REVIEW OF A POPULATION OF IMPLEMENTED COMBINED HEAT AND POWER PROJECTS

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ABSTRACT

Combined heat and power (CHP) projects have been growing in popularity in Maine because they can reduce facility energy costs while improving resiliency and reducing/eliminating dependence on grid-supplied electricity. Cost savings are driven by improved total efficiency versus traditional utility-scale power generation; the thermal energy associated with power generation in a CHP project can be recovered and used on-site, offsetting the energy use associated with heating loads. This paper characterizes the implementation gaps between successful and unsuccessful proposals as submitted to a state energy efficiency program using example implementations. The authors reviewed CHP proposals to identify the criteria and metrics associated with successful proposals. Common criteria associated with successful implementation are identified, as are the common obstacles associated with projects that were not successfully implemented. Using retrospective calculations, the authors identify facilities that are good candidates for CHP, comparing the metrics to project implementation to assess the implementation accuracy.

INTRODUCTION

The promotion of CHP technology and its use in the industrial sector has grown in recent years through the Environmental Protection Agency (EPA) Combined Heat and Power (CHP) Partnership program and various federal acts that have promoted the implementation of these systems through tax credits and policy initiatives. A 2012 executive order specifically promotes CHP in industrial facilities with the goal of installing 40 gigawatts of new, cost-effective CHP by the end of 2020. These efforts extend to the state level, with CHP systems addressed in many energy and environmental policies, standards, and regulations – many of which include tax credits, monetary incentives/rebates, and loan programs. The Department of Energy's (DOE's) CHP Policies and incentives database (dCHPP) lists 132 state and federal energy, environmental, and portfolio standards, policies, plans, and regulations that address CHP installations, as well as 167 state and federal rebate, incentive, grant, loan, and tax benefit programs.

Despite this promotion, the number of CHP installations as tracked by the Department of Energy (DOE) Combined Heat and Power Database (Database) has been decreasing over the last 10 years[1]. Figure 1 presents a plot of the Database information for the years 2005-2015.

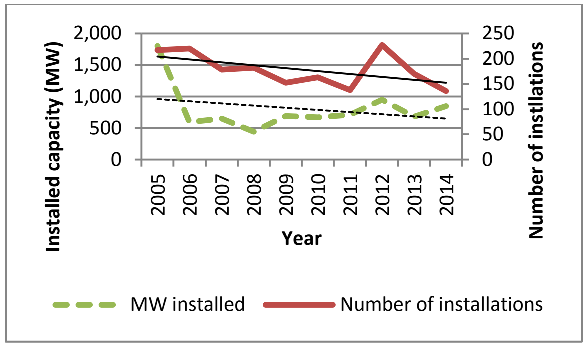

Figure 1. National CHP installations, 2005–2015

This decline in CHP installations follows decades of substantial CHP growth between the 1980s and 2005. The catalyst for this growth was the Public Utility Regulatory Policies Act (PURPA) of 1978, which created favorable regulations and economic conditions for CHP installations. The plot of CHP installation data for the PURPA era is presented in Figure 2.

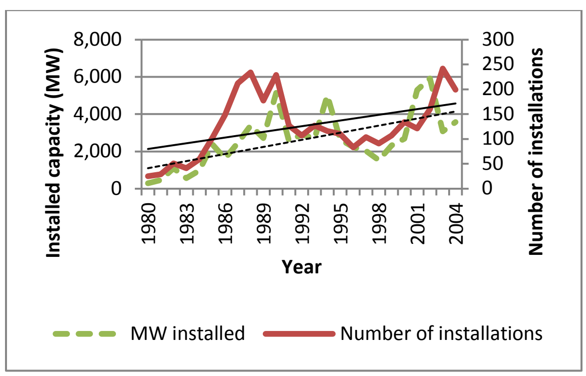

Figure 2. National CHP installations, 1980–2004

[1] From June 1, 2005, through June 1, 2015

PURPA, combined with technological advancements in CHP systems, led to the creation of large CHP facilities that essentially operated as utility-scale power plants but without many of the regulations(4). There are several factors that combined in 2005 to result in the downward trend in installations that can be seen in Figure 1, above. Revisions to PURPA, the continued deregulation of utilities, and high and volatile gas prices due to natural disasters and economic uncertainty brought utility-scale CHP to an end (4). Of further note in Figures 1 and 2, above, is the difference in the average size of CHP units installed before and after 2005. Figure 3 illustrates this observation.

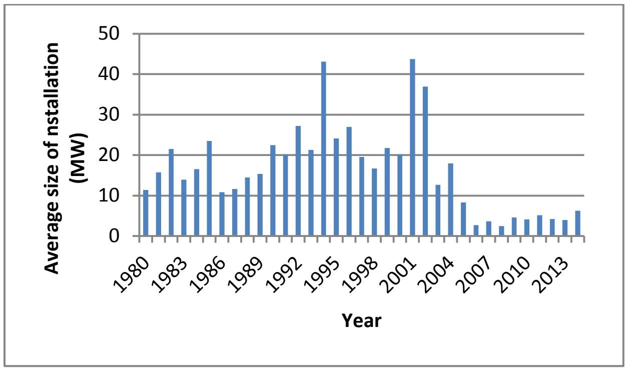

Figure 3. Average capacity of installed units, 1980–2015

The impact of economic conditions, fuel cost, and regulatory changes in 2005 and 2006 are clearly displayed; the average capacity per installation between 1980 and 2005 was 20.7 MW. The average capacity per installation between 2005 and 2015 was 4.1 MW – an 80% reduction.

Despite the downward trend in total installations, the average number of CHP installations per year has increased from pre-2005 levels. Between 1980 and 2005, there was an average of 129 CHP installations per year. Between 2005 and 2015, the average was 174 installations per year. The trend of more numerous, smaller CHP installations is credited to several factors including the desire for resiliency, an interest in greenhouse gas emissions reductions, and state support of growth for behind-the-meter installations (1).

Over the same time period, interest and installations of CHP systems in Maine have been increasing, with twenty-nine CHP projects having been proposed to the Efficiency Maine Trust since 2009. Not all of these projects were implemented, and several are still in the proposal stage.

Efficiency Maine Programs

The Efficiency Maine Trust is the state's independent administrator of energy efficiency programs. Efficiency Maine's mission is to lower the cost and environmental impacts of energy in Maine by promoting cost-effective energy efficiency and alternative energy systems. Efficiency Maine began incentivizing CHP systems in 2009 with funding from the American Recovery and Reinvestment and Act of 2009. Their involvement in promoting CHP continued through their Large Customer Program (the Program), which provided technical assistance and cash incentives to promote new and cost-effective behind-the-meter CHP installations. The Program supports up to 50% of the project costs at an incentive rate of $0.28/kWh with a cap of $1,000,000 for behind-the-meter CHP projects.

Project Population

The Program has seen a range of application types and technologies including reciprocating internal combustion (IC) engines, backpressure steam turbines (BPT), condensing extraction steam turbines, and an organic Rankine cycle unit powered via waste heat from a biogas-fueled IC engine. Units are fired by natural gas (NG), biomass, and biogas generated from anaerobic digestion processes. System sizes range from 75 kW to 10,000 kW with project costs ranging from $300,000 to $5M and up. A summary of the project characteristics is presented in Table 1.

ID	Type	Size (kW)	Status	Fuel Type
1	Trigen IC engine	150	Implemented	NG
2	Anaerobic digester and IC engine	1,000	Implemented	Biogas
3	IC Engine	150	Implemented	NG
4	IC Engine	250	Not implemented	NG
5	BPT	600	Not implemented	Biomass
6	BPT	315	Not implemented	
10	BPT	1,980	Not implemented	NG
11	IC Engine	75	Not implemented	NG
15	IC Engine	75	Implemented	NG
16	Anaerobic digester and IC engine	460	Implemented	Biogas
17	BPT	400	Implemented	NG

ID	Type	Size (kW)	Status	Fuel Type
18	BPT	600	Implemented	Biomass
19	BPT	600	Implemented	Biomass
20	BPT	450	Implemented	Biomass
21	Trigen IC engine	250	Not implemented	NG
22	Anaerobic digester and IC engine	1,000	Implemented	Biogas
24	Condensing extraction steam turbine	10,000	Implemented	Biomass
25	IC engine with ORC heat recovery generation	760	Implemented	Biogas
26	Trigen IC engine	200	Not implemented	NG
27	Trigen IC engine	65	Not implemented	NG

Table 1. Project population characteristics

DATA ANALYSIS

This section presents the approach and findings of the analysis.

Analysis Approach

The authors reviewed the project files for each CHP proposal that has been submitted to Efficiency Maine since 2009. Projects were included in the analysis when sufficient information existed in the file to assess the baseline and proposed energy use, thermal efficiency of the proposed system, and fuel costs for the specific location. As such, the projects in the analysis include projects that have been built and those that have not moved forward but were analyzed.

The authors sought to compare the results of two "rule of thumb" tests to the reality of CHP installations. In other words, how do the results of a high-level screening align with the actual project implementation? The two rules of thumb considered were the EPA's spark spread (SS) estimator tool[2], which recommends further investigation of potential projects when the tool calculates a positive SS value, and a fuel cost ratio (FCR) test of the electrical power cost to fuel cost.

[2] https://www.epa.gov/sites/production/files/2015-09/spark_spread_estimator.xlsm

The EPA SS estimator uses site-specific inputs to estimate the total cost of on-site power generation and compare it to the cost of fuel. Per the tool documentation, "Spark spread is the difference per kilowatt-hour (kWh) between the current delivered electricity price and the total cost to generate power with a CHP system. A numerically positive spark spread result indicates that the CHP project returns more than the cost of capital. The greater the spark spread, the higher the potential return on investment" (3). It should be noted that the EPA emphasizes that this estimator is for preliminary assessment only; a positive SS value only indicates that the facility might benefit from a CHP system and that further detailed investigation is warranted. The tool lacks the granularity needed to identify the coincidence of peak electrical or thermal demand and CHP system supply.

The second rule of thumb concerns the FCR of grid-supplied electricity to the cost of fuel, both expressed in $/MMBtu. If this ratio is greater than 4, the project is considered to be a good candidate for further investigation (2).

Neither approach is used by the Efficiency Maine program, which conducts rigorous assessments of the proposed projects using third-party engineering firms to assess the eligibility of the projects as they relate to Program participation rules. The approach typically consists of hourly analyses making use of historic site-specific energy and cost data and manufacturer-specific dynamic performance curves for the proposed systems. The Efficiency Maine review is substantially more rigorous then the high-level rules of thumb.

Findings

The findings compare the SS and FCR values to the project implementation and provide insight into why some projects with favorable SS and FCR values did not move forward and why some with unfavorable values were implemented. Table 2 provides a list of projects, their implementation status, and their SS and FCR values. The highlighted cells indicate favorable SS and FCR values.

Project ID	SS	FCR
Implemented		
1	-0.028	3.5
3	0.029	5.0
15	-0.006	3.6
17	0.046	4.2
18	0.051	7.3
20	0.084	8.8
24	0.032	6.5

Project ID	SS	FCR
Not implemented		
4	-0.045	1.7
5	-0.004	5.3
10	0.031	4.1
11	-0.011	2.6
21	No CHP	3.7
26	0.010	4.3
27	No CHP	5.5

Table 2. SS and FCR values for project population

Implemented projects.

Of the seven implemented projects that were reviewed, five had positive SS and favorable FCR values and two had negative SS and unfavorable FCR values. Projects 1 and 15 both failed the high-level rule-of-thumb screening but passed the Efficiency Maine screening and their internal requirements for cost effectiveness. Both of these installations are in municipal facilities, though it is difficult to identify if that similarity is meaningful.

The fuel type used in the implemented projects plays an important role in the SS and FCR values. Of the seven implemented projects, four are NG and three are biomass. The biomass projects are located at lumber/pulp and paper facilities, where their cost per MMBtu of energy is 40%–60% lower than the cost per MMBtu of projects implemented with NG. Table 3 provides a summary of the SS and FCR values for implemented projects broken out by fuel type.

Project ID	SS	FCR
Biomass		
18	0.051	7.3
20	0.084	8.8
24	0.032	6.5
Average	**0.056**	**7.5**
NG		
1	-0.028	3.5
3	0.029	5.0
15	-0.006	3.6
17	0.046	4.2
Average	**0.010**	**4.1**

Table 3. SS and FCR values by fuel type for implemented projects

Biomass-fueled projects have higher SS and FCR values than NG projects and higher benefit-cost-ratio values than the NG projects when screened with Efficiency Maine's benefit-cost-ratio tool. The more favorable metrics produced by the biomass projects are a function of the fuel cost and facility operation.

The biomass-fueled facilities require large quantities of steam for their process operations and run for 90%–95% of the year. They take advantage of the existing infrastructure and thermal loads to size the steam turbine systems for thermal load-following. The high thermal demands and long run times result in higher overall thermal efficiency, which translates into a more economical use of fuel. Additionally, these facilities are located in the heart of Maine's timber and lumber industry (a substantial geographic portion of the state) and consume large volumes of biomass. Their proximity to the fuel source and large-volume orders result in lower fuel costs in terms of $/MMBtu.

Non-implemented projects.

Of the seven reviewed projects that were not implemented, two had a positive SS and favorable FCR, and one had a negative SS but a favorable FCR. Table 4 provides a breakout of these by fuel type.

Project ID	SS	FCR
Biomass		
5	-0.004	5.3
Average	**-0.004**	**5.3**
NG		
4	-0.045	1.7
10	0.031	4.1
11	-0.011	2.6
21	No CHP	3.7
26	0.010	4.3
27	No CHP	5.5
Average	**-0.004**	**3.6**

Table 4. SS and FCR values by fuel type for non-implemented projects

The "No CHP" indicator in Table 4, above, for the SS of projects 21 and 27 indicates that the EPA SS estimator does not recommend CHP for this given location. Each of the projects is detailed in the following sections.

Project 5.

Although this project has not been implemented yet, a detailed study was recently completed; the owner is reviewing it to determine if they will proceed. The proposal is for a BPT at a lumber mill with year-round heating loads from the presence of lumber drying kilns. The capital costs of this project were significantly higher than those estimated by the EPA SS estimator because of the need for a retrofit of one of the kilns' steam coils and a larger boiler to drive the proposed 600 kW BPT. The SS is not positive because of the low electric rate ($0.72/kWh) but still has a favorable FCR because of the low fuel costs ($4/MMBtu). In agreement with the marginally positive SS and FCR results, the customer has decided to request bids and submit an application for project funding.

Project 4.
A detailed study was also recently completed for this project. The study proposes the installation of a 250 kW CHP unit at a hospital facility. Year-round thermal loads are favorable for CHP, but the negative SS and 1.7 FCR indicate less-than-favorable fuel cost economics. This was also visible in the relatively high simple payback before the incentive of 10 years. The customer has indicated that they will not pursue the project under current conditions.

Project 10.
This project screening resulted in favorable metrics. An incentive was awarded by Efficiency Maine in support of the installation, but the site has not proceeded. It is understood that the business was undergoing a period of growth and did not want to expend capital on a CHP system at that time. The facility has a proven record of commitment to energy efficiency and is likely to revisit this project in the near future.

Project 11.
This 75 kW installation is in development at a small hospital. Similar to projects 5 and 4, a detailed study was completed to establish the project economics. A negative SS and an FCR of less than 4 indicated unfavorable economics, which was confirmed by the 13.6 years of simple payback before any potential incentive. However, the customer has decided to pursue the project because of their interest in power resiliency and long-term efficiency goals.

Project 21.
This project entailed the creation of a small district heating area. A municipal facility would install a CHP system to serve their own thermal and electrical loads and would sell additional thermal and electrical energy to several manufacturing and warehousing sites in the immediate vicinity. As the sales arrangements had not yet begun, the economics and performance of the project had to be based on the verifiable impact of the CHP system, meaning that only the loads at the municipal facility could be considered in the analysis. The relatively low thermal demands of the facility resulted in poor metrics. The EPA SS estimator identified this site as a poor candidate for CHP.

Project 26.
This project at a beverage distribution center included the installation of a single-effect absorption chiller to use the thermal capacity of the CHP unit during the summer. The SS and FCR were already marginal for this project, and the additional cost and limited efficiency of the absorption chiller further exacerbated the project economics.

Project 27.
This project was proposed at a relatively small brewing facility that had year-round cooling loads for their coolers but limited thermal demands. An absorption chiller was proposed to fully use the thermal capacity of the CHP unit during the summer. Because of the facility's small thermal needs, the EPA SS estimator did not recommend CHP for this facility.

CONCLUSION

The rules of thumb SS and FCR values are both good indicators of a project's economic attractiveness over a range of facility types and project technologies and generally results in a more conservative assessment of a project's economic viability than the more rigorous analysis performed by Efficiency Maine. The authors have found the rules of thumb – SS greater than 0, and FCR greater than 4 – to be good indicators of how projects will perform as related to the project qualifying criteria of the Efficiency Maine program. The rule-of-thumb metrics successfully predicted which projects would be and would not be implemented 71% of the time. In most instances where the metrics did not accurately predict implementation, there are atypical circumstances that impact the project economics or motivations beyond economics, such as resiliency and environmental stewardship.

While this review demonstrates the usefulness of the metrics in the high-level assessment of candidates' projects, it also reinforces what is already known about successful CHP installations. Each proposed installation must be carefully analyzed with granular, site-specific data. Despite this, these rules of thumb (which can be calculated quickly using basic facility data) are relatively good indicators of successful projects without requiring an in-depth engineering study. Notably, the SS calculation is driven by not only fuel and electric cost rates but also the facility's monthly electric and fuel usage and hours of operation, all of which have a positive influence on SS values. The electric and fuel usages affect the SS through a thermal credit, which is defined as "the fuel cost avoided by having CHP provide thermal energy to the site, per kWh," (3) and reduces the effective cost to generate power ($/kWh). This value is maximized by using 100% of the thermal and electrical output of the unit.

Despite slightly negative SS and unfavorable FCR results, the annual cost savings and simple payback periods for some projects are within reasonable ranges. The addition of efficiency program incentive dollars is often the deciding factor in whether CHP projects are implemented.

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