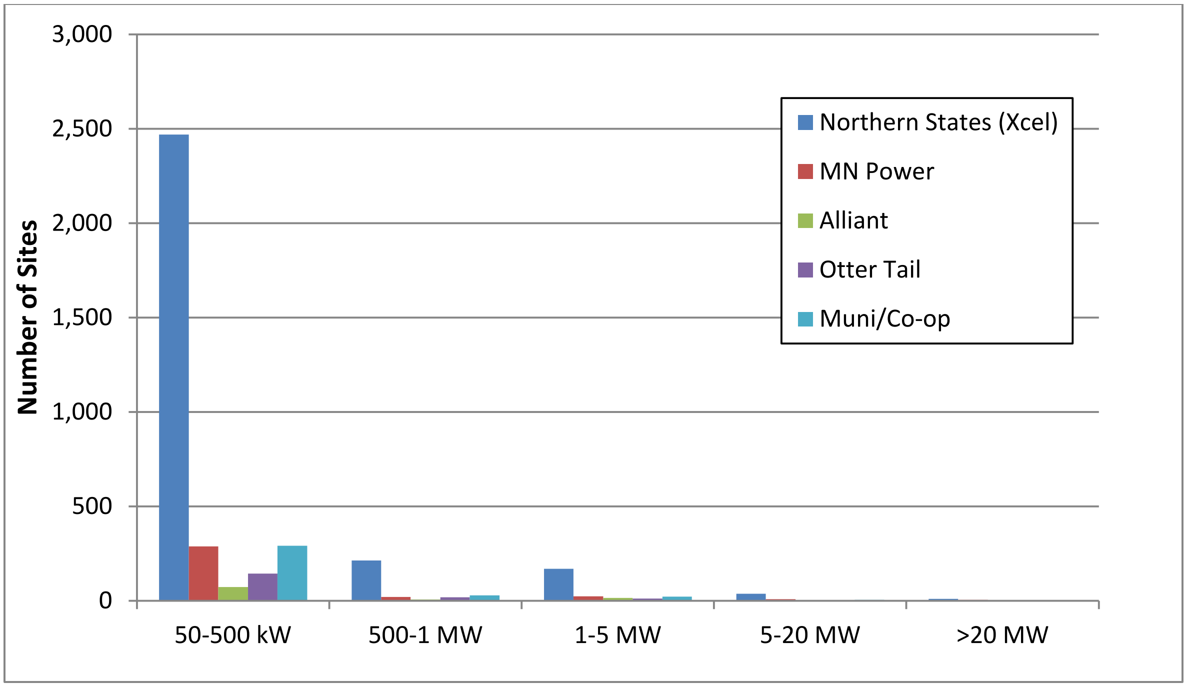

Figure 12. Minnesota CHP Technical Potential (Sites) by Utility

Figure 13 profiles existing CHP capacity and remaining CHP potential by utility service area in Minnesota.

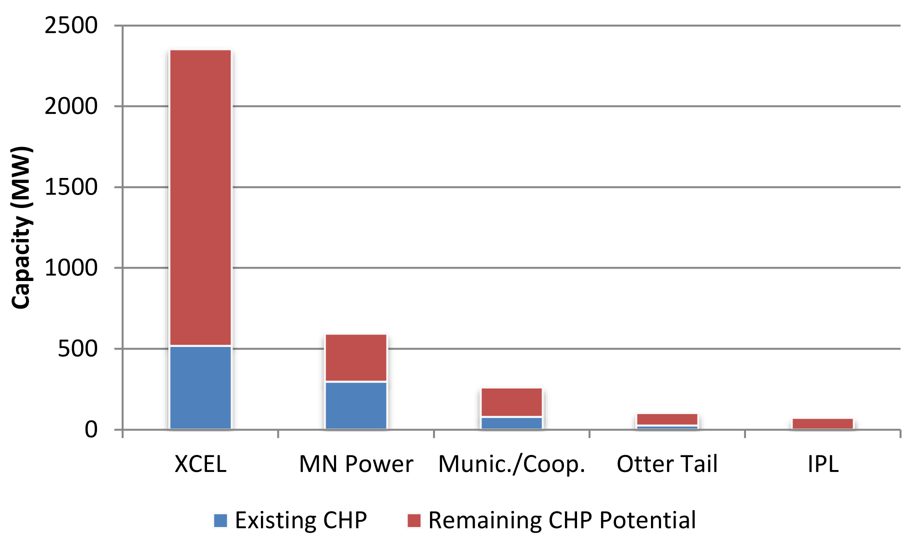

Figure 13 . Existing CHP and Total Remaining CHP Potential by Utility Territory

Table 6 and Table 7 summarize the current technical potential estimates by application and size. The technical potential for CHP is highest in industrial sectors that currently have a large amount of existing CHP installations, such as paper production, chemicals, and food processing.

Commercial facility CHP technical potential is heavily concentrated in the size ranges below 5 MW, where about 81 percent of the technical potential lies. This potential is boosted by several large applications that incorporate cooling into the CHP system design, including college/universities, commercial buildings, multifamily buildings, hospitals, and hotels.

Table 8 summarizes the sector-specific growth percentages used to calculate the expected growth in CHP in the industrial and commercial sectors (EIA AEO 2014, Tables 32 and 33). Table 9 and Table 10 show the expected growth in CHP sites and capacity in the industrial and commercial sectors, taking into account the technical potential and the EIA sector-specific growth rates.

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SIC	Application	50 kW - 500 kW		500 kW - 1 MW		1 MW - 5 MW		5 MW - 20 MW		> 20 MW		Total	
		# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW
20	Food Processing	160	30.3	32	22.3	47	97.3	8	75.1	4	107.7	251	332.6
22	Textiles	14	2.7	1	0.8	1	1.8	0	0.0	0	0.0	16	5.3
24	Lumber and Wood	137	23.3	17	12.5	12	17.0	5	44.1	0	0.0	171	97.0
26	Paper Manufacturing	59	12.8	25	16.9	14	30.4	8	72.1	4	143.2	110	275.4
27	Printing/Publishing	18	2.8	2	1.2	0	0.0	0	0.0	0	0.0	20	4.0
29	Refinery	0	0.0	5	3.4	1	3.5	1	18.4	2	203.0	9	228.3
28	Chemicals	160	27.3	30	20.8	53	134.8	15	195.5	2	114.9	260	493.4
30	Rubber and Plastics	165	25.2	13	8.6	1	1.9	0	0.0	0	0.0	179	35.7
33	Primary Metals	28	6.4	8	5.8	8	18.6	1	16.4	1	107.6	46	154.7
34	Fabricated Metals	58	6.5	1	0.5	0	0.0	0	0.0	0	0.0	59	7.1
35	Machinery-Computers	11	1.6	0	0.0	1	1.3	0	0.0	0	0.0	12	2.9
38	Instruments	3	0.2	0	0.0	0	0.0	0	0.0	0	0.0	3	0.2
37	Transportation	36	5.3	6	3.9	4	9.2	1	8.3	1	23.0	48	49.7
39	Misc. Manufacturing	11	1.4	0	0.0	1	1.3	0	0.0	1	30.8	13	33.4
	Total	**860**	**145.8**	**140**	**96.7**	**143**	**317.0**	**39**	**429.9**	**15**	**730.1**	**1,197**	**1,719.5**

Table 6. On-Site CHP Technical Potential at Existing Industrial Facilities in 2014

SIC	Application	50 kW - 500 kW		500 kW - 1 MW		1 MW - 5 MW		5 MW - 20 MW		> 20 MW		Total	
		# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW
43	Post Offices	4	0.4	0	0.0	1	1.1	0	0.0	0	0.0	5	1.5
52	Big Box Retail	371	40.1	10	6.6	2	2.4	0	0.0	0	0.0	383	49.2
4222	Refrigerated Warehouses	15	2.1	2	1.1	0	0.0	1	6.7	0	0.0	18	9.9
4581	Airports	3	0.7	0	0.0	0	0.0	1	19.1	0	0.0	4	19.8
4952	Wastewater /District Energy	11	1.1	0	0.0	1	2.8	0	0.0	1	70.9	13	74.7
5411	Food Sales	178	38.2	22	13.8	0	0.0	0	0.0	0	0.0	200	52.1
5812	Restaurants	460	47.2	0	0.0	1	1.4	0	0.0	0	0.0	461	48.5
6512	Commercial Buildings	N/A	63.2	N/A	221.2	N/A	94.8	0	0.0	0	0.0	N/A	379.2
6513	Multifamily Housing	N/A	26.1	N/A	63.0	N/A	19.6	0	0.0	0	0.0	N/A	108.7
7011	Hotels	252	36.2	13	8.2	7	11.4	1	7.8	0	0.0	273	63.6
7211	Laundries	17	2.6	4	2.7	0	0.0	0	0.0	0	0.0	21	5.3
7374	Data Centers	35	5.9	4	2.5	5	9.7	1	6.1	0	0.0	45	24.2
7542	Carwashes	28	1.9	0	0.0	0	0.0	0	0.0	0	0.0	28	1.9
7832	Movie Theaters	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1
7991	Health Clubs	42	5.5	4	2.3	2	4.0	0	0.0	0	0.0	48	11.8
7997	Golf Clubs	115	12.0	2	1.0	0	0.0	0	0.0	0	0.0	117	13.1
8051	Nursing Homes	295	38.0	9	6.0	4	5.4	0	0.0	0	0.0	308	49.5
8062	Hospitals	82	17.0	36	24.2	28	55.8	1	5.8	1	22.3	148	125.1
8211	Schools (k-12)	210	15.9	0	0.0	0	0.0	0	0.0	0	0.0	210	15.9
8221	Colleges & Universities	58	11.2	19	14.4	22	46.3	10	87.0	1	21.0	110	179.8
8412	Museums	10	1.6	1	1.0	0	0.0	0	0.0	0	0.0	11	2.6
9100	Government	204	30.7	19	14.9	10	13.9	0	0.0	0	0.0	233	59.5

		50 kW - 500 kW		500 kW - 1 MW		1 MW - 5 MW		5 MW - 20 MW		> 20 MW		Total	
SIC	Application	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW
9223	Correctional Facilities	7	0.7	1	0.9	12	25.7	0	0.0	0	0.0	20	27.2
9711	Military	5	0.9	1	0.5	2	5.1	0	0.0	0	0.0	8	6.6
	Total	**2,403**	**399.2**	**147**	**384.4**	**97**	**299.3**	**15**	**132.5**	**3**	**114.1**	**2,665**	**1,329.6**

Table 7. On-Site CHP Technical Potential at Existing Commercial Facilities in 2014

SIC ID	Application	Yearly 2014-2040 Growth Rate	Cumulative 2014-2040 Growth Rate
20	Food & Beverage	1.8%	58.6%
22	Textiles	0.0%	0.0%
24	Lumber and Wood	0.5%	15.0%
25	Furniture	1.4%	42.7%
26	Paper	1.8%	58.2%
27	Printing/Publishing	0.3%	7.4%
28	Chemicals	2.6%	97.1%
29	Petroleum Refining	0.0%	0.0%
30	Rubber/Misc Plastics	2.1%	69.6%
32	Stone/Clay/Glass	1.9%	61.8%
33	Primary Metals	1.0%	30.8%
34	Fabricated Metals	1.8%	60.7%
35	Machinery/Computer Equip	2.6%	95.6%
37	Transportation Equip.	2.9%	110.6%
38	Instruments	2.8%	106.4%
39	Misc Manufacturing	4.5%	212.8%
49	Gas Processing	1.3%	39.2%
4952	Water Treatment/Sanitary	0.7%	18.8%
9223	Prisons	1.4%	45.3%
9711	Military	1.4%	45.3%
7211	Laundries	1.4%	45.3%
7542	Carwashes	1.4%	45.3%
7991	Health Clubs	1.4%	45.3%
7997	Golf/Country Clubs	1.4%	45.3%
4222	Refrigerated Warehouses	1.4%	45.3%
6513	Multi-Family Buildings	1.5%	47.2%
7011	Hotels	1.2%	37.3%
7374	Data Centers	4.0%	177.2%
8051	Nursing Homes	1.2%	38.0%
8062	Hospitals	1.2%	38.0%
8221	Colleges/Universities	0.5%	13.5%
43	Post Offices	1.4%	45.3%
52	Big Box Retail	1.0%	29.5%
4581	Airports	1.4%	45.3%
5411	Food Sales	1.0%	30.2%

SIC ID	Application	Yearly 2014-2040 Growth Rate	Cumulative 2014-2040 Growth Rate
5812	Restaurants	1.1%	32.3%
6512	Commercial Buildings	1.2%	34.9%
7832	Movie Theaters	0.5%	14.2%
8211	Schools	0.5%	13.5%
8412	Museums	0.5%	14.2%
9100	Government Facilities	1.2%	34.9%

Table 8. Minnesota Sector-Specific Growth Projections Through 2040

Sources: EIA AEO 2014, Tables 32 and 33; ICF International

SIC	Application	50-500 kW	500-1 MW	1-5 MW	5-20 MW	>20 MW	Total
20	Food Processing	48.1	35.4	154.3	119.1	170.9	527.7
22	Textiles	2.7	0.8	1.8	0.0	0.0	5.3
24	Lumber and Wood	26.8	14.3	19.6	50.8	0.0	111.5
26	Paper Manufacturing	20.3	26.7	48.1	114.0	226.6	435.7
27	Printing/Publishing	3.0	1.3	0.0	0.0	0.0	4.3
29	Refinery	0.0	3.4	3.5	18.4	203.0	228.3
28	Chemicals	53.8	41.0	265.7	385.3	226.5	972.3
30	Rubber and Plastics	42.7	14.6	3.2	0.0	0.0	60.5
33	Primary Metals	8.4	7.5	24.3	21.4	140.7	202.4
34	Fabricated Metals	10.5	0.9	0.0	0.0	0.0	11.4
35	Machinery-Computers	3.1	0.0	2.5	0.0	0.0	5.6
38	Instruments	0.3	0.0	0.0	0.0	0.0	0.3
37	Transportation	11.3	8.1	19.3	17.5	48.4	104.7
39	Misc. Manufacturing	4.3	0.0	4.0	0.0	96.2	104.5
	Total	**235.2**	**154.1**	**546.2**	**726.6**	**1,112.2**	**2,774.3**

Table 9. Industrial CHP Market Segments, Existing Facilities and 2014-2040 Growth

SIC	Application	50-500 kW	500-1 MW	1-5 MW	5-20 MW	>20 MW	Total
43	Post Offices	0.6	0.0	1.5	0.0	0.0	2.2
52	Big Box Retail	52.0	8.6	3.1	0.0	0.0	63.7
4222	Refrigerated Warehouses	3.0	1.5	0.0	9.8	0.0	14.3
4581	Airports	1.0	0.0	0.0	27.7	0.0	28.7
4952	Wastewater /District Energy	1.3	0.0	3.3	0.0	84.2	88.8
5411	Food Sales	49.7	18.0	0.0	0.0	0.0	67.8
5812	Restaurants	62.4	0.0	1.8	0.0	0.0	64.2
6512	Commercial Buildings	85.2	298.4	127.9	0.0	0.0	511.5
6513	Multifamily Housing	38.4	92.8	28.8	0.0	0.0	160.0
7011	Hotels	49.7	11.3	15.6	10.7	0.0	87.3
7211	Laundries	3.8	3.9	0.0	0.0	0.0	7.7
7374	Data Centers	16.4	7.0	26.9	16.9	0.0	67.1
7542	Carwashes	2.8	0.0	0.0	0.0	0.0	2.8
7832	Movie Theaters	0.1	0.0	0.0	0.0	0.0	0.1
7991	Health Clubs	8.0	3.3	5.8	0.0	0.0	17.1
7997	Golf Clubs	17.5	1.5	0.0	0.0	0.0	19.0
8051	Nursing Homes	52.5	8.3	7.5	0.0	0.0	68.3
8062	Hospitals	23.4	33.4	77.0	8.0	30.8	172.7
8211	Schools (k-12)	18.0	0.0	0.0	0.0	0.0	18.0
8221	Colleges & Universities	12.7	16.3	52.6	98.8	23.8	204.2
8412	Museums	1.8	1.1	0.0	0.0	0.0	2.9
9100	Government	41.3	20.1	18.8	0.0	0.0	80.2
9223	Correctional Facilities	1.0	1.3	37.4	0.0	0.0	39.6
9711	Military	1.3	0.8	7.5	0.0	0.0	9.6
	Total	**544.1**	**527.7**	**415.4**	**171.9**	**138.8**	**1,797.8**

Table 10. Commercial CHP Market Segments, Existing Facilities and 2014-2040 Growth

Waste Heat to Power CHP Technical Potential

In addition to exploring the technical potential of traditional topping cycle CHP in Minnesota, this assessment also evaluated the potential for waste heat to power (WHP) in the state. Waste heat to power is the process of capturing heat discarded by an existing process to generate power. Table 10 and Table 11 show current waste heat to power technical potential in Minnesota by utility and by application.

Utility	# of Sites	WHP Potential (MW)
Alliant	1	1.7
MN Power	6	6.3
Muni/Co-Op	3	9.0
Northern States (Xcel)	19	123.2
Otter Tail	6	5.6
Total	**35**	**145.8**

Table 11. Waste Heat to Power Technical Potential by Utility

NAICS Code	Application	# of Sites	WHP Potential (MW)
311313	Beet Sugar Manufacturing	2	0.5
322121	Paper (except Newsprint) Mills	1	0.4
324110	Petroleum Refineries	2	93.1
325193	Ethyl Alcohol Manufacturing	1	5.8
327213	Glass Container Manufacturing	1	1.5
327993	Mineral Wool Manufacturing	1	1.6
331110	Iron and Steel Mills and Ferroalloy Manufacturing	1	19.3
331492	Secondary Smelting and Alloying of Nonferrous Metal	1	1.1
486210	Pipeline Transportation of Natural Gas	22	21.7
562212	Solid Waste Landfill	3	0.9
Total		**35**	**145.8**

Table 12. Waste Heat to Power Technical Potential by Application

Economic Potential

The economic potential for CHP is quantified using simple payback for CHP systems. Payback is defined as the amount of time (i.e. number of years) before a system can recoup its initial investment. For each site included in the technical potential analysis, an economic payback is calculated based on the appropriate CHP system cost and performance characteristics and energy rates for that system size and application. This section lays out the economic conditions in Minnesota that were used to calculate the payback for each technical potential application and size range.

Energy Price Projections

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 for a facility with electric and thermal energy requirements to cost-effectively utilize CHP.

Electric Price Estimation

State-average spark spreads may mask the differences between utility-specific rates on project economics, so ICF researched the applicable rates (i.e. full service and partial service/standby rates) for the four largest utilities in Minnesota to develop an avoided cost estimate for each utility. The avoided cost is an important concept for evaluating the treatment of onsite generation by partial requirement tariff structures. One of the key economic values of onsite generation is the displacement of purchased electricity and the avoidance of those costs. Ideally, the reduction in electricity price should be commensurate with the reduction in purchased electricity. In other words, if the onsite system reduces electricity consumption by 80 percent, the cost of electricity purchases would also be reduced by 80 percent. However, only a portion of the full retail rate is avoided by on-site generation due to fixed customer charges, demand charges, and standby rate structures. The economics of CHP are negatively impacted if partial requirements rates are structured such that only a small portion of the electricity price can be avoided.

The utilities analyzed include Interstate (Alliant), Minnesota Power, Northern States (Xcel) and Otter Tail. The rates for CHP customers for each utility are shown in Table 13, Table 14, Table 15 and Table 16.

System Size Range (kW)	50-500	500-1,000	1,000-5,000	5,000-20,000	> 20,000
High Load Factor Traditional (hours)	8760	8760	8760	8760	8760
CHP Availability (%)	95%	95%	95%	95%	95%
Voltage Class	Secondary	Secondary	Primary	Transmission	Transmission
Tariff Class	540	540	540	540	540
Avoided Rate, $/kWh	0.0615	0.0607	0.0587	0.0585	0.0585
Avoided Rate as % of Retail Rate	91%	92%	93%	93%	94%

Table 13. Interstate (Alliant) CHP High Load Customer Electric Rate Summary

System Size Range (kW)	50-500	500-1,000	1,000-5,000	5,000-20,000	> 20,000
High Load Factor Traditional (hours)	8760	8760	8760	8760	8760
CHP Availability (%)	95%	95%	95%	95%	95%
Voltage Class	Secondary	Secondary	Primary	Primary	Transmission
Tariff Class	25	25	55/75	55/75	55/75
Avoided Rate, $/kWh	0.0700	0.0700	0.0560	0.0560	0.0530
Avoided Rate as % of Retail Rate	90%	90%	89%	89%	95%

Table 14. Minnesota Power CHP High Load Traditional Customer Electric Rate Summary

System Size Range (kW)	50-500	500-1,000	1,000-5,000	5,000-20,000	> 20,000
High Load Factor Traditional (hours)	8760	8760	8760	8760	8760
CHP Availability (%)	95%	95%	95%	95%	95%
Voltage Class	Secondary	Secondary	Primary	Primary	Transmission
Tariff Class	A14	A14	A15	A15	A15
Avoided Rate, $/kWh	0.0710	0.0691	0.0670	0.0643	0.0633
Avoided Rate as % of Retail Rate	87%	87%	90%	93%	96%

Table 15. Northern States (Xcel) Energy CHP High Load Customer Electric Rate Summary

System Size Range (kW)	50-500	500-1,000	1,000-5,000	5,000-20,000	> 20,000
High Load Factor Traditional (hours)	8760	8760	8760	8760	8760
CHP Availability (%)	95%	95%	95%	95%	95%
Voltage Class	Secondary	Secondary	Primary	Transmission	Transmission
Tariff Class	Standby Service (Firm)	Standby Service (Firm)	Standby Service (Firm)	Standby Service (Firm)	Standby Service (Firm)
Avoided Rate, $/kWh	0.0753	0.0725	0.0562	0.0542	0.0496
Avoided Rate as % of Retail Rate	84%	85%	80%	79%	81%

Table 16. Otter Tail CHP High Load Customer Electric Rate Summary

The escalation rate for real electricity prices over the 2014-2040 timeframe was 1.1 percent per year and was taken from the EIA Annual Energy Outlook 2014 (EIA Electric Power Projections).

Natural Gas Price Estimation

The natural gas prices used in the analysis by system size and representative year are shown below in Table 17. These prices reflect the 2013 annual Minnesota state-average rates (EIA Natural Gas Prices). The specific rate for each size range is assigned as follows:

- 50 – 500 kW: MN Commercial average
- 500 – 1 MW: MN Industrial average + 20 percent[4]
- 1 – 5 MW: MN Industrial average
- 5 – 20 MW: MN Industrial average
- >20 MW : MN Citygate average + 10 percent

The escalation rate for real natural gas prices over the 2014-2040 timeframe was 1.3 percent per year and was taken from the EIA Annual Energy Outlook 2014 (EIA Electric Power Projections).

[4] 20 percent adder based on past natural gas tariff analysis for these size categories

Year	50-500 kW	500-1 MW	1-5 MW	5-20 MW	> 20 MW
2014	$6.64	$5.95	$4.96	$4.96	$4.83
2020	$7.18	$6.43	$5.36	$5.36	$5.22
2030	$8.17	$7.32	$6.10	$6.10	$5.95
2040	$9.31	$8.34	$6.95	$6.95	$6.77

Table 17. Natural Gas Price by CHP System Size Bin (2014$/MMBtu)

CHP Technology Cost and Performance

CHP systems use fuel to generate electricity and useful heat for the customer. There are many different technologies and products that are capable of generating electricity and useful heat. While these technologies differ in terms of system configuration and operation, the economic value of CHP depends on key factors common to all CHP technologies:

- Installed capital cost of the system, on a unit basis expressed in $/kWh. A subset of capital costs are emissions treatment equipment costs that are required to bring some CHP systems into compliance with California (or other regional non-attainment areas) emissions requirements.
- Fuel required to generate electricity, commonly expressed as the heat rate in Btu/kWh. All heat rates in this report are expressed in terms of the high heating value (HHV) of the fuel. This is the same basis on which natural gas is measured and priced for sale. Vendors typically express engine heat rates in terms of lower heating value (LHV) which does not include the heat of vaporization of the moisture content of the exhaust. Consequently, vendor efficiency and heat rate quotes for natural gas fueled equipment are about 10-11 percent higher than HHV estimates, which reflects the difference in the HHV and LHV heat contents for a given volume of natural gas.
- Useful thermal energy produced per unit of electricity output (again expressed as Btu/kWh).
- Non-fuel operating and maintenance costs, expressed on unit basis in $/kWh. These annual costs include amortization of overhaul costs that can be required after a number of years of operation.
- Economic life of the equipment.

The cost and performance parameters for the representative CHP systems used in this analysis are based on CHP technology characterizations prepared for NYSERDA and the EPA (EPA CHP Partnership Program). These technology characterizations are currently being updated by ICF. Data is presented on the representative CHP system characteristics that were used for each size range category in Table 18. The top portion of the table shows the CHP system characteristics for traditional heat utilization (hot water or steam) while the bottom portion of the table shows the additional cost and performance parameters associated with a CHP system used for cooling. In the cooling markets, the additional cost to add chiller capacity to the CHP system is shown in Figure 12. These costs depend on the sizing of the absorption chiller, which in turn depends on the amount of usable waste heat that the CHP system produces.

Market Size Bin Technology	50-1,000 kW 800 kW RE	1-5 MW 3000 kW RE	5-20 MW 10 MW GT	>20 MW 40 MW GT
Capacity, kW	800	3,000	10,000	40,000
Total Capital Cost, $/kW	$2,800	$2,050	$1,850	$1,250
Heat Rate, Btu/kWh	9,760	9,800	11,765	9,220
Thermal Output, Btu/kWh	4,299	4,200	4,674	3,189
Electric Efficiency, %	35.0%	34.8%	29.0%	37.0%
CHP Overall Efficiency	79.0%	77.7%	68.7%	71.6%
O&M Costs, $/kWh	$0.018	$0.016	$0.009	$0.005
Economic Life, years	15	15	20	20
Avoided Boiler Efficiency	80%	80%	80%	80%
Avoided AC Efficiency, kW/ton	0.68	0.68	0.68	0.68
Cooling Hours	2,000	2,000	2,000	2,000
Absorption Cooling Efficiency, Btu/ton	17,000	17,000	17,000	10,435
Avoided Cooling, kWh/kW	603	589	458	837
Capital Cost Adder, $/kWe	$450	$325	$186	$148

Table 18. CHP Cost and Performance Assumptions

Notes: "RE" is reciprocating engine; "GT" is gas turbine

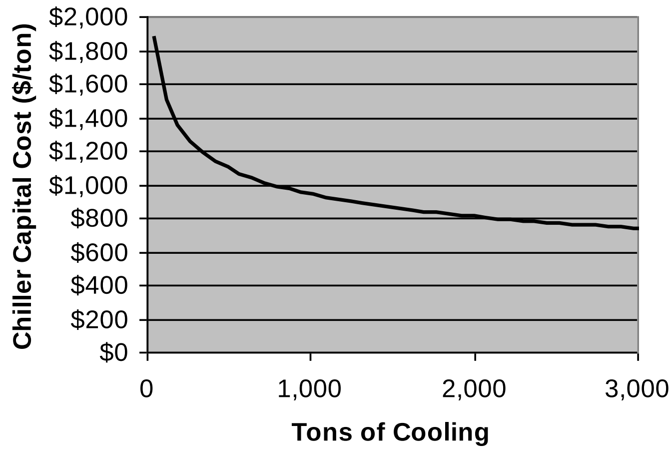

Figure 14. Absorption Chiller Capital Costs

Economic Potential Results

CHP project economics are site-specific. Utility-specific electricity rates and tariff structures, natural gas prices, and site-specific conditions (i.e. space availability and integration into existing thermal and electric systems, permitting, siting and grid interconnection requirements) all contribute to the unique economics of each CHP system. An estimate of economic potential by system size range was developed for this analysis using Minnesota-specific electricity and natural gas rates and representative CHP equipment cost and performance characteristics. Simple yearly paybacks were calculated for the five CHP system size categories for all of the applications.

The payback calculation was conducted for each electric utility in the state and the potential in terms of megawatts was categorized into four payback categories representing the degree of economic potential:

- Strong potential – simple payback < 5 years
- Moderate potential – simple payback 5 to 10 years
- Minimal potential – simple payback >10 years

Table 19 presents the economic potential based on current electricity and natural gas prices, and equipment cost and performance characteristics. As shown, 316.2 MW of the total economic potential of 1,249.3 MW has a payback less than 5 years, with all of this potential occurring in Northern States (Xcel) service territory. Just over 102 MW has a payback in the 5 to 10 year range. All of the sites with payback under 10 years are large sites in the >20 MW size range.

Table 20 and Table 21 show the WHP economic potential based on WHP cost and performance characteristics and similar electricity and natural gas price assumptions used in the CHP economic potential analysis. While the total WHP technical potential is less than 5% of the CHP technical potential, the majority of the WHP economic potential has an expected payback of less than 5 years.

Market and Utility	Payback (years) < 5	5 to 10	> 10
High Load Factor Traditional Market			
Interstate (Alliant)	0.0	25.1	97.8
Minnesota Power	0.0	244.3	110.3
Northern States (Xcel)	462.5	0.0	675.8
Otter Tail	0.0	0.0	44.2
Muni/Co-op	0.0	69.1	99.1
High Load Factor Cooling Market			
Interstate (Alliant)	0.0	0.0	6.8
Minnesota Power	0.0	22.3	47.3
Northern States (Xcel)	0.0	21.0	399.9
Otter Tail	0.0	0.0	31.5
Muni/Co-op	0.0	0.0	31.9
Low Load Factor Traditional Market			
Interstate (Alliant)	0.0	0.0	0.1
Minnesota Power	0.0	0.0	1.5
Northern States (Xcel)	0.0	4.0	25.0
Otter Tail	0.0	0.0	0.6
Muni/Co-op	0.0	0.0	1.0
Low Load Factor Cooling Market			
Interstate (Alliant)	0.0	0.0	16.1
Minnesota Power	0.0	0.0	44.7
Northern States (Xcel)	0.0	0.0	478.8
Otter Tail	0.0	0.0	30.2
Muni/Co-op	0.0	0.0	58.3
Total MW	462.5	385.7	2,200.9

Table 19. CHP Economic Potential (MW) by Payback (years)

Electric Utility	Payback (years)			Total
	< 5	5 - 10	>10	
Alliant	0.0	1.7	0.0	1.7
MN Power	0.0	4.1	2.2	6.3
Muni/Co-Op	5.8	2.5	0.7	9.0
Northern States (Xcel)	115.5	2.9	4.8	123.2
Otter Tail	0.0	3.3	2.3	5.6
Total MW	**121.3**	**14.5**	**10.1**	**145.8**

Table 20. Waste Heat to Power Economic Potential by Electric Utility

NAICS Code	Application	Payback (years)			Total
		< 5	5 - 10	>10	
311313	Beet Sugar Manufacturing	0.0	0.2	0.3	0.5
322121	Paper (except Newsprint) Mills	0.0	0.0	0.4	0.4
324110	Petroleum Refineries	93.1	0.0	0.0	93.1
325193	Ethyl Alcohol Manufacturing	5.8	0.0	0.0	5.8
327213	Glass Container Manufacturing	1.5	0.0	0.0	1.5
327993	Mineral Wool Manufacturing	1.6	0.0	0.0	1.6
331110	Iron and Steel Mills and Ferroalloy Manufacturing	19.3	0.0	0.0	19.3
331492	Secondary Smelting and Alloying of Nonferrous Metal	0.0	1.1	0.0	1.1
486210	Pipeline Transportation of Natural Gas	0.0	13.2	8.5	21.7
562212	Solid Waste Landfill	0.0	0.0	0.9	0.9
Total MW		**121.3**	**14.5**	**10.1**	**145.8**

Table 21. Waste Heat to Power Economic Potential by Application

Market Penetration

Based on the calculated economic potential, a market diffusion model is used to determine the cumulative CHP market penetration over the analysis timeframe. The market penetration represents an estimate of CHP capacity that will actually enter the market between 2014 and 2040. This value discounts the economic potential to reflect non-economic screening factors and the rate that CHP is likely to actually enter the market.

Rather than use a single yearly payback value as the sole determinant of economic potential, the market acceptance rate has also been included.

Three market acceptance curves were analyzed: "average" acceptance, "strong prospects", and "utility" acceptance (Figure 15). These curves indicate the assumed level of payback required to consider installing CHP. The average acceptance curve represents the expected project acceptance of the majority of customers. As can be seen from the figure, for the average acceptance curve, more than 30 percent of customers surveyed 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 a weighted average cost of capital (WACC) of about 50 percent.

Potential explanations for rejecting a project with such high returns include 1) The average customer does not believe that the results are valid and is attempting to mitigate this perceived risk by requiring very high projected returns before a project would be accepted, and 2) The facility has limited capital and is rationing its ability to raise capital for higher priority projects (i.e. market expansion, product improvement, etc.).

The strong prospect curve represents customers that are already familiar with distributed generation projects like CHP systems or customers who have other driving factors behind the desire to install CHP (such as reliability, environmental pressures, etc.) that lead them to accept projects with longer paybacks.

Both the average and strong prospects curves are based on survey data (Primen 2003).

In addition, the author developed a curve to estimate the behavior of utilities investing in CHP projects based on their low cost of capital and long-term investment horizons. For context, as explained in the companion report ("Minnesota Combined Heat and Power Policies and Potential," FVB Energy 2014), Xcel Energy's WACC is estimated to be 7.34 percent, equivalent to a simple payback of slightly over 10 years. In the "utility" curve in the figure, it is assumed that only 40 percent of utilities would be willing to invest in CHP with a 10 year payback. The percentage willing to invest increases to 85 percent with a payback of 8 years (equivalent to a WACC of 11.0 percent, which is far higher than normal utility WACC.

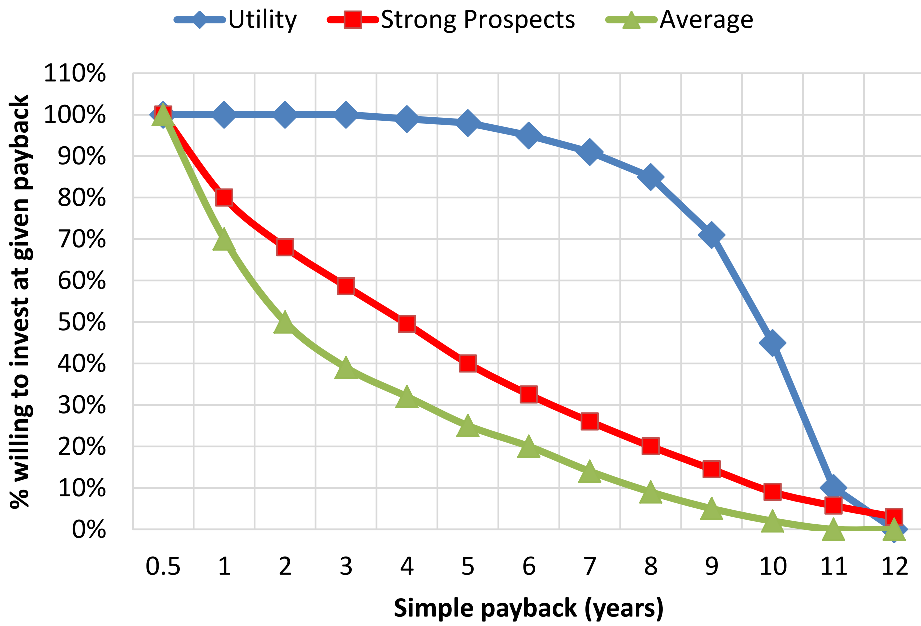

Figure 15. Payback Acceptance Curves

Sources: Average and Strong Prospects curves from Primen, 2003. Utility curve estimated by FVB Energy.

For each market segment, the CHP market penetration represents the technical potential multiplied by the share of customers that would accept the payback calculated in the economic potential section.

The rate of market penetration is based on a *Bass diffusion curve* with allowance for growth in the maximum market. This function determines cumulative market penetration over the analysis timeframe. 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, and is shown in Figure 16. In the generalized form used in this analysis, growth in the number of ultimate adopters is allowed. The shape of the curve is determined by an initial market penetration estimate and growth rate of the technical market potential.

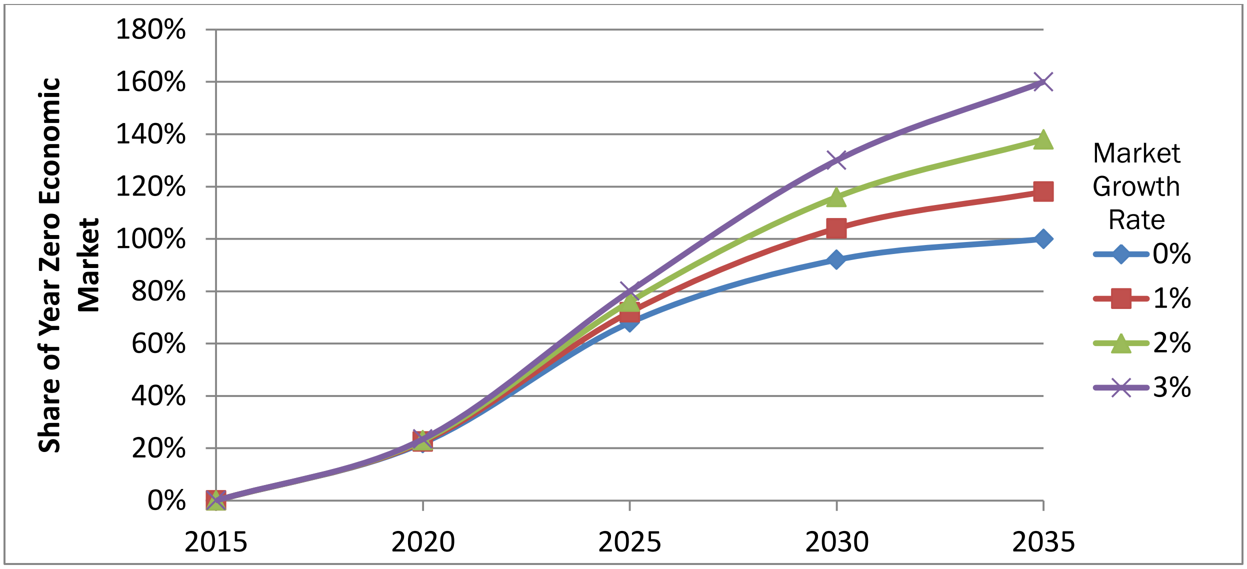

Figure 16. Example Bass Diffusion Curve for CHP Market Penetration

Base Case CHP Market Penetration Results

For the CHP base case, representing the expected market penetration with an average market acceptance curve and currently existing policies, the majority of the CHP market penetration is in the high load factor traditional market segment (238 MW of 252 MW by 2040). There is zero CHP that reaches the market in the low load factor traditional market segment (not shown) and minimal market penetration in the high and low load factor cooling market segments. No new biomass CHP is projected in the base case. From a utility standpoint, most of the CHP market penetration is in the Xcel territory (187 MW of 252 MW by 2040). Minnesota Power and Alliant show relatively low levels of market penetration, and Otter Tail has zero market penetration in the base case.

Figure 17 shows the projected CHP penetration rate over the analysis timeframe by market segment. The scale on the y-axis (i.e. cumulative CHP market penetration) has been revised to allow for easier comparison between the base case and the various policy cases. Figure 18 shows market penetration by utility. Table 22 shows detailed cumulative results for state projections of CHP market penetration.

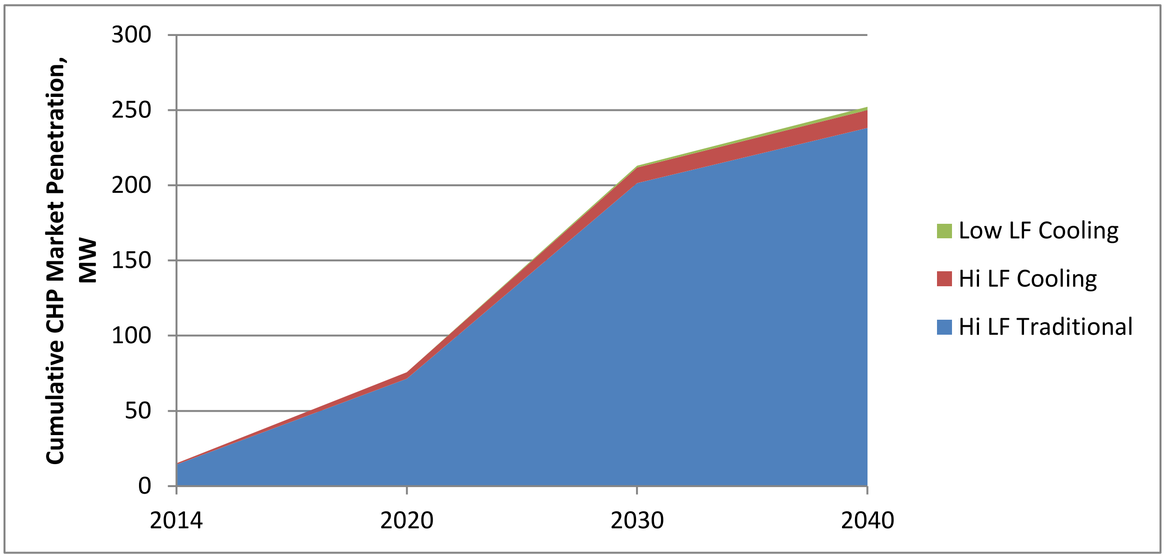

Figure 17. Base Case CHP Cumulative Market Penetration by Market Segment, 2014-2040 [5]

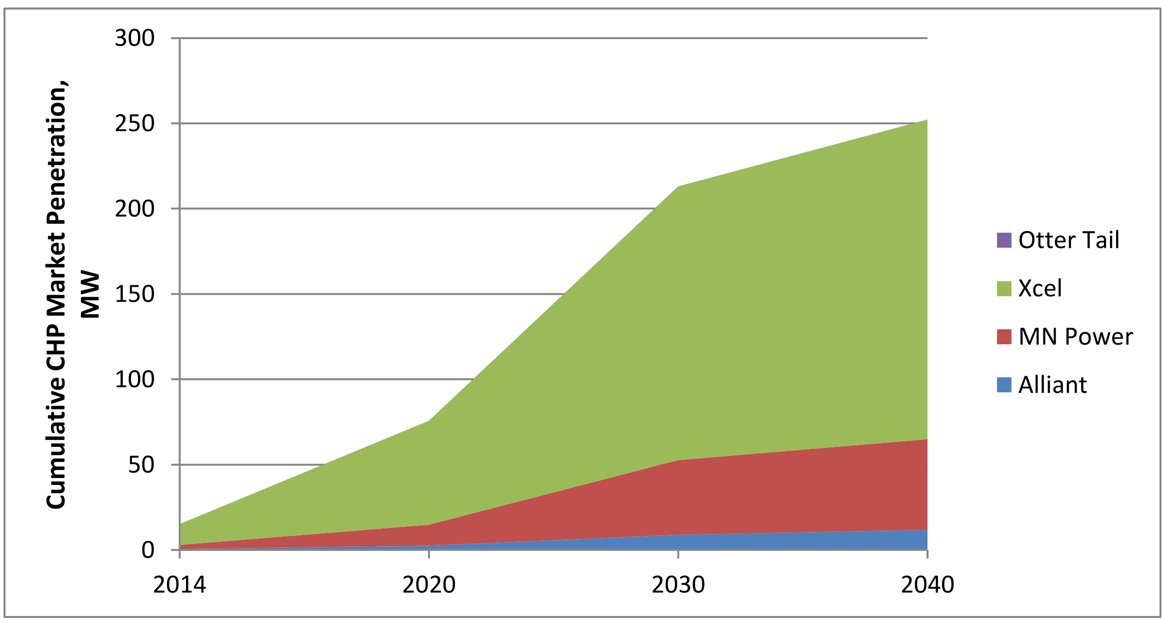

Figure 18. Base Case CHP Cumulative Market Penetration by Utility, 2014-2040

[5] "Hi LF Traditional" is the "high load factor traditional" market segment, "Hi LF Cooling" is the "high load factor cooling" market segment, "Low LF Cooling" is the "low load factor cooling" market segment

Cumulative Market Penetration (MW)	2014	2020	2030	2040
Industrial	15	75	211	249
Commercial/Institutional	0	0	0	1
Cumulative Market Penetration	15	75	211	250
Avoided Electric Cooling	0	1	2	2
Total	15	76	213	252
Annual Electric Energy (Million kWh)				
Industrial	121	604	1,690	1,990
Commercial/Institutional	0	0	1	4
Total	121	604	1,692	1,993
Cumulative Market Penetration by Size and Year (MW)				
50-500 kW	0.0	0.0	0.0	0.0
500kW-1,000kW	0.0	0.0	0.0	0.0
1-5 MW	0.0	0.0	2.2	5.1
5-20 MW	0.0	0.0	7.0	16.3
>20 MW	15.0	74.9	201.9	228.4
Total Market	15.0	74.9	211.1	249.8
Avoided CO2 Emissions Compared to No Policy Case, Annual Basis (thousand MT)	35	174	493	581
Cumulative Avoided CO2 Emissions (thousand MT)	35	521	5,788	11,157

Table 22. Minnesota Base Case CHP Market Penetration Results

Waste Heat to Power Market Penetration Results

The total amount of expected waste heat to power market penetration is 49.6 MW, with the majority of this located in Northern States' service territory. The combined market penetration for Alliant, MN Power and Otter Tail is only 1 MW. The WHP market penetration methodology is calculated consistently with the CHP methodology. Table 23 and Table 24 break down WHP market penetration by utility and application.

Electric Utility	Market Penetration (MW)
Alliant	0.2
MN Power	0.4
Muni/Co-Op	2.1
Northern States (Xcel)	46.5
Otter Tail	0.4
Total	**49.6**

Table 23. Base Case Waste Heat to Power Market Penetration by Utility

NAICS Code	Application	Market Penetration (MW)
311313	Beet Sugar Manufacturing	0.0
322121	Paper (except Newsprint) Mills	0.0
324110	Petroleum Refineries	38.6
325193	Ethyl Alcohol Manufacturing	1.8
327213	Glass Container Manufacturing	0.4
327993	Mineral Wool Manufacturing	0.4
331110	Iron and Steel Mills and Ferroalloy Manufacturing	6.8
331492	Secondary Smelting and Alloying of Nonferrous Metal	0.1
486210	Pipeline Transportation of Natural Gas	1.4
562212	Solid Waste Landfill	0.0
Total		**49.6**

Table 24. Base Case Waste Heat to Power Market Penetration by Application

CHP Policy Scenarios

To evaluate the impact of various potential policies on expected CHP market penetration, a variety of modifications were made the base case analysis to incorporate incentives or alternative acceptance rates. In addition to the base case, 14 scenarios (two revised base cases and twelve policy scenarios) were analyzed. A summary of the scenarios and can be found in Table 25.

The first set of scenarios involved changing the market acceptance values for the base case with no other incentives included. Scenarios 1 and 2 are based around electric and natural gas utility Conservation Improvement Program (CIP) incentives targeted at end-users. Each scenario was modeled with either capital incentives, operational incentives, or a combination of both capital and operating incentives. Scenario 3 was based on a CIP incentive for utility ownership of CHP where the utility would receive an operating incentive and also evaluate the economics of the CHP project based on higher acceptance rates. Scenario 5 was based on incorporating higher required percentages of electricity to be attained from CHP to meet an Alternative Portfolio Standard (APS). Due to the uncertainty of REC values in the future, this scenario was evaluated as a sensitivity curve showing the impact on CHP market penetration of a variety of REC values in $/MWh. Finally, scenario 6 was based on requiring electric utilities to evaluate CHP projects first during their Integrated Resources Planning (IRP) process. The values modeled for these scenarios involved valuing CO_2 at various prices on a $/tonne basis.

Scenario Number	Scenario Name	CIP Description	CIP Incentive	Market Acceptance	IRP Incentive: CO_2 Price ($/tonne)
0.1	Strong Prospects (Base Case)	N/A	N/A	Strong Prospects	N/A
0.2	Utility Acceptance (Base Case)	N/A	N/A	Utility Acceptance	N/A
1.1	CIP Gas Utility #1	Capital Incentive ($/1000 Btu-hr)	$100	Average	N/A
1.2	CIP Gas Utility #2	Operating Gas Rate Discount ($/MMBtu, 15 yrs)	$0.75	Average	N/A
1.3	CIP Gas Utility #3	Capital Incentive and Operating Gas Rate Discount ($/1000 Btu-hr and $/MMBtu, 15 yrs)	$100, $0.75	Average	N/A
2.1	CIP Electric Utility #1	Capital Incentive ($/kW)	$500	Average	N/A
2.2	CIP Electric Utility #2	Operating Electric Rate Discount ($/MWh, 15 yrs)	$10.00	Average	N/A
2.3	CIP Electric Utility #3	Capital Incentive and Operating Gas Rate Discount ($/kW and $/MWh, 15 yrs)	$500, $10.00	Average	N/A
3.1	CIP Gas Utility #4	Operating Gas Rate Discount ($/MMBtu, 15 yrs)	$0.75	Utility	N/A
3.2	CIP Electric Utility #4	Operating Electric Rate Discount ($/MWh, 15 yrs)	$10.00	Utility	N/A
5	APS	Various $/MWH REC Values	N/A	Average	N/A
6.1	IRP #1	N/A	N/A	Average	$20
6.2	IRP #2	N/A	N/A	Average	$40
6.3	IRP #3	N/A	N/A	Average	$60

Table 25. CHP Policy Scenario Summary

Notes:

CIP: Conservation Improvement Program

RPS: Renewable Portfolio Standard

APS: Alternative Portfolio Standard

IRP: Integrated Resource Planning

A summary of the market penetration results for natural gas CHP by policy scenario is shown in Table 26 for topping cycle CHP and in Table 27 for WHP. The scenarios with the largest impact were those that used the utility acceptance curve. Due to the number of policy scenarios, specific results disaggregated by utility and load factor market type are shown in Appendix A.

Scenario	Scenario Name	2014	2020	2030	2040
0	Base Case	15	76	213	252
0.1	Strong Prospects (Base Case)	30	148	434	511
0.2	Utility Acceptance (Base Case)	76	378	1,115	1,349
1.1	CIP Gas Utility #1: $100/Mbtu-hr	24	120	356	410
1.2	CIP Gas Utility #2: $0.75/MMBtu	23	117	315	354
1.3	CIP Gas Utility #3: $100/Mbtu-hr and $0.75/MMBtu	32	162	461	515
2.1	CIP Electric Utility #1: $500/kW	32	162	457	534
2.2	CIP Electric Utility #2: $10/MWh	29	146	410	449
2.3	CIP Electric Utility #3: $500/kW and $10/MWh	50	249	714	790
3.1	CIP Gas Utility #4: $0.75/MMBtu and Utility Acceptance	109	545	1,644	1,878
3.2	CIP Electric Utility #4: $10/MWh and Utility Acceptance	131	657	2,027	2,261
6.1	IRP #1: $20/tonne CO2	23	115	334	389
6.2	IRP #2: $40/tonne CO2	28	141	432	499
6.3	IRP #3: $60/tonne CO2	37	187	549	632

Table 26. CHP Policy Scenario Results by Year (Capacity, MW)

Scenario	Scenario Name	WHP Market Penetration (MW)
0	Base Case	49.6
0.1	Strong Prospects (Base Case)	57.2
0.2	Utility Acceptance (Base Case)	81.6
1.1	CIP Gas Utility #1: $100/Mbtu-hr	54.2
1.2	CIP Gas Utility #2: $0.75/MMBtu	52.6
1.3	CIP Gas Utility #3: $100/Mbtu-hr and $0.75/MMBtu	57.3
2.1	CIP Electric Utility #1: $500/kW	57.8
2.2	CIP Electric Utility #2: $10/MWh	55.4
2.3	CIP Electric Utility #3: $500/kW and $10/MWh	65.3
3.1	CIP Gas Utility #4: $0.75/MMBtu and Utility Acceptance	97.0
3.2	CIP Electric Utility #4: $10/MWh and Utility Acceptance	108.1
6.1	IRP #1: $20/tonne CO2	53.6
6.2	IRP #2: $40/tonne CO2	56.8
6.3	IRP #3: $60/tonne CO2	60.7

Table 27. Waste Heat to Power Market Penetration by Scenario

The raw results from the ICF model using the Utility Acceptance curve resulted in very high numbers (up to 2,000 MW by 2030). This magnitude of CHP is unlikely to be achievable with the high capacity factors needed for sound CHP economics. Further, Policy Options 3.1 and 3.2 were developed with the idea that incentives would be offered to customers or third parties to build CHP, but that utilities would also be encouraged and incented to use their capital to build CHP. The model was not structured to address this diversity of potential decision-makers. Therefore, as discussed in the companion report ("Assessment of the Technical and Economic Potential for CHP in Minnesota"), the estimates for Policy Options 3.1 and 3.2 were revised downward as summarized below.

The effect of an Alternative Portfolio Standard (APS) was explored by analyzing the effect of an equivalent REC price on CHP market penetration. Various levels of APS requirements will incentivize higher levels of renewables, increasing the demand for RECs, and increasing the price for RECs, all else equal. Figure 19 examines the effect of a changing REC price on base case cumulative CHP market penetration.

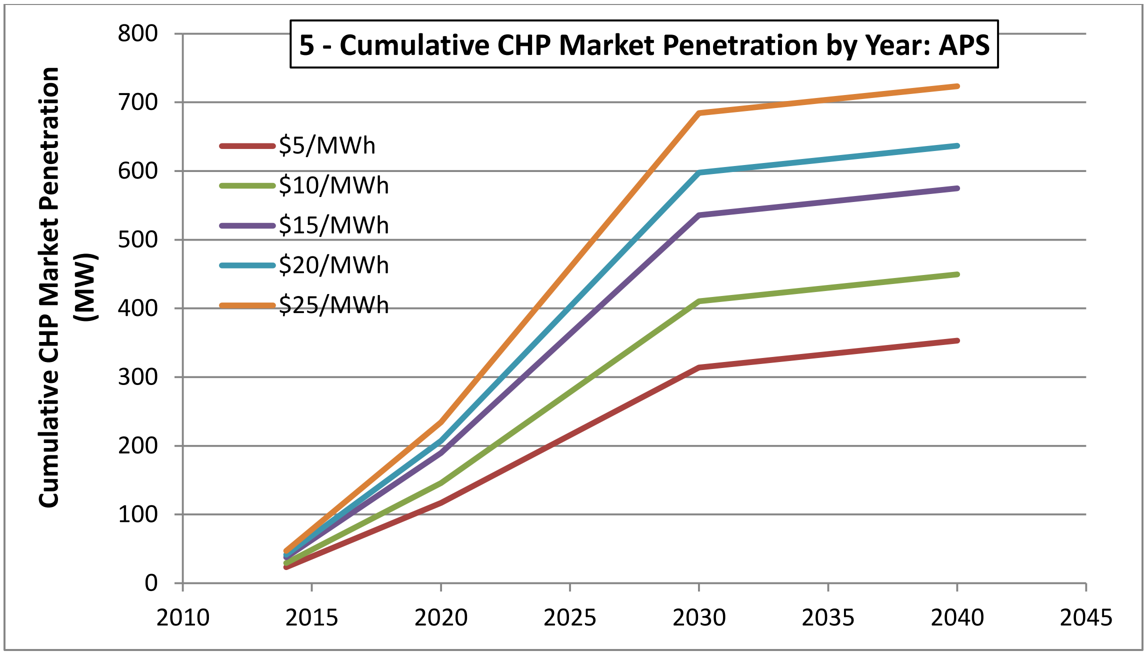

Figure 19. Cumulative CHP Market Penetration by Year at Varying REC Prices

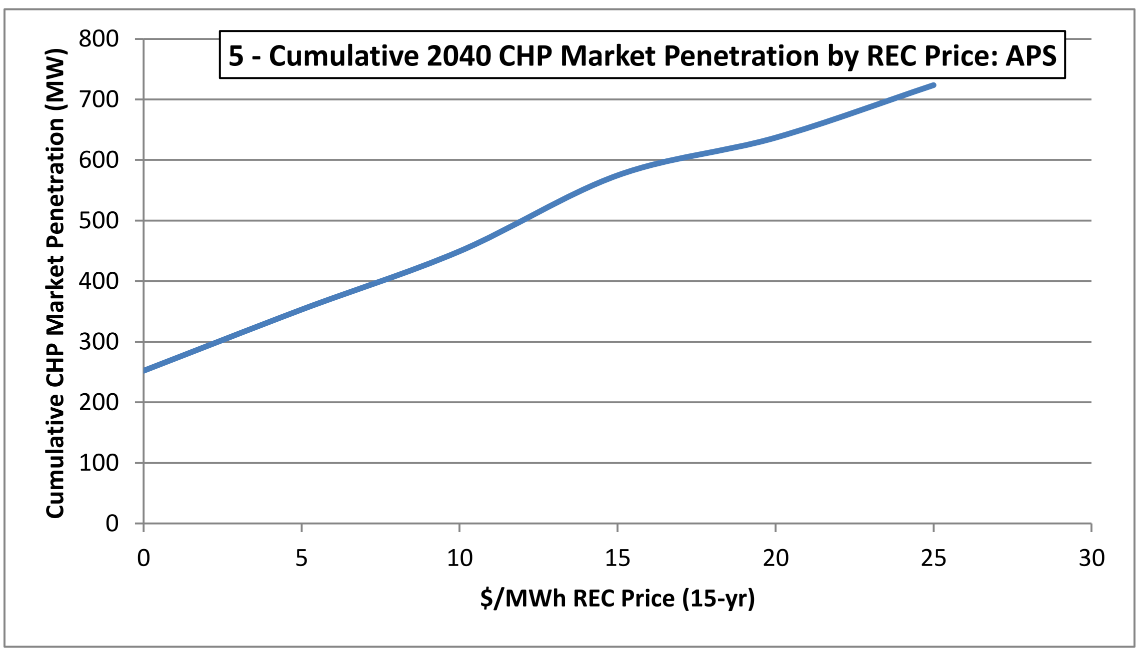

Figure 20. Cumulative 2040 CHP Market Penetration by REC Price

In addition to ICF's estimates of gas-fired CHP, FVB projected bioenergy CHP for scenarios other than gas utility program scenarios. The cumulative results for 2030 are summarized in Figure 21.

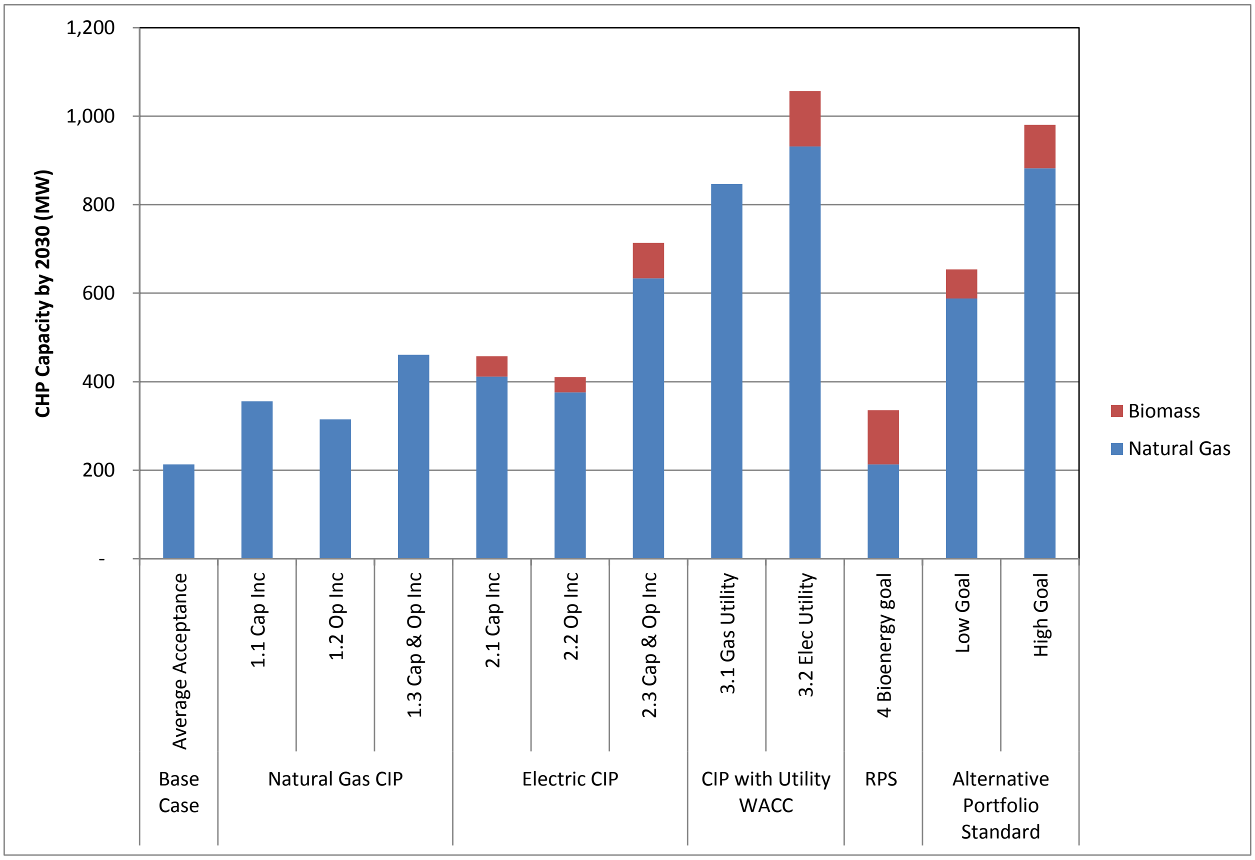

Figure 21. Summary of Estimated 2030 CHP Market Penetration with Policy Options

Conclusions

Of the 3,195 MW of existing CHP/WHP technical potential in Minnesota, 984 MW has economic potential with a payback of less than 10 years. The 984 MW of economic potential is located mostly in the high load factor markets in Xcel and Minnesota Power territories, with smaller amounts present in Alliant and municipal/coop territory. Economic potential is determined by calculating payback, which takes into account:

- Electric rate analysis by utility, system size, and market sector, for both standard customers and CHP customers;
- EIA natural gas prices (2013 Minnesota commercial, industrial, and citygate) by CHP system size; and
- Current and expected CHP cost and performance characteristics by technology type for various CHP sizes.

Generally, calculated payback is lower for larger customers, stemming from lower CHP system costs as a result of economies of scale, better CHP system performance characteristics, and lower natural gas prices.

The 984 MW of CHP economic potential with a payback of less than 10 years is then pared down to CHP market penetration. Additional CHP of 213 MW and 252 MW are projected to be implemented by 2030 and 2040, respectively, without new policies (Base Case). In addition, a Base Case market penetration of 50 MW is estimated for Waste Heat to Power. This capacity is almost all in Xcel service territory with some in Minnesota Power and Alliant territory.

CIP incentives (either capital or operating incentives) for customer investment in CHP, at levels consistent with recent levels of CIP expenditures per unit of electricity or natural gas saved, are estimated to result in approximately 100 to 240 MW of additional CHP beyond the Base Case. More substantial CIP incentives (combining capital and operating incentives) for customer investment in CHP, are estimated to result in approximately 250 to 500 MW of additional CHP beyond the Base Case.

Deploying the relatively low Weighted Average Cost of Capital (WACC) of utilities to build CHP can significantly enhance CHP economics. Utility investment in CHP is estimated to result in approximately 630 to 840 MW of additional CHP beyond the Base Case. At the high end of this range, CHP would more than double by 2030.

The economic viability of bioenergy CHP is dependent on range of site-specific factors, in particular cost-effective access to biofuel, making it difficult to project on a statewide basis. The technical potential for bioenergy CHP among current energy users in Minnesota is about 230 MW. Little or no market penetration of biomass CHP is expected in the Base Case. With the range of policy options evaluated, 35 to 125 MW of new biomass CHP is projected.

An Alternative Portfolio Standard is estimated to result in approximately 440 to 770 MW of additional CHP beyond the Base Case (for Low and High APS targets). At the high end of this range, CHP would more than double by 2030.

While these calculated economic potential and market penetration figures provide insight into the amount of CHP and WHP that could penetrate the market in Minnesota, there are other factors and uncertainties that affect the economics and expected market penetration. Some of these factors include:

- The presence of beneficial policies or incentives to encourage CHP growth. The policy scenarios evaluated in this study show increases in expected CHP market penetration between 40% and 800%.
- The potential for electric rate increases due to the retirement of coal generation plants.
- Gas rates, especially for larger (i.e. > 20 MW) customers, can be negotiated on a case-by-case basis with the utility, generally resulting in more favorable rates for the customer.
- Variations in customer acceptance rates of CHP or WHP systems with longer paybacks.

Overall, multiple factors point toward increasing levels of distributed generation market penetration in the United States. Some of these factors include the abundance of low-cost natural gas, technology advancements, emissions compliance, as well as favorable policies and incentives. CHP will continue to play an important role meeting demands for distributed generation, particularly in applications with favorable electric and thermal loads.

In Minnesota, the potential for CHP is constrained by relatively low electricity prices. However, the analysis shows that with supportive policies CHP can achieve significant growth in Minnesota.

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Appendix A

This appendix shows market-specific and utility-specific CHP market penetration data by scenario as well as scenario-specific summary figures.

Scenario Number	Market	2014	2020	2030	2040
0.0	Hi LF Traditional	14.3	71.3	201.4	238.1
0.0	Hi LF Cooling	0.9	4.3	10.4	11.9
0.0	Low LF Cooling	0.0	0.0	1.2	2.2
0.1	Hi LF Traditional	27.3	136.5	393.4	463.1
0.1	Hi LF Cooling	2.1	10.7	30.1	34.9
0.1	Low LF Cooling	0.2	0.8	10.2	12.9
0.2	Hi LF Traditional	70.7	353.6	1,015.6	1,223.2
0.2	Hi LF Cooling	4.7	23.6	74.1	88.8
0.2	Low LF Cooling	0.2	0.9	25.2	37.1
1.1	Hi LF Traditional	22.8	113.9	337.8	388.8
1.1	Hi LF Cooling	1.2	6.0	15.6	17.8
1.1	Low LF Cooling	0.1	0.5	2.4	3.6
1.2	Hi LF Traditional	21.8	108.8	288.2	324.9
1.2	Hi LF Cooling	1.5	7.6	22.2	23.7
1.2	Low LF Cooling	0.1	0.5	4.5	5.5
1.3	Hi LF Traditional	29.9	149.5	423.0	474.1
1.3	Hi LF Cooling	2.3	11.4	31.5	33.7
1.3	Low LF Cooling	0.3	1.4	6.0	7.2
2.1	Hi LF Traditional	29.7	148.5	414.2	483.2
2.1	Hi LF Cooling	2.2	10.8	32.9	37.7
2.1	Low LF Cooling	0.5	2.3	10.2	12.6
2.2	Hi LF Traditional	26.5	132.3	367.8	404.5
2.2	Hi LF Cooling	2.4	12.1	34.6	36.1
2.2	Low LF Cooling	0.3	1.4	7.9	8.8
2.3	Hi LF Traditional	43.9	219.5	619.1	688.0
2.3	Hi LF Cooling	4.7	23.7	71.5	76.3
2.3	Low LF Cooling	1.2	5.9	23.0	25.5
3.1	Hi LF Traditional	94.8	474.1	1,395.6	1,603.2

Scenario Number	Market	2014	2020	2030	2040
3.1	Hi LF Cooling	12.3	61.6	174.6	189.3
3.1	Low LF Cooling	1.9	9.6	74.0	85.9
3.2	Hi LF Traditional	109.7	548.6	1,655.6	1,863.2
3.2	Hi LF Cooling	17.6	87.9	267.9	282.6
3.2	Low LF Cooling	4.2	21.0	103.1	114.9
6.1	Hi LF Traditional	21.8	108.8	314.0	365.1
6.1	Hi LF Cooling	1.2	6.0	18.4	20.9
6.1	Low LF Cooling	0.0	0.2	1.7	2.6
6.2	Hi LF Traditional	26.5	132.6	403.6	465.4
6.2	Hi LF Cooling	1.5	7.7	23.2	27.0
6.2	Low LF Cooling	0.2	1.0	5.0	6.6
6.3	Hi LF Traditional	34.6	172.9	502.2	577.6
6.3	Hi LF Cooling	2.5	12.7	36.7	42.1
6.3	Low LF Cooling	0.4	1.9	9.7	11.9

Table A1. CHP Market Penetration by Market and Scenario

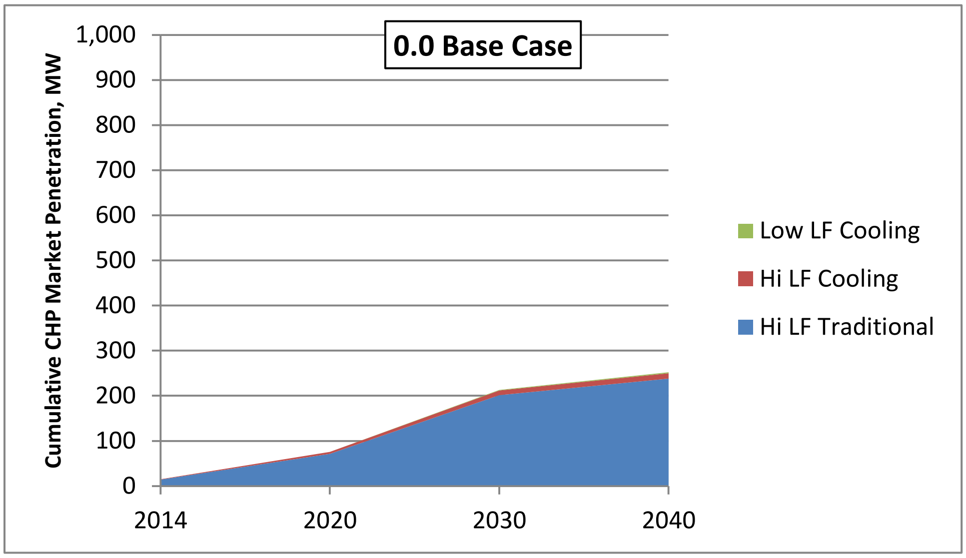
Scenario Number	Utility	2014	2020	2030	2040
0.0	Alliant	0.5	2.6	8.9	11.8
0.0	MN Power	2.5	12.3	43.8	53.1
0.0	Xcel	12.2	60.8	160.3	187.3
0.0	Otter Tail	0.0	0.0	0.0	0.0
0.1	Alliant	0.9	4.3	16.7	23.5
0.1	MN Power	5.7	28.4	87.0	102.6
0.1	Xcel	23.1	115.4	330.1	384.6
0.1	Otter Tail	0.0	0.0	0.0	0.1
0.2	Alliant	2.4	12.2	46.1	67.1
0.2	MN Power	23.2	115.9	306.1	344.6
0.2	Xcel	50.0	250.0	762.8	937.4
0.2	Otter Tail	0.0	0.0	0.0	0.0
1.1	Alliant	0.9	4.5	15.0	20.3
1.1	MN Power	5.3	26.5	76.8	88.8
1.1	Xcel	17.9	89.4	264.1	301.1

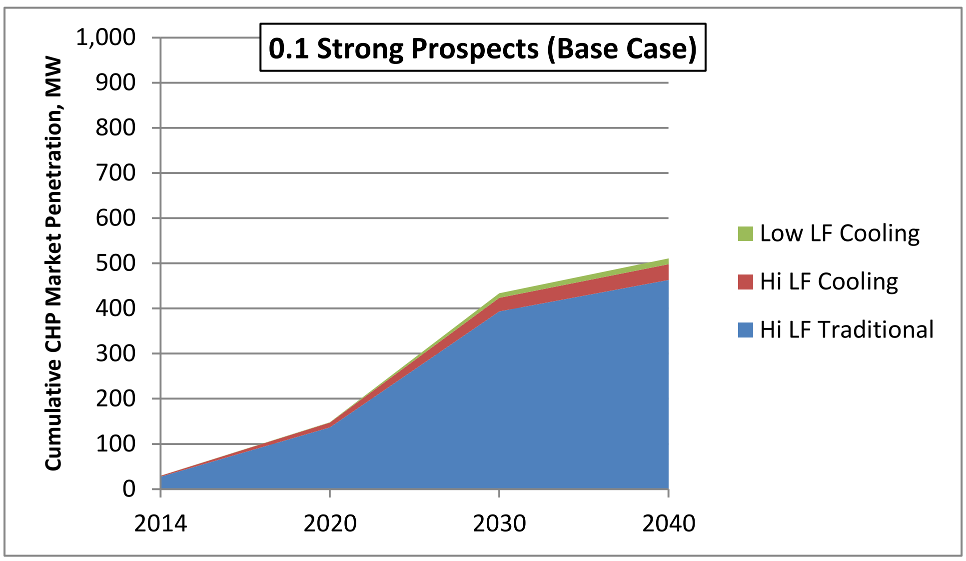
Scenario Number	Utility	2014	2020	2030	2040
1.1	Otter Tail	0.0	0.0	0.0	0.0
1.2	Alliant	0.7	3.6	12.0	14.9
1.2	MN Power	5.3	26.5	70.8	80.1
1.2	Xcel	17.3	86.7	232.1	259.0
1.2	Otter Tail	0.0	0.0	0.0	0.0
1.3	Alliant	1.5	7.3	23.0	28.3
1.3	MN Power	6.8	33.8	99.6	111.6
1.3	Xcel	24.2	121.1	337.8	374.8
1.3	Otter Tail	0.0	0.1	0.1	0.2
2.1	Alliant	1.2	6.1	20.8	28.7
2.1	MN Power	8.6	42.9	109.1	124.2
2.1	Xcel	22.5	112.7	327.2	380.4
2.1	Otter Tail	0.0	0.0	0.1	0.2
2.2	Alliant	1.2	6.2	20.7	23.6
2.2	MN Power	6.8	33.8	87.1	96.4
2.2	Xcel	21.1	105.7	302.2	329.1
2.2	Otter Tail	0.0	0.1	0.3	0.3
2.3	Alliant	2.5	12.3	43.9	51.7
2.3	MN Power	11.2	56.1	147.1	162.2
2.3	Xcel	36.0	180.2	520.3	573.5
2.3	Otter Tail	0.1	0.5	2.3	2.4
3.1	Alliant	4.4	22.1	81.3	102.2
3.1	MN Power	26.0	129.8	334.7	373.3
3.1	Xcel	78.7	393.3	1,228.3	1,402.9
3.1	Otter Tail	0.0	0.0	0.0	0.0
3.2	Alliant	7.1	35.7	135.1	156.0
3.2	MN Power	28.4	142.2	372.4	411.0
3.2	Xcel	95.6	478.1	1,512.7	1,687.3
3.2	Otter Tail	0.3	1.5	6.4	6.4
6.1	Alliant	0.7	3.6	15.5	20.7
6.1	MN Power	5.3	26.5	71.1	83.3
6.1	Xcel	17.0	84.9	247.4	284.5

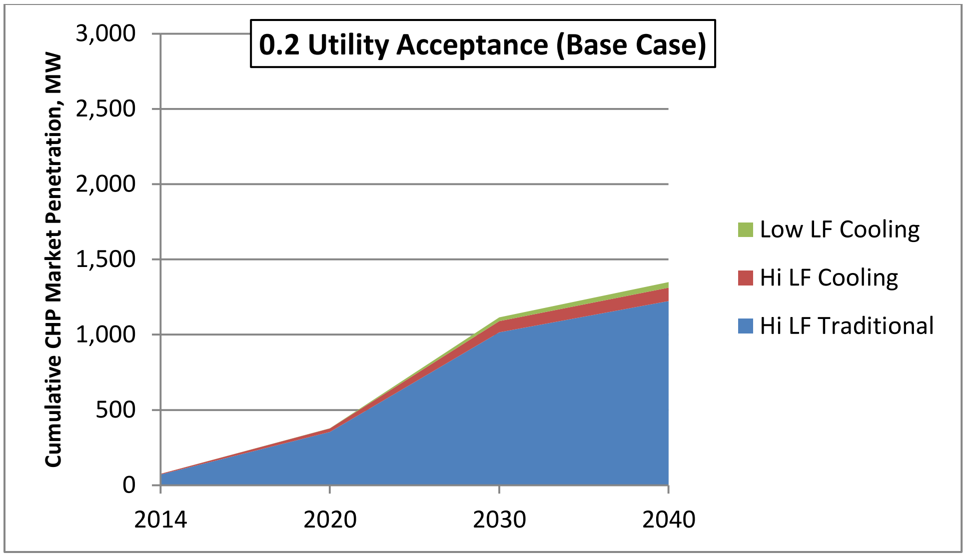
Scenario Number	Utility	2014	2020	2030	2040
6.1	Otter Tail	0.0	0.0	0.0	0.1
6.2	Alliant	1.3	6.6	22.8	29.9
6.2	MN Power	6.8	33.8	92.1	105.4
6.2	Xcel	20.2	100.9	316.6	363.2
6.2	Otter Tail	0.0	0.1	0.4	0.5
6.3	Alliant	1.8	9.0	35.2	43.9
6.3	MN Power	9.2	46.1	120.7	137.6
6.3	Xcel	26.4	131.9	390.4	447.4
6.3	Otter Tail	0.1	0.5	2.2	2.7

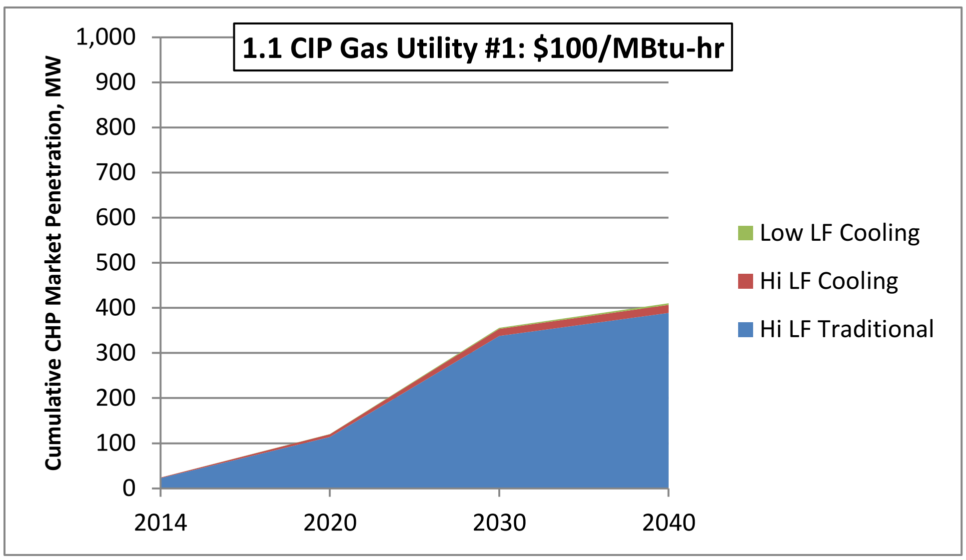
Table A2. CHP Market Penetration by Utility and Scenario

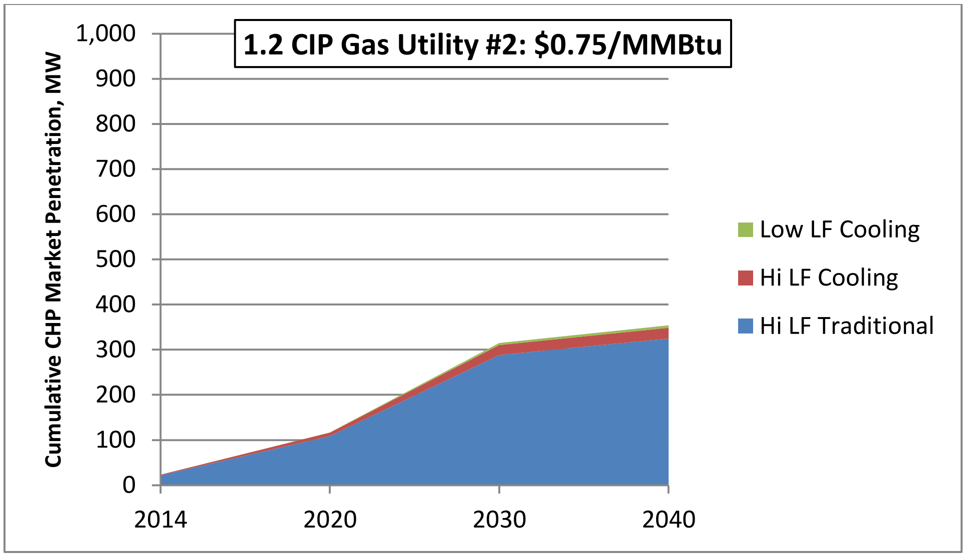
Figures A1-A14. Scenario-specific CHP Market Penetration by Market Segment



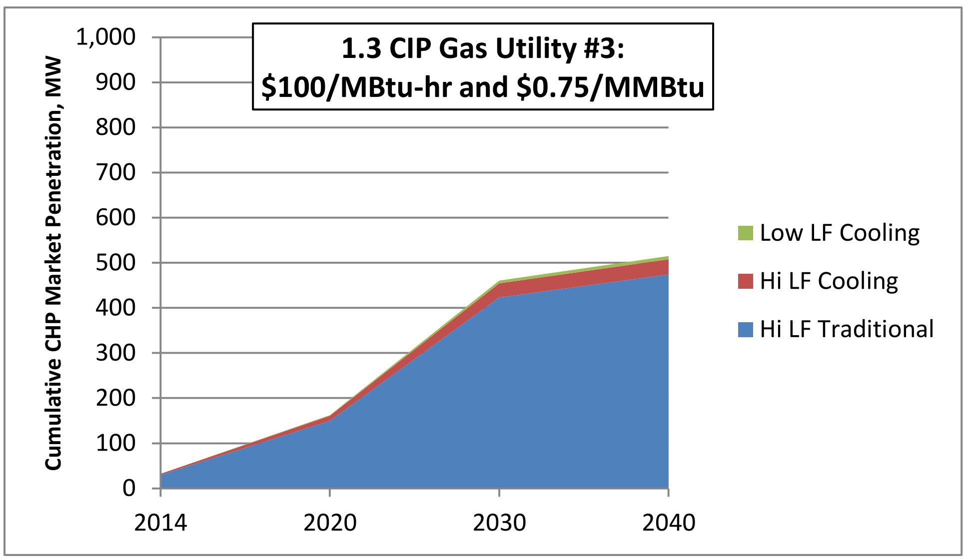



0.2 Utility Acceptance (Base Case)
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional

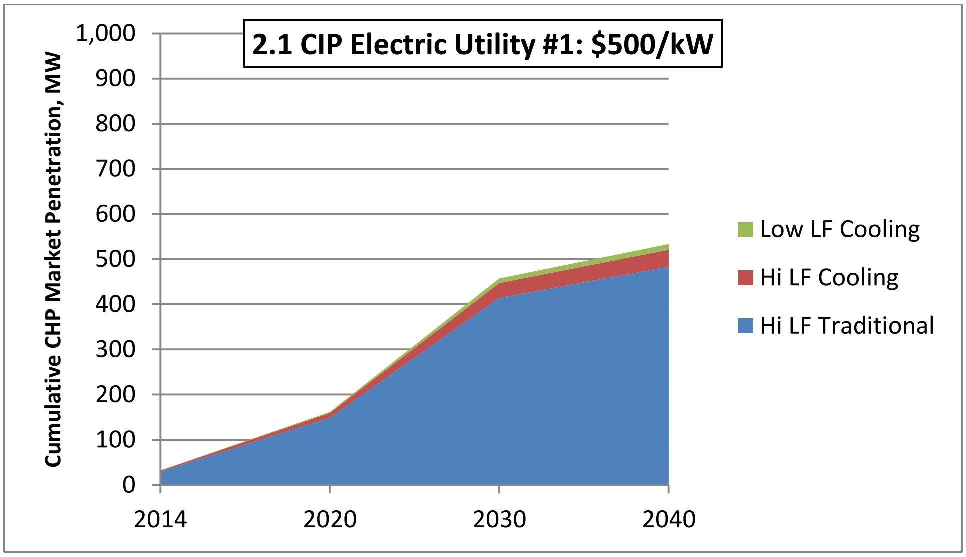

1.1 CIP Gas Utility #1: $100/MBtu-hr
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional

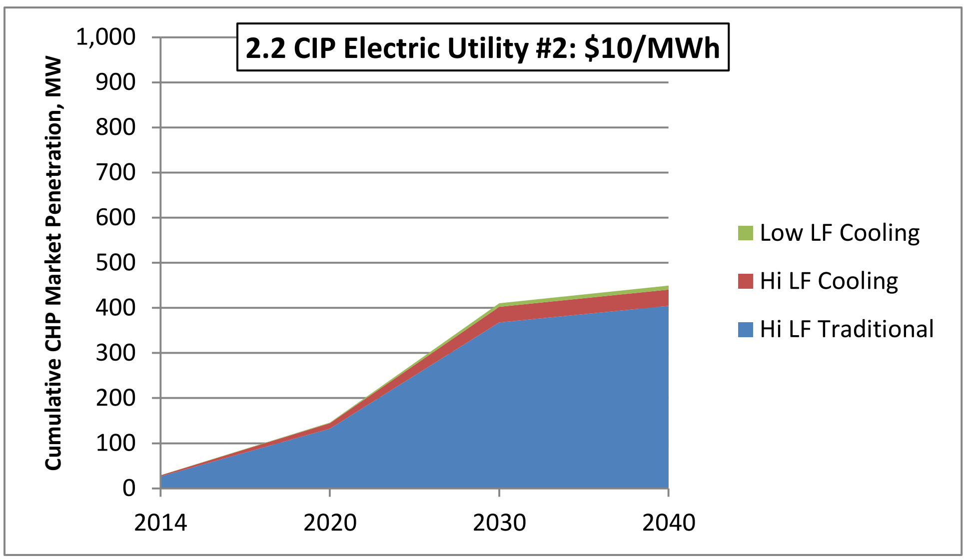


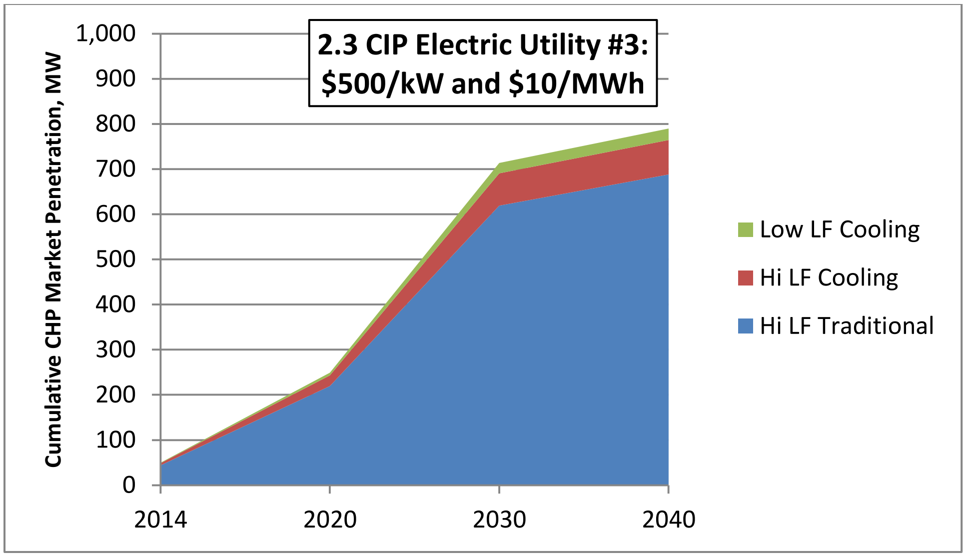
1.2 CIP Gas Utility #2: $0.75/MMBtu
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional

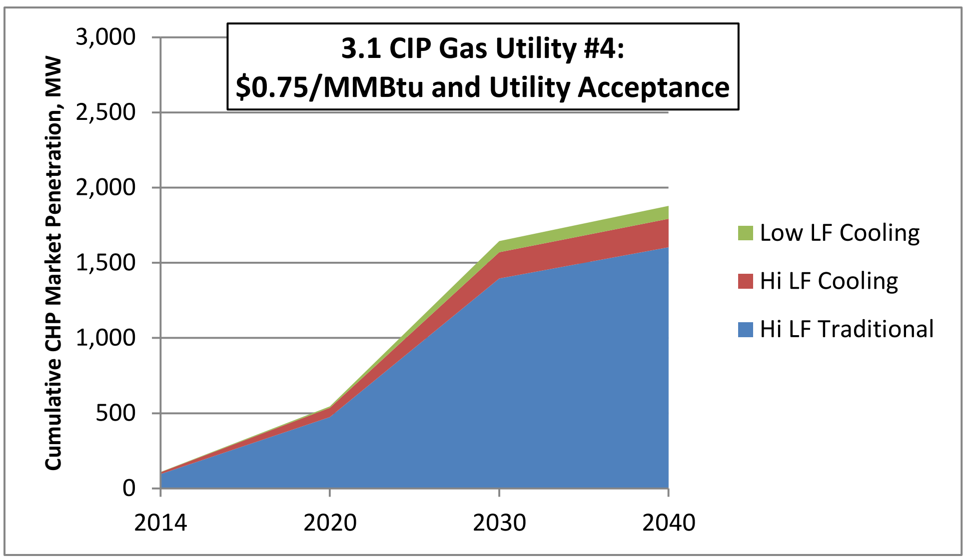


1.3 CIP Gas Utility #3:
$100/MBtu-hr and $0.75/MMBtu
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


2.1 CIP Electric Utility #1: $500/kW
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


2.2 CIP Electric Utility #2: $10/MWh
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


2.3 CIP Electric Utility #3:
$500/kW and $10/MWh
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


3.1 CIP Gas Utility #4:
$0.75/MMBtu and Utility Acceptance
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
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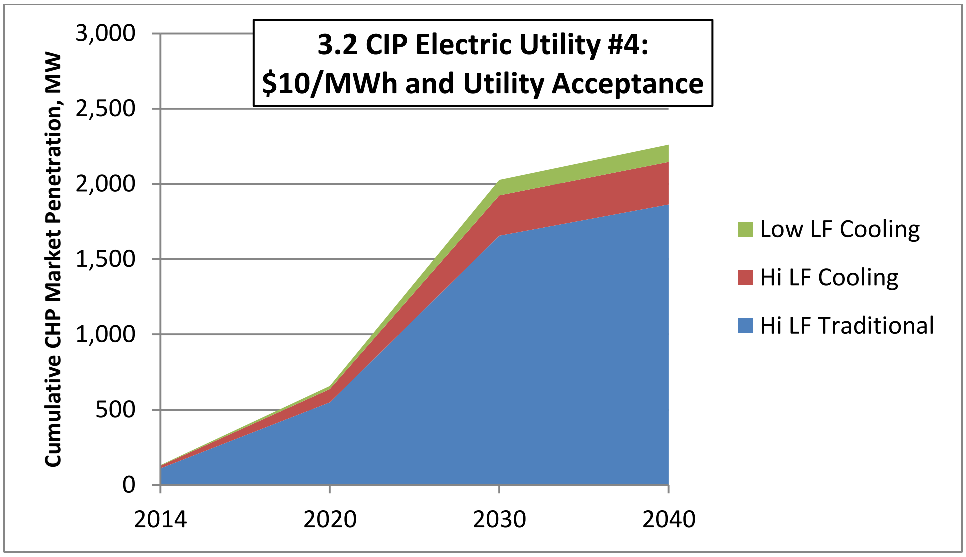
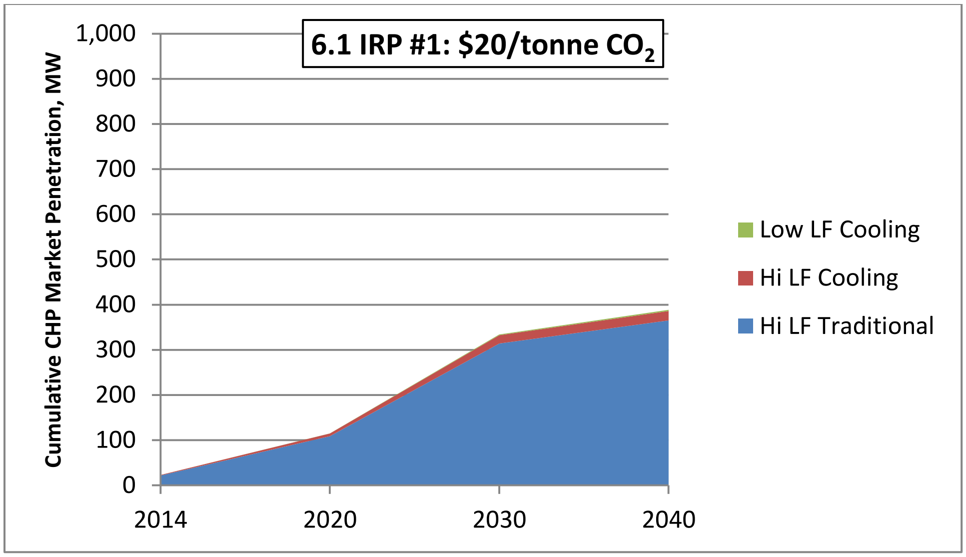
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


3.2 CIP Electric Utility #4:
$10/MWh and Utility Acceptance
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


6.1 IRP #1: $20/tonne CO_2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
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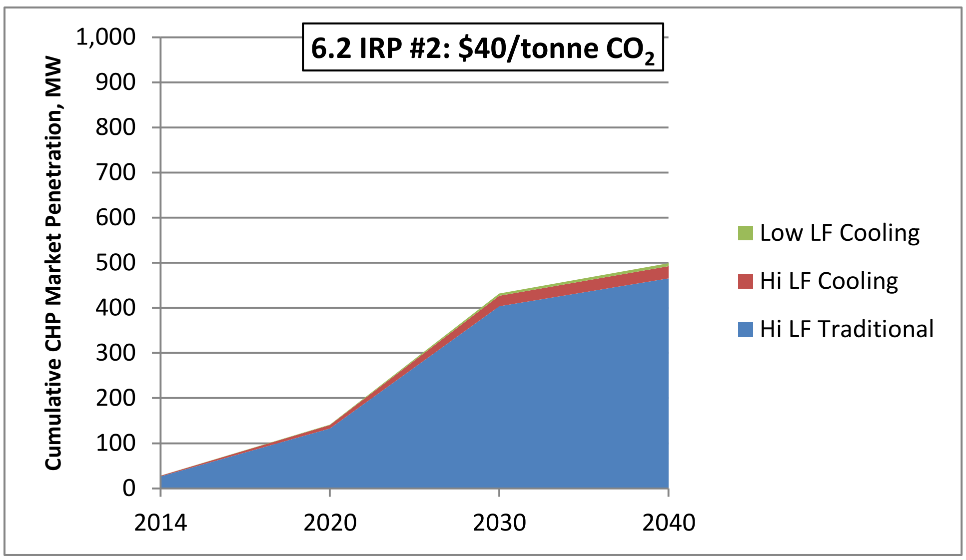
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional


6.2 IRP #2: $40/tonne CO_2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
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100
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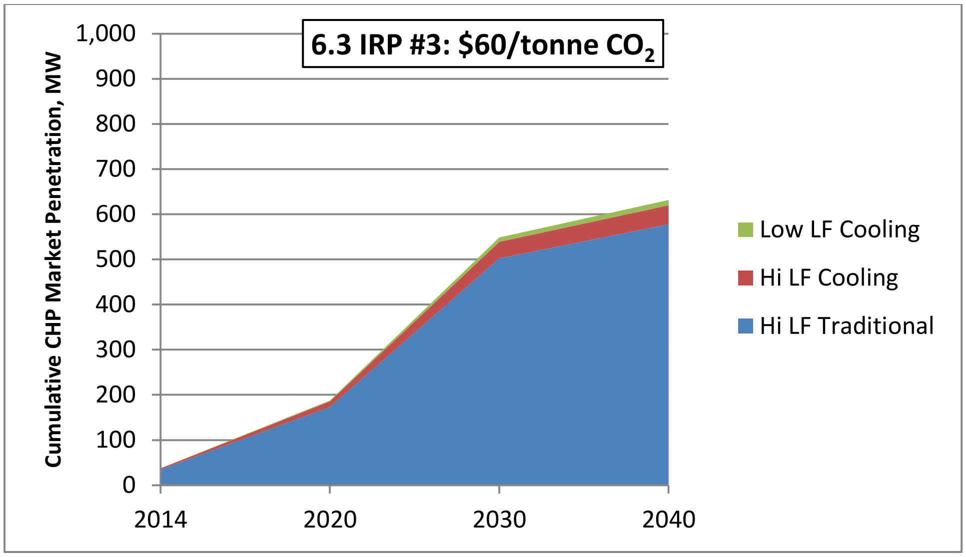
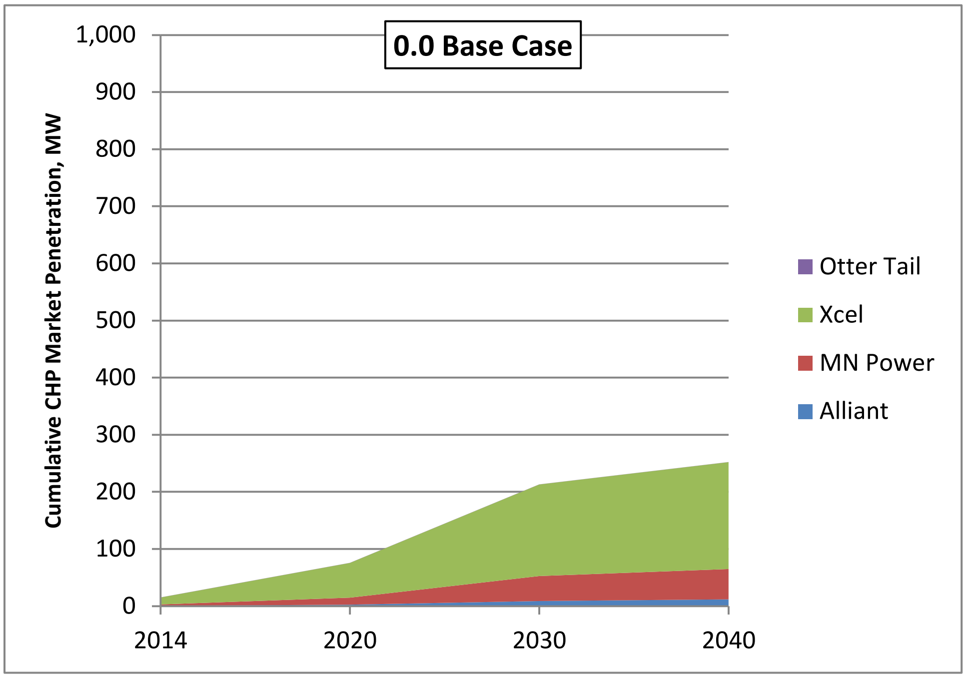
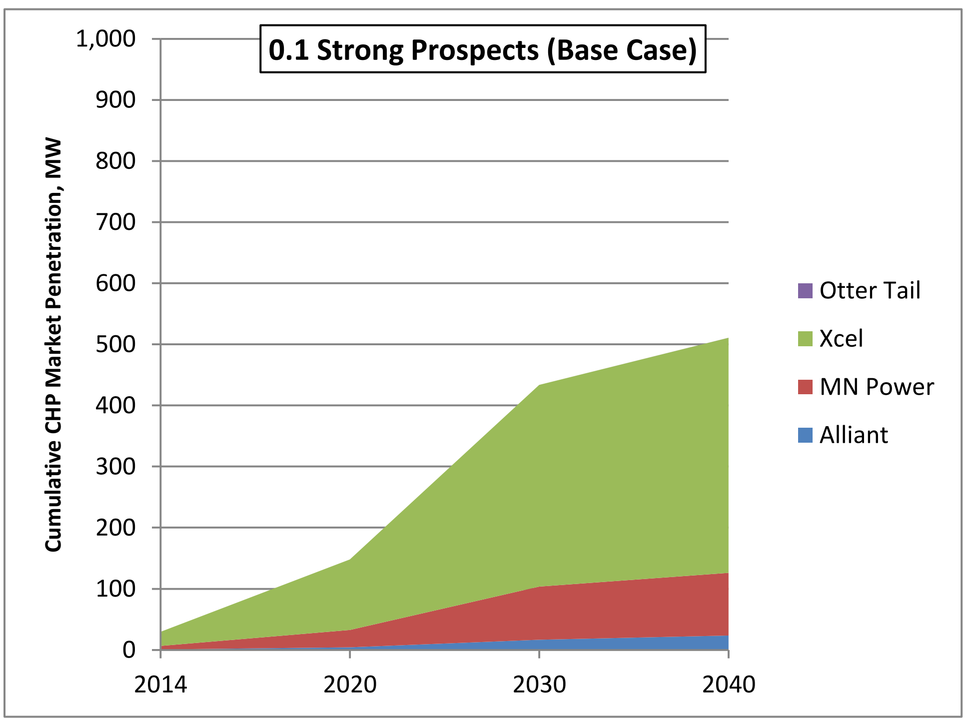
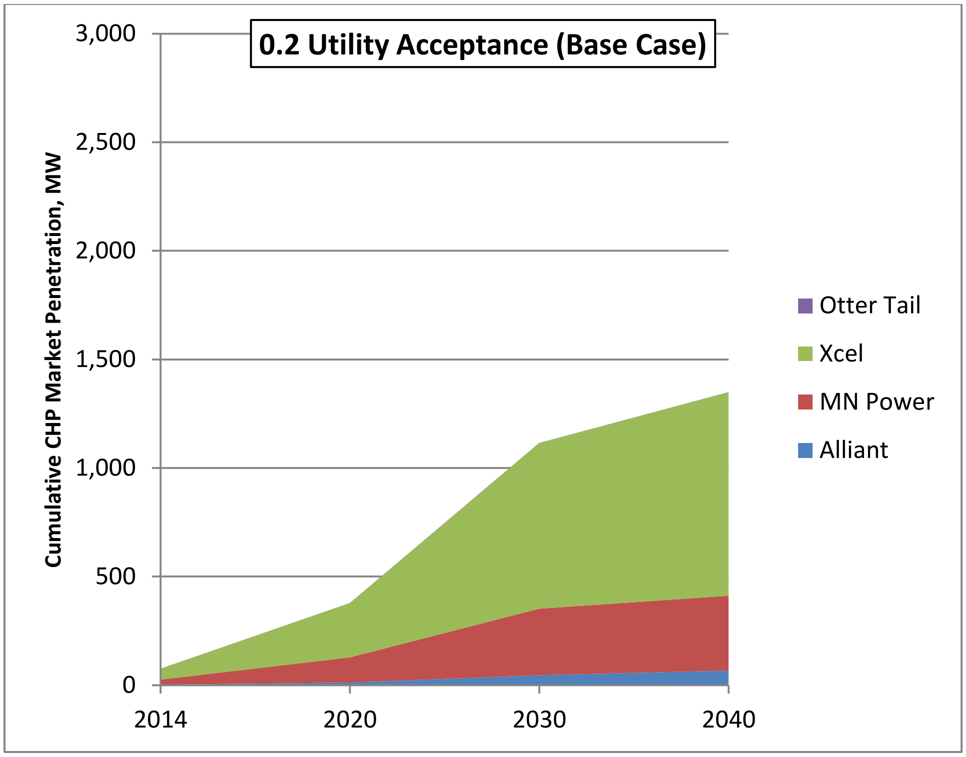
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional

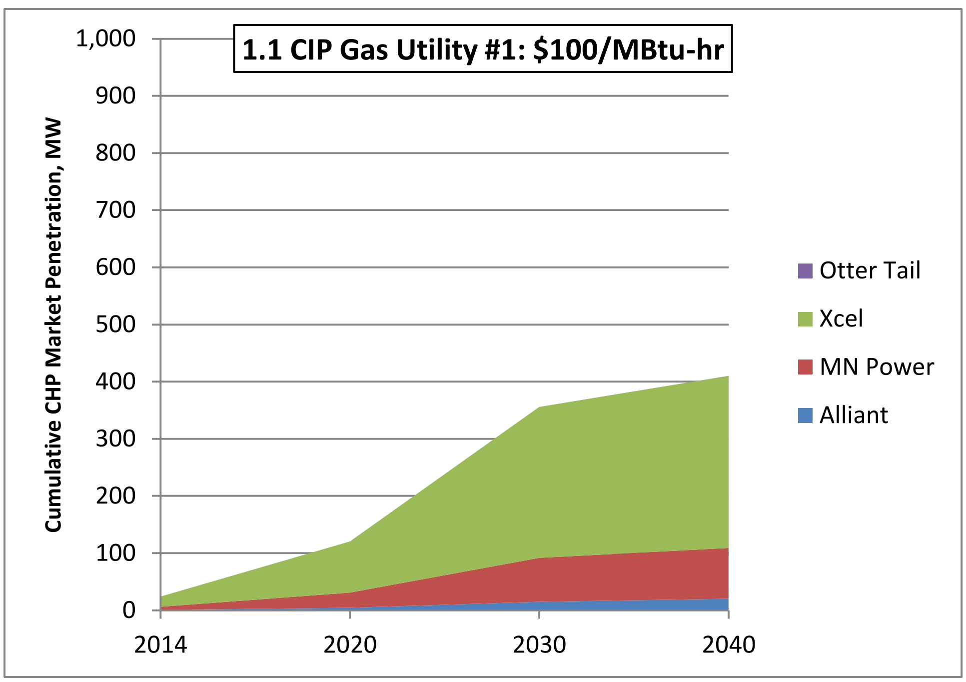

6.3 IRP #3: $60/tonne CO2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Low LF Cooling
Hi LF Cooling
Hi LF Traditional

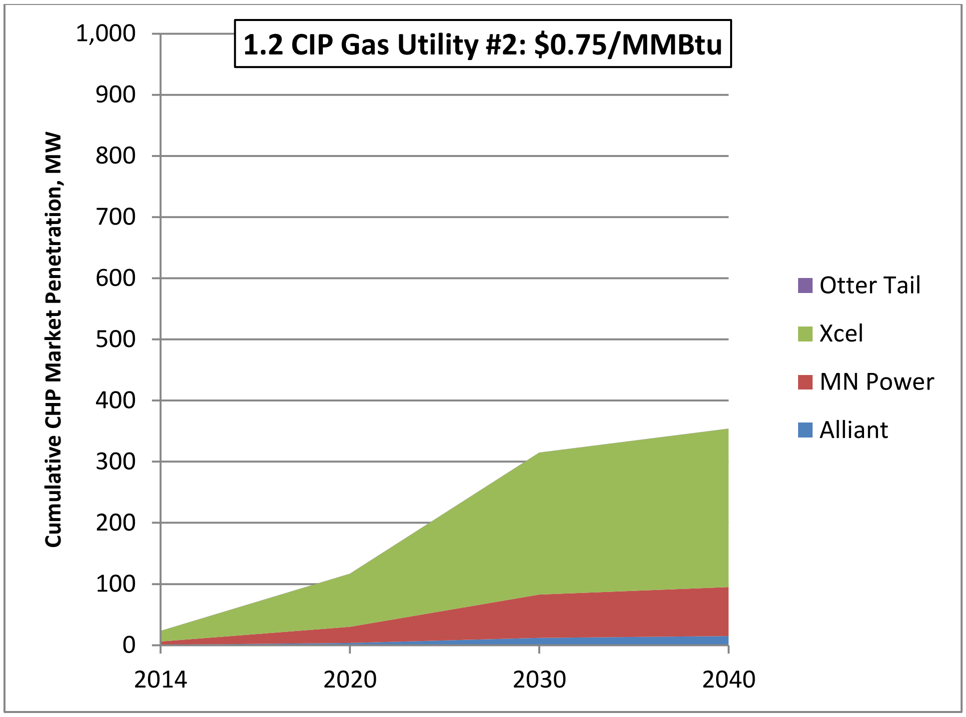
Figures A15-A28: Scenario-specific CHP Market Penetration by Utility

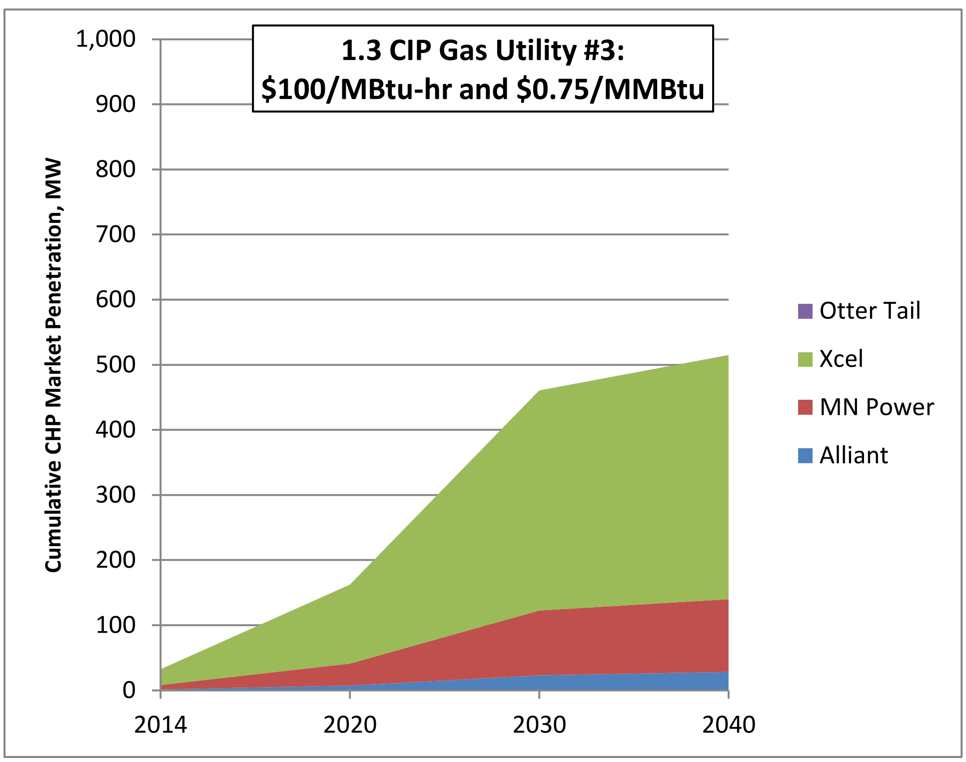


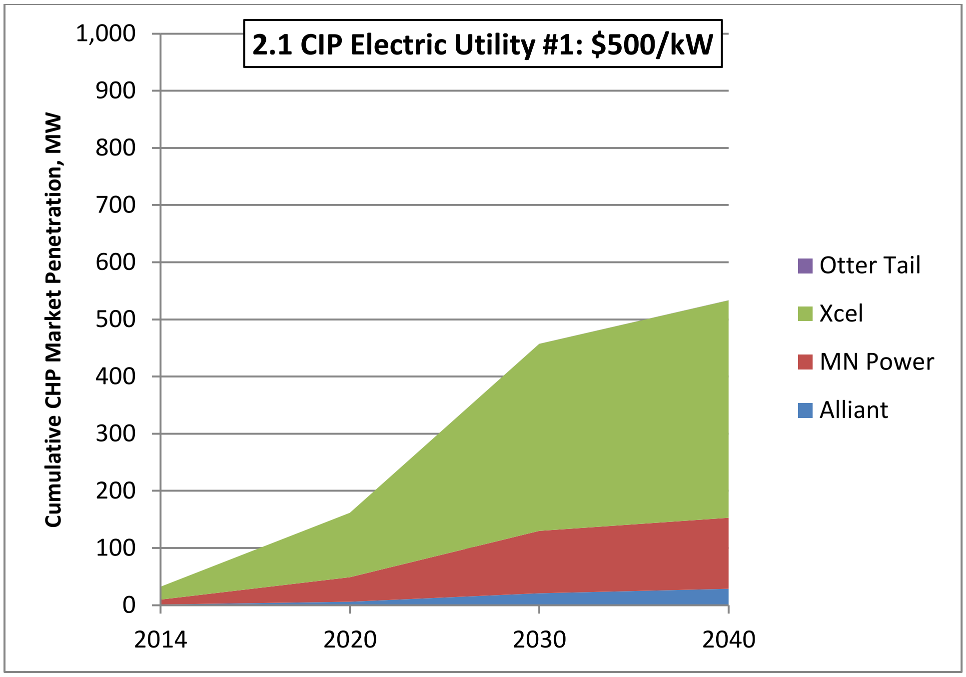


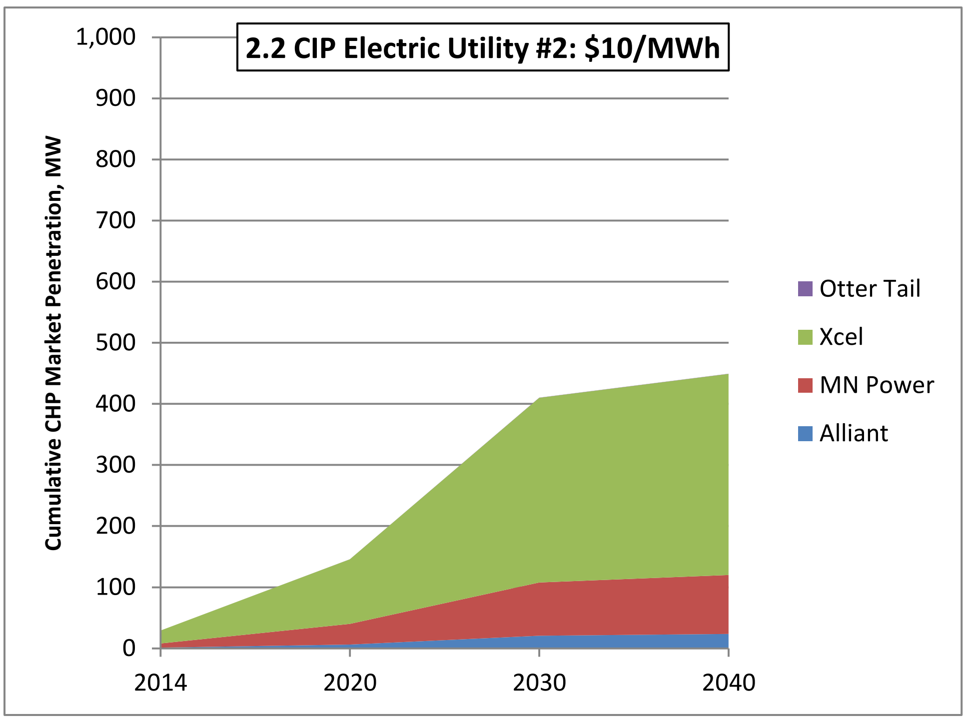

0.2 Utility Acceptance (Base Case)
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant

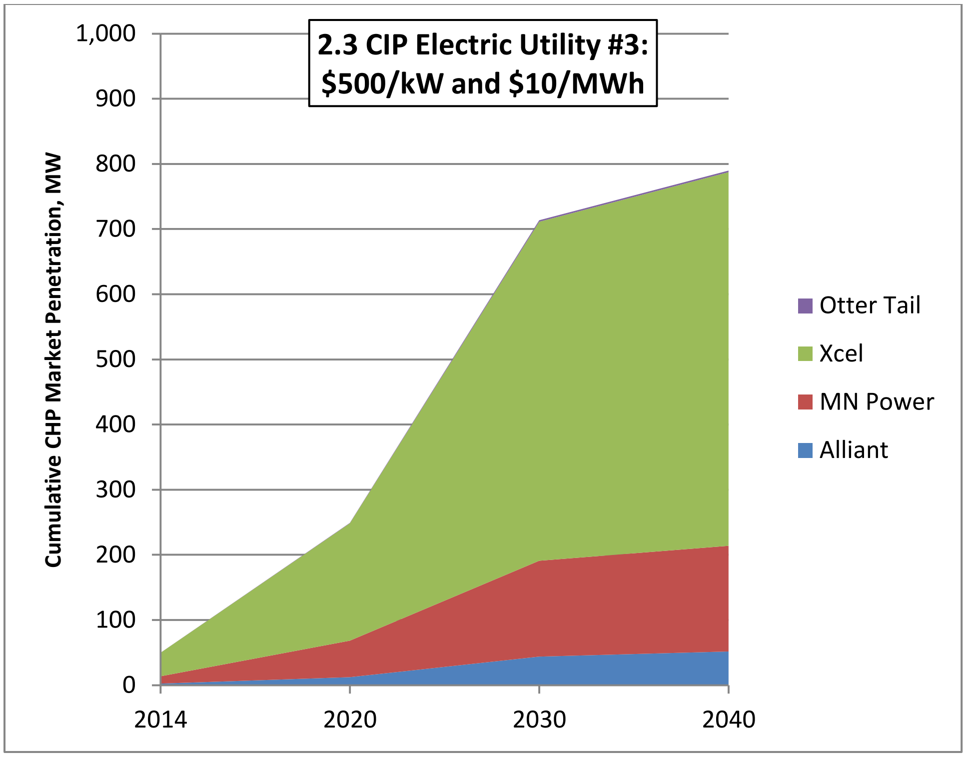

1.1 CIP Gas Utility #1: $100/MBtu-hr
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


1.2 CIP Gas Utility #2: $0.75/MMBtu
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant

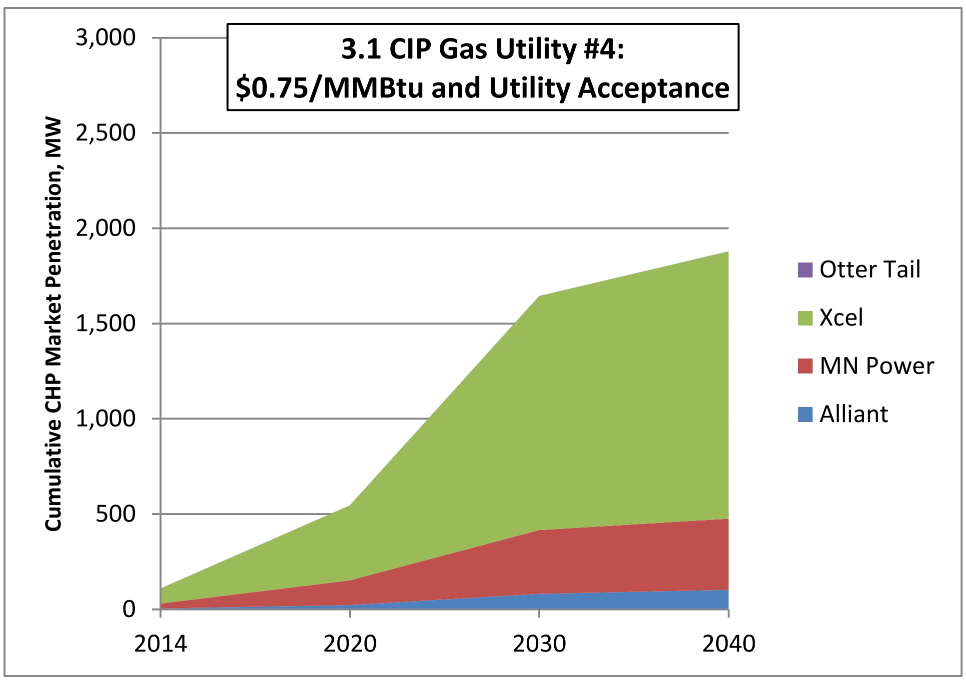

1.3 CIP Gas Utility #3:
$100/MBtu-hr and $0.75/MMBtu
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


2.1 CIP Electric Utility #1: $500/kW
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant

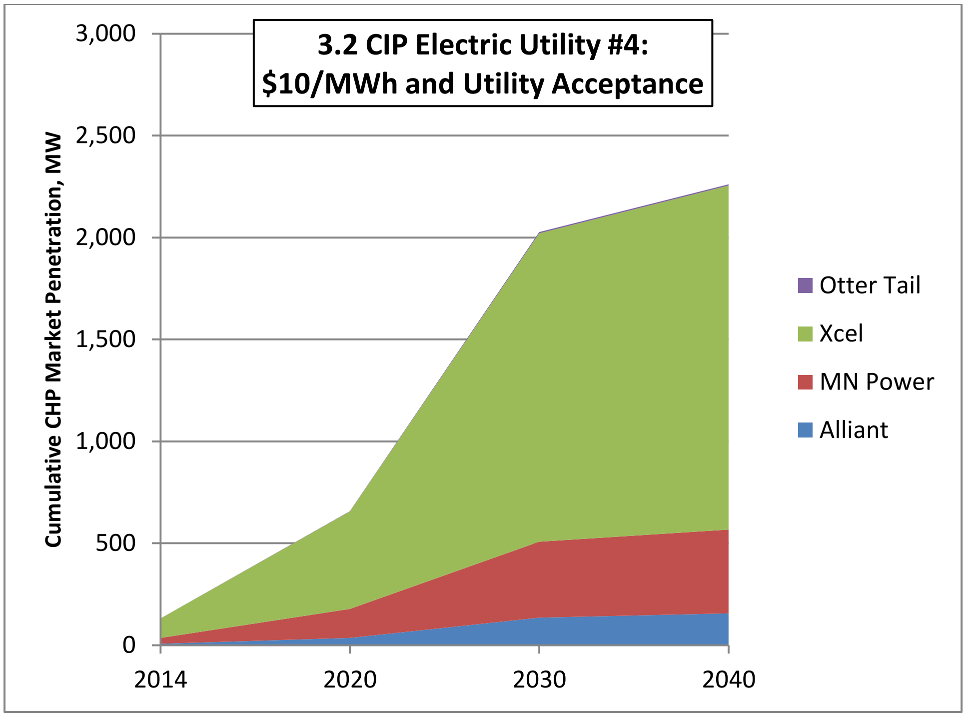

2.2 CIP Electric Utility #2: $10/MWh
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant

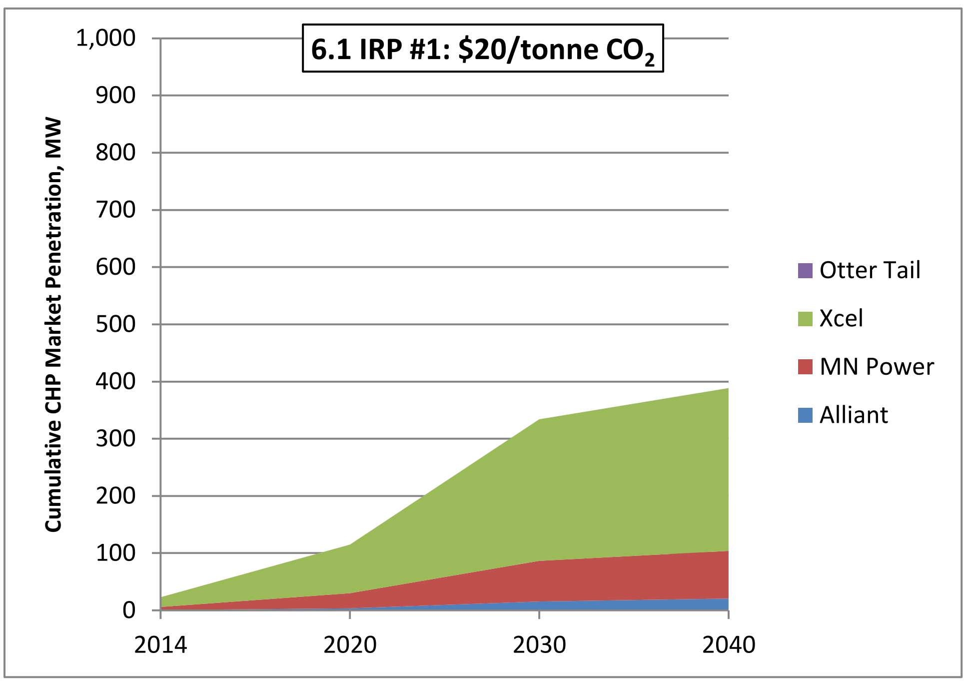


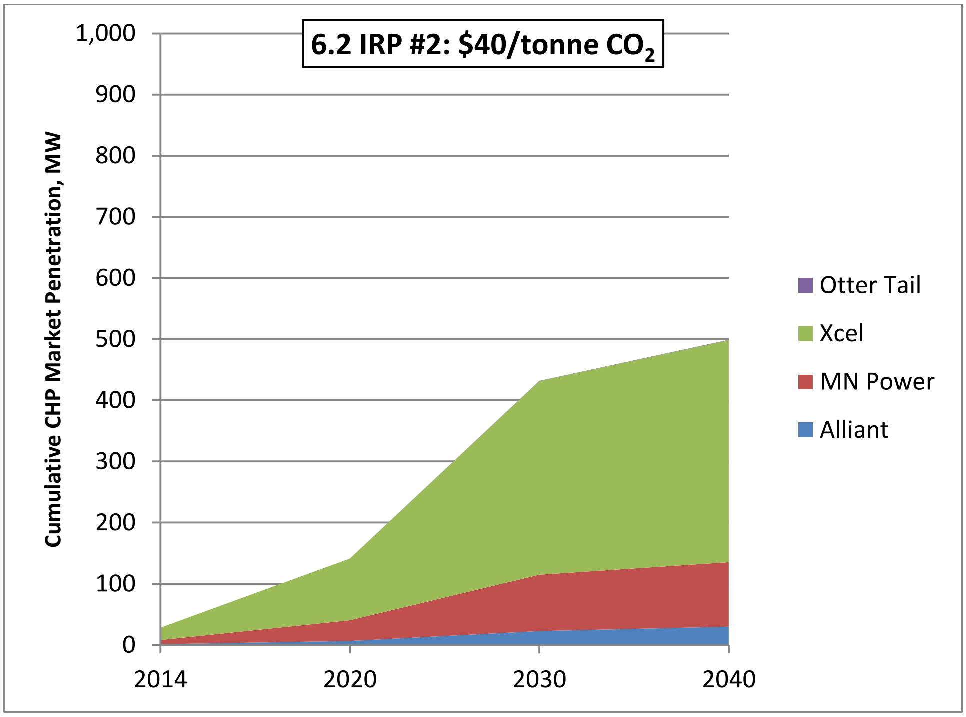
2.3 CIP Electric Utility #3:
$500/kW and $10/MWh
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant

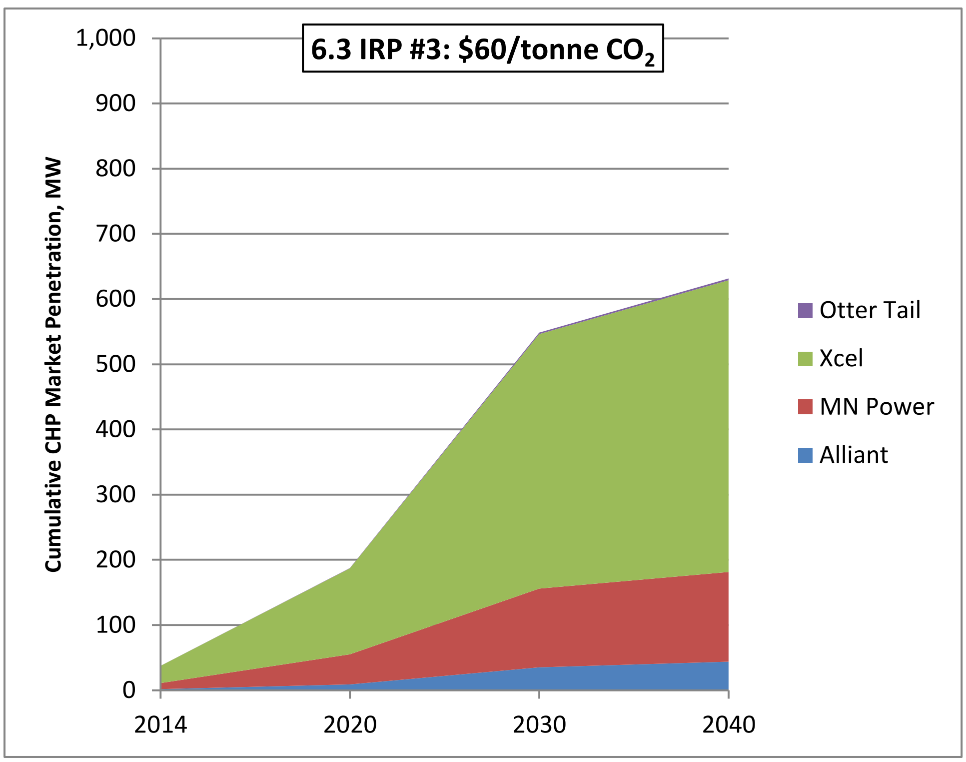


3.1 CIP Gas Utility #4:
$0.75/MMBtu and Utility Acceptance
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


3.2 CIP Electric Utility #4:
$10/MWh and Utility Acceptance
Cumulative CHP Market Penetration, MW
3,000
2,500
2,000
1,500
1,000
500
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


6.1 IRP #1: $20/tonne CO_2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


6.2 IRP #2: $40/tonne CO2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant


6.3 IRP #3: $60/tonne CO2
Cumulative CHP Market Penetration, MW
1,000
900
800
700
600
500
400
300
200
100
0
2014
2020
2030
2040
Otter Tail
Xcel
MN Power
Alliant