Understanding Early Retirement of Combined Heat and Power (CHP) Systems: Going Beyond First Year Impacts Evaluations

William Marin, Itron Inc.
Myles O'Kelly, Itron Inc.
Kurt Scheuermann, Itron Inc.

ABSTRACT

Combined heat and power (CHP) programs operate at the nexus of technology, policy, economics, and behavior. Every day, CHP owners and operators face decisions about when and how to operate their CHP systems. Changes in natural gas prices, tariffs, maintenance costs, and local air quality regulations may lead CHP operators to reduce or discontinue system operation. CHP systems are typically expected to remain in operation approximately 20 years. However, in California, approximately 25 percent of small (≤ 5 MW) natural gas fueled CHP projects that received strictly capacity-based incentives from the Self-Generation Incentive Program (SGIP) between 2001 and 2010 have been taken offline or decommissioned in fewer than ten years. Average annual retirement rates for certain technologies ranged from 5-10 percent of capacity.

Early retirement of CHP projects has important implications for program design and evaluation. The assumption that first year savings from CHP projects persist throughout expected system life is likely to over-estimate actual lifetime savings. To better understand lifetime CHP impacts, programs should be regularly evaluated. CHP impacts evaluations should rely on metered data continuously collected throughout the life of a representative sample of projects. Surveys should be conducted regularly to establish the operational status of un-metered projects.

As an increasing number of states are turning to CHP to help meet energy and environmental goals, it is important that program administrators, regulators, and evaluators understand that savings from CHP systems cannot be taken for granted over the assumed equipment life.

Introduction

Combined heat and power (CHP) or cogeneration, is the simultaneous production of electrical and thermal energy from a single fuel source. In a traditional energy services baseline, electricity and heat are generated from different sources – electricity is typically provided by the transmission and distribution (T&D) system, and heat is generated on-site from boilers. CHP encompasses a range of distributed generation technologies capable of capturing heat that would otherwise be emitted into the atmosphere during the electricity generation process and redirecting it for a useful purpose.

In recent years there has been increased interest in small (≤ 5 MW), natural gas fired CHP systems. Several reasons explain this interest, including energy reliability, grid stability, and greenhouse gas (GHG) emissions. The use of a natural gas fueled CHP system tends to increase facility natural gas consumption, but this increase is accompanied by energy and GHG reductions from two sources:

- Electricity generated on-site by a CHP system displaces natural gas that would have been used in a central station power plant to generate electric power used on-site as well as electric power associated with T&D line losses (typically 7-8% total), and
- Heat recovered from a CHP system displaces natural gas that would otherwise have been used in a boiler.

Several states have encouraged growth in behind-the-meter CHP using programs offering direct financial incentives as well as other types of support. The California SGIP represents one of the largest and longest-lived incentive programs for distributed energy resources (DERs) and CHP technologies in the country. From 2001 to 2014 the installation of a total of 482 small natural gas fueled CHP systems was supported by the SGIP's capacity based incentives. Prime mover types encompassed by this activity included fuel cells, gas turbines, internal combustion (IC) engines, and microturbines.

The overall economic performance of CHP depends on numerous factors, including maintenance and fuel costs, tariff structures, efficiency, and utilization. Utilization involves several aspects, including operating hours and level, and service life. Unlike many other energy savings measures, behind-the-meter CHP systems can be used as much (or as little) as a host customer chooses because conventional backups are typically retained. While CHP system utilization can be expressed in terms that describe hourly or monthly use, the general focus of this paper is longer term; namely, the characterization of CHP system utilization for entire years.

The specific focus is classification of system status (functional versus non-functional), and its use for developing summary information describing service lives for groups of systems. Program cost-effectiveness analyses – either ex-ante projections or ex-post actuals – routinely incorporate the effective useful life (EUL) measure of service life. The EUL is "the median number of years that the measures installed under the program are still in place and operable" (TecMarket Works 2004, 398). Actual EULs may be substantially different from system economic lifetimes that may be assumed for individual systems ex-ante, which typically are on the order of 20 years for small CHP (SENTECH 2010, 13).

Background

Small CHP systems installed through the SGIP have been the focus of numerous impacts evaluations, the most recent of which covers operations during 2013 (Itron 2015). An archive of SGIP reports is maintained on a California Public Utilities Commission web site (CPUC 2015). The impacts evaluation work has yielded large quantities of metered performance data that are useful for quantifying the operating status and retention of CHP systems. Program process evaluation studies have produced information that helps explain impacts evaluation results.

Metered data compiled for impacts evaluation purposes served as the foundation for an initial study of SGIP system retention (Cooney, Stoops & Thompson 2007). This analysis included estimation of survival functions using metered data for 38 microturbines and 91 IC engines. Effective useful life was defined as the median value for the distributions implied by the survival functions. The EUL results for microturbines (4.7 years) and IC engines (4.4 years) represent the estimated age at which half of systems remain functional while half are non-functional (survival proportion = 50%). At the time of this analysis all gas turbines and fuel cells, and more than half of IC engines and microturbines, remained functional. Host customers were called to ascertain system status and collect information about experiences with non-functional systems. Substantial portions of respondents with non-functional microturbines or IC engines reported reliability problems; smaller portions identified high fuel price as being responsible for removal of the system from service.

A subsequent process evaluation included examination of the performance diminution noted in the Eighth Year Impacts evaluation Report (Barnes, Firestone & Cooney 2010). Hourly metered data from CHP systems installed between 2002 and 2008 were analyzed, and interviews were conducted of 43 system owners. While increasing fuel costs were found to partially explain the reduction in utilization, the interviews highlighted the complex nature of CHP system operations and maintenance. Approximately half of those interviewed reported "significant technical problems" with their systems. One conclusion of this study was that small CHP systems require a 'champion' within the host customer organization.

Consequently, the high likelihood of employee turnover during the course of a 15-20 year CHP system lifetime creates risk to sustained operations.

Findings of the SGIP process evaluation were entirely consistent with results of previous work seeking to dispel the notion that small CHP ownership, operations, and maintenance is as simple is pushing a 'Green Button' (Kleibler-Viglionne 2011). Others have described possible CHP system design and implementation issues that can be addressed with commissioning or re-commissioning (Sweetser 2008).

The California Energy Commission sponsored additional work to examine actual performance of SGIP CHP systems (Beyene & Hickman 2012). A team from San Diego State University performed 14 site visits that included interviews of plant operators. Those interviews suggested that insufficient routine maintenance oftentimes was a contributing factor to removal of systems from service. The role of routine maintenance in preventing major breakdowns, and the types of costs resulting from those breakdowns, were described. The authors concluded that such breakdowns were a major contributor to growing sentiment that CHP is not reliable. Several strategies (e.g., continuous commissioning) for maximizing probability of project success were outlined.

In 2011 due in part to concerns over the reliability with which small CHP delivers ongoing GHG emissions reductions the SGIP modified its incentive design. Rather than rely solely on up-front, strictly capacity based incentives, CHP systems 30 kW and larger started having half of their overall incentives tied to actual performance during the first five years. Payment mechanisms are the program's last "carrot" available to ensure long-term success of the project. Program participation levels have been relatively modest since the new performance based incentive (PBI) was instituted.

Several other states besides California, including New York and Massachusetts, currently implement programs that offer financial incentives for the installation of CHP systems behind-the-meter. Program eligibility criteria are important considerations since they represent the program's first line of defense against unexpected performance degradation. For example, in New York's CHP Acceleration Program, CHP technologies are limited to those listed in NYSERDA's catalog of CHP technologies.

In the future, small CHP is capable of contributing to achievement of GHG emissions reductions goals, even in states like California where conventional electricity sources are becoming cleaner and greener (Rocklin & Hite 2015). However, the ability of these systems to contribute cost-effectively will hinge in part on actual system lifetimes. For this reason it is important that actual system lifetimes be monitored, and support programs continue to develop and share information about actual utilization and the factors driving it.

Overview

This paper's findings are based on data collected in support of annual impact evaluations of California's SGIP. Metered generator output data and operating status and experience information collected from system owners were used to classify the status of each system during each year of its life to date. Actual system operational status was classified as Normal, Off, or Decommissioned:

- *Normal*, the system was online and operating normally during the period in question.
- *Off*, the system did not generate electricity during the period in question but is still installed at the host site.
- *Decommissioned*, the system has been physically removed from the host site and will never operate again.

Operational status of projects grouped by prime mover type was summarized to produce a chart of portion of capacity remaining online versus system age. Annual average operating levels were calculated for each prime mover type and age. Together, the information in these two charts captures the relationship between savings rate and system age.

Data Collection

The annual average utilization level and classification of the operational status of CHP projects was established using two types of data:

- *metering of electrical generation, and*
- *host customer responses to operational status surveys*

Metered Generation Data

Metered electric net generator output (NGO) data provide information on the amount of electricity generated by CHP projects net of ancillary loads such as pumps and compressors. Electric NGO data are collected from a variety of sources, including meters installed by Itron and its subcontractors under the direction of the SGIP Program Administrators (PAs), and meters installed by project hosts, applicants, electric utilities, and third parties. Because many different meters are in use among the many different providers, these electric NGO data arrive in a wide variety of data formats. Some formats require processing to be associated with the correct project and put into a format common to all projects. During processing to the common format all electric NGO data pass through a rigorous quality control review. Only data that pass the review are accepted for use in this paper.

Metered data from SGIP systems were collected from 2001 through 2013 for a representative sample of projects. In total, 18 distinct data providers provided metered data for 370 projects.

Operations Status Survey

Operations status surveys are used to obtain information from systems with large savings potential but no metered data. Annual operations status surveys were conducted to classify operational status between 2009 and 2013. For the most recent (2013) classification of operational status, a total of 126 systems were targeted with a success rate of 71 percent. The surveys seek to determine which of the three categories of operational status the projects without metered data fit into.

In the process of collecting operational status information, host customers often share the circumstances and decisions that led to operational decisions. The data supporting this paper were collected from an impact evaluation study and strictly speaking customer decision-making is outside of an impact evaluation scope. However, customer responses provide useful anecdotal information that provides critical insights into industry trends.

SGIP Program Tracking Data

Program tracking data were used to determine SGIP project type, size, and age. Characteristics of systems encompassed by the analysis are summarized in Table 1.

Table 1. System Characteristics

System Type	Size Range (kW)*	Number of Systems
Fuel Cell – CHP	5 – 1,400	88
Fuel Cell – Electric Only (Elec.)[1]	100 – 2,800	83
Gas Turbine	1,210 – 4,600	9
IC Engine	60 – 2,220	187
Microturbine	28 – 1,200	109

* Total site-level capacity, not the capacity of individual prime movers.

Analytic Methodology

The metered data along with the operations status information were used to classify a project as online or offline during any given year.

For projects with available metered data, annual capacity factors (CFs) were calculated as follows:

$$CF = \frac{\sum_{h=0}^{8,760} NGO_h(kWh)}{System\ Size\ (kW) \cdot 8{,}760\ hrs}$$

Capacity factor is a metric of a system's utilization. An annual capacity factor of one indicates full utilization, meaning that a system operated at full capacity during every hour of the entire year. A capacity factor of zero indicates that the system did not operate at all during the year in question. In this paper, we set a threshold of CF = 0.05 to characterize systems as online or off. Systems with a capacity factor greater than or equal to 0.05 are considered online. Systems with a capacity factor less than 0.05 are categorized as offline.

Where metered data were not available, survey data were used to classify the operational status of specific projects. Hosts that responded with an "Off" operational status had a capacity factor of zero assigned during the time period in question. Similarly, hosts who respond with a decommissioned operational status have a capacity factor of zero starting from the date the system was decommissioned through the remainder of the evaluation period.

Using program tracking data, the projects were grouped by their age based on the date the upfront incentive was issued. A typical CHP project goes through several commissioning phases before entering normal operations. Several approval steps are required from the electric distribution company, the gas distribution company, and local air quality districts. Consequently, the CHP system is energized several times before the start of normal (or commercial) operations. In the SGIP, a site-inspection by a third-party consultant is required before an upfront incentive payment is issued. By this point, the system is expected to be fully commissioned and operating normally. As a simplifying assumption, we use the upfront incentive payment date to determine a system's age. A system in its first year of operation (regardless of what calendar year) has an age of one. For example, if two systems entered normal operations in 2005 and 2010, operational data from 2005 and 2010 are classified as first year operations for each project respectively.

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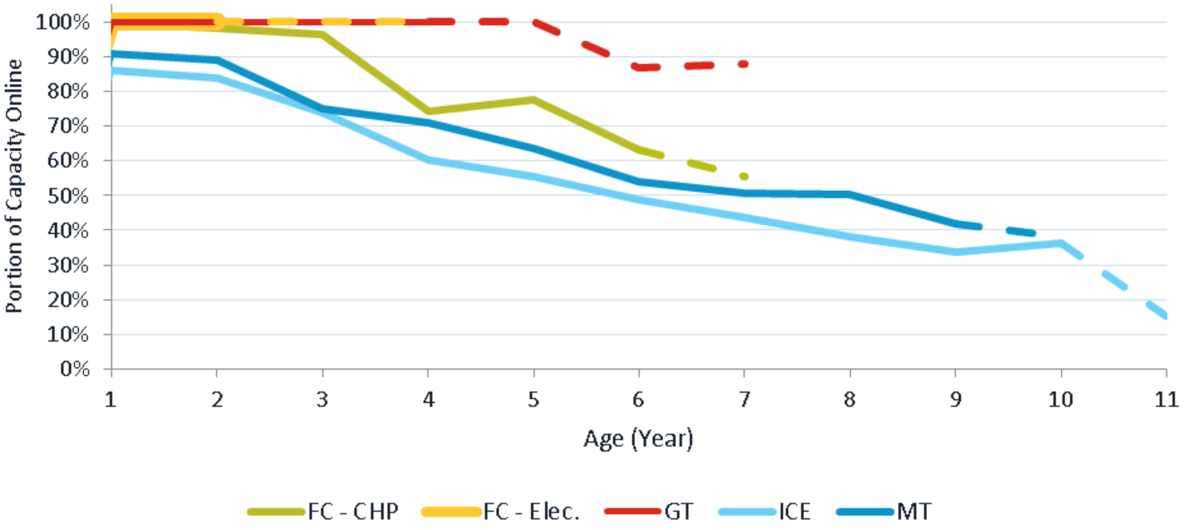
[1] Electric only fuel cells are solid oxide systems most commonly installed in large commercial applications. Unlike other CHP technologies, electric only fuel cells utilize all of their recovered thermal energy internally and have no waste heat available for external end uses.

Results

Results are depicted graphically in Figure 1, which shows the portion of system capacity with data that remain online as a function of age. Dashed lines are drawn when the sample size falls below five projects.



* FC = Fuel Cell, GT = Gas Turbine, ICE = Internal Combustion Engine, MT = Microturbine

Figure 1. Portion of Capacity Online Versus Age

Figure 1 makes it clear that as projects age they are more likely to be offline or decommissioned. After ten years of operation, only 36 percent of the internal combustion engine capacity and 38 percent of the microturbine capacity was online. Both technology types exhibit a decrease in online capacity of six to seven percent per year. All CHP fuel cells have remained online for two years but starting in year three they began to exhibit an attrition rate similar to internal combustion engines and microturbines. Recall that CHP systems are expected to have a useful life on the order of 20 years. In the SGIP, approximately one-third of the internal combustion engine and microturbine capacity was offline well before the expected useful life. Electric-only fuel cells are newer technologies that thus far have remained online during their entire life in the program. All gas turbines remained online until after their fifth year of operation, when attrition begins to take place.

One possible reason for the superior performance of gas turbines is that they represent a much larger capital investment relative to smaller CHP systems. A detailed study of the causes for system attrition are beyond the scope of this paper, however, some of the most frequently received anecdotal comments during operational status surveys include:

- The CHP system did not meet the host customer's performance expectations and consequently the economics are no longer viable,
- The CHP system experienced a technical malfunction and repairs are not supported by the manufacturer,
- The CHP system service warranty expires and the host customer loses interest in the project,
- The host customer changed (new business owner) and the new owner has no interest in operating the CHP system,
- Local air quality rules have changed and the installed equipment no longer meets air district rules,
- The manufacturer went out of business.

Figure 2 summarizes the responses of the annual operational status surveys by technology type. Electric-only fuel cells and gas turbines are not shown for one of two reasons: metered data were available from all projects, or no projects were believed to be offline and therefore were not targeted for a survey.

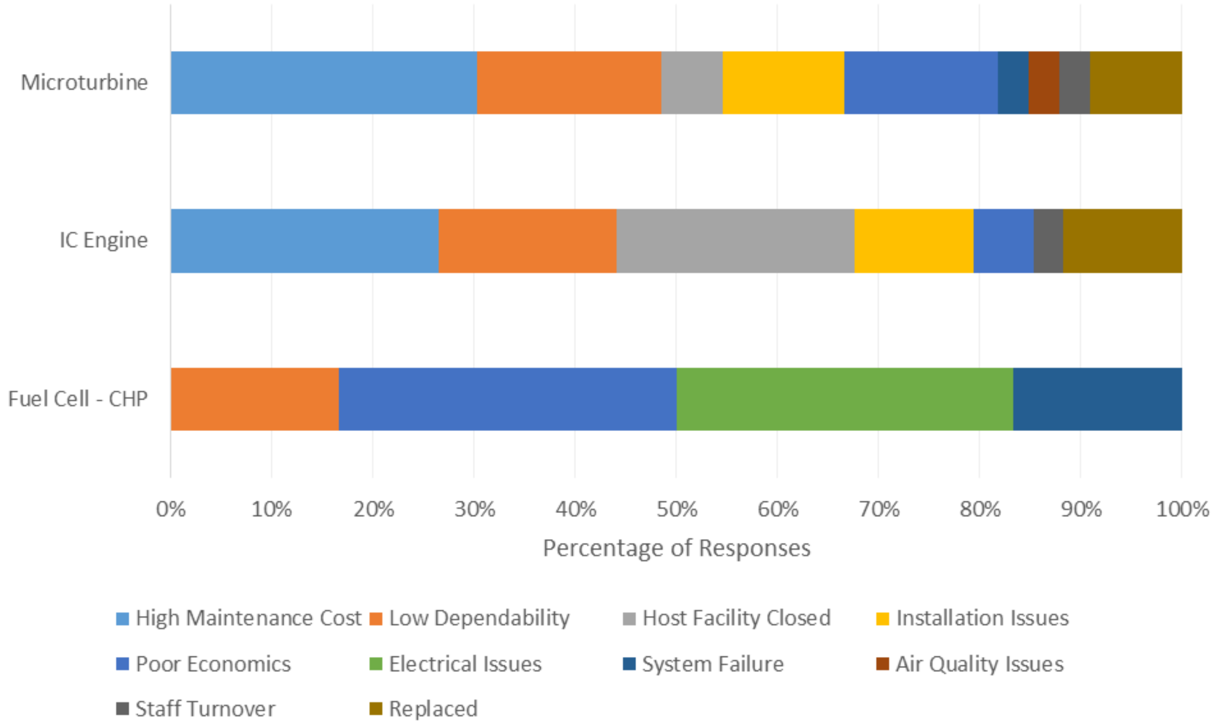


Figure 2. Summary of Operational Status Survey Responses by Technology Type

Among systems deemed decommissioned, 15 percent reported high maintenance costs and 10 percent reported dependability issues as the primary cause. Another eight percent reported business or facility closures, problems the CHP industry cannot directly address.

Figure 3 examines the utilization of the portion of projects that have remained online as a function of age. This analysis eliminates offline or decommissioned systems and examines the behavior of operational projects only.

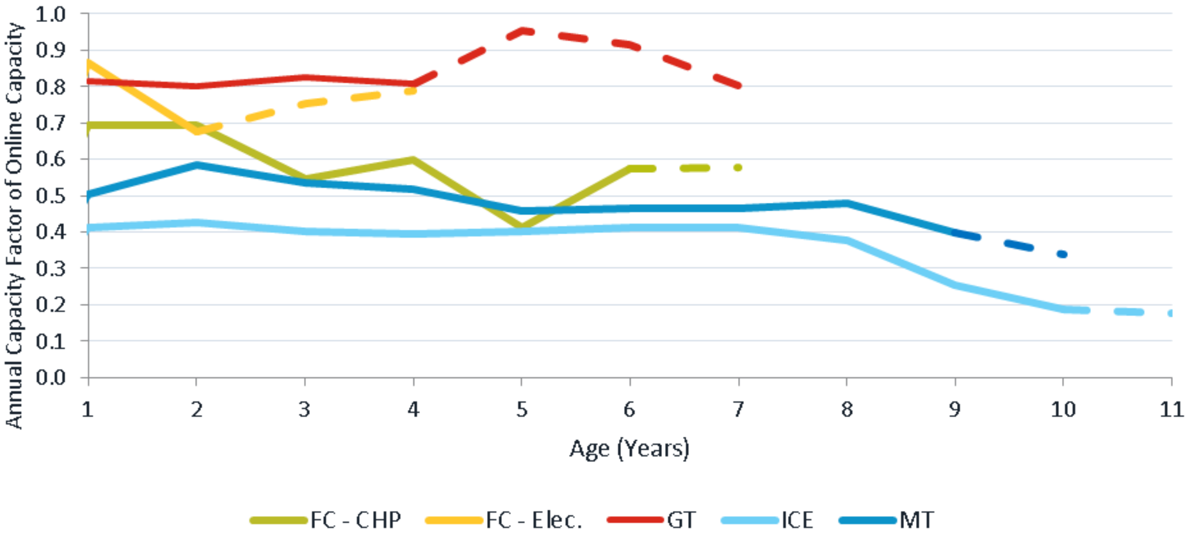


Figure 3. Capacity Factor of Online Capacity versus Age

Capacity factors for online projects have remained relatively constant as a function of age. Electric-only fuel cells and gas turbines started their lives with high capacity factors and maintained them as they age. Internal combustion engines and microturbines began their lives at or below 50 percent capacity factor and remained there for most of their operating history. This suggests that most of the internal combustion engine and microturbine capacity in the SGIP was originally intended to operate in load following or partial power mode, not as baseload capacity. Low capacity factors among online projects are not necessarily indicators of poor performance. For example, a project that only operates from 9 a.m. – 5 p.m. during weekdays would have an annual capacity factor of 0.24. This may be sufficient to meet a host customer's needs.

Discussion

Emerging Technologies, Emerging Markets

It is important to recognize that the results presented in this paper apply to a specific period of time and reflect a particular set of circumstances. Conditions elsewhere or for different periods of time would likely be different. While combined heat and power is a very well established practice, for example in the pulp and paper industry where large CHP is routinely utilized, employment of small CHP for residential, commercial, institutional, and industrial applications was in its infancy when the first SGIP systems were commissioned. Since those oldest SGIP systems entered service the market has developed substantially and many valuable lessons have been learned and incorporated into successive generations of existing technologies, as well as into altogether new technologies. Valuable lessons have also been learned on the business side of the industry as various ownership and maintenance models have been used for SGIP projects. While some such ventures ended in business failures, the lessons learned could produce better performance in the future. While lessons learned from the SGIP are extremely important, it would be unwise to assume that small CHP performance in the future will mirror the results presented here.

Periodic Overhauls

The need for periodic overhauls is one factor that distinguishes CHP systems from some other energy efficiency measures. Combustion-based CHP technologies are driven by rotating machinery that wears over time. Similarly, non-combustion CHP technologies like fuel cells have components that must be regularly replaced to ensure efficient operation over time. This is important because even if original plans included budgeting for overhaul costs, conditions may change, and each overhaul occasion represents a time of risk to continued CHP system utilization. Table 2 summarizes the number of overhauls required during the typical projected life of a CHP project.

Table 2. Hours to Overhaul by Technology Type

	Internal Combustion Engine	**Gas Turbine**	**Microturbine**	**Fuel Cell**
Hours to overhauls (EPA 2015, 1-6)	30,000 - 60,000	25,000 - 50,000	40,000 - 80,000	32,000 - 64,000
Approx. overhauls during 20-year lifetime	3 - 6	4 - 7	2 - 4	3 - 5

Table 2 shows that a CHP system operator will be faced with two to seven distinct opportunities to discontinue a project during a 20-year lifetime. At each overhaul, the CHP operator must weigh the cost of the overhaul against the expected savings before the next overhaul. By then electricity prices, rate structures, and host customer economics may have changed and CHP operation may no longer be cost-effective to the host.

Conclusions

The incidence of CHP system retirements observed among CHP systems participating in California's Self-Generation Incentive Program demonstrates that actual lifetimes are often less than 10 years, much less than typical economic lifetimes included in pro-forma financial projections. In certain cases, we have seen CHP projects decommissioned during their first year of operation. Numerous possible explanations for actual system lifetimes were revealed during conversations with host customers to ascertain current system status.

CHP system retirements have a direct impact on program evaluation. If first year savings are assumed to persist for 20 years, they will likely over-estimate program lifetime savings. On the other hand, reducing CHP useful life to 5-10 years will discount savings from projects that continue to operate 15-20 years. A program impacts evaluation approach combining metering with operations status interviews will likely maximize evaluation cost effectiveness.

Recommendations

CHP system performance degradation has important implications when developing evaluation plans. Ideally, we recommend that CHP program impacts be evaluated yearly and that project savings be calculated each year, not just during their first year of operations. Savings should be calculated using metered data from a stratified sample of projects and not from deemed savings equations. Regular process evaluations can provide significant value in understanding the experiences of participants in the program.

Program administrators should establish eligibility criteria and payment mechanisms that encourage long-term operation of CHP systems. Establishing a prescriptive list of eligible technologies and manufacturers as is the case with NYSERDA's CHP program helps mitigate some risk but limits the program's ability to support the development of new technologies. Performance-based incentives that are tied to annual capacity factor promote sustained savings during the PBI payment period, but their effectiveness beyond the payment period is yet to be seen.

Finally, proper tools for screening CHP applications are essential for project success. No amount of incentives can improve the performance of a project located at a site with a mismatched electrical or thermal load. Detailed screening tools based on electricity/gas demand data and driven by engineering calculations should be used to ensure that CHP systems are sized appropriately to customer loads.

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