Actual Performance of CHP DG Systems Installed for Industrial Applications in California

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ABSTRACT

Combined heat and power (CHP) systems installed in distributed generation (DG) applications offer the promise of energy savings in all sectors. However, the total number of installations to date of smaller systems (<5 MW) remains far below future levels projected in various potential studies. Smaller DG CHP remains an emerging technology so little information is readily available about the actual performance of operational systems. This is important because the savings potential of DG CHP is not guaranteed. Realization of actual savings hinges on proper system design, application, and operation. Numerous design and operational parameters influence DG CHP project financial performance, including: electric capacity factor, electrical conversion efficiency, and heat recovery rate. During the past several years California's Self-Generation Incentive Program has provided financial support for installation of dozens of DG CHP systems for industrial applications. Electric output and fuel input data available for many of these projects provide a rich source of information about actual performance. This information should be of interest to many stakeholders, including: regulatory and legislative bodies involved with design or implementation of DG CHP programs, customers considering installing DG CHP, and vendors of DG CHP systems. In this paper results of analysis of actual electric capacity factors and electrical conversion efficiencies for several years are presented for more than a dozen DG CHP systems in industrial applications.

Introduction

Since 2001 the Self-Generation Incentive Program (SGIP) in California has been encouraging utility customers to adopt a variety of distributed generation technologies. The list of eligible technologies, which has varied through the years, has included combined heat and power systems using microturbines, internal combustion engines and fuel cells operating on natural gas; biogas systems; wind turbines, and solar photovoltaics. As of the writing of this paper the list of eligible technologies was limited to wind turbines and fuel cells. However, from 2001 through 2008 a total of 331 customers participating in the program installed combined heat and power systems operating on natural gas. The focus of this paper is on 53 of those projects fueled with natural gas, operating in industrial applications, and using microturbines and internal combustion engines.

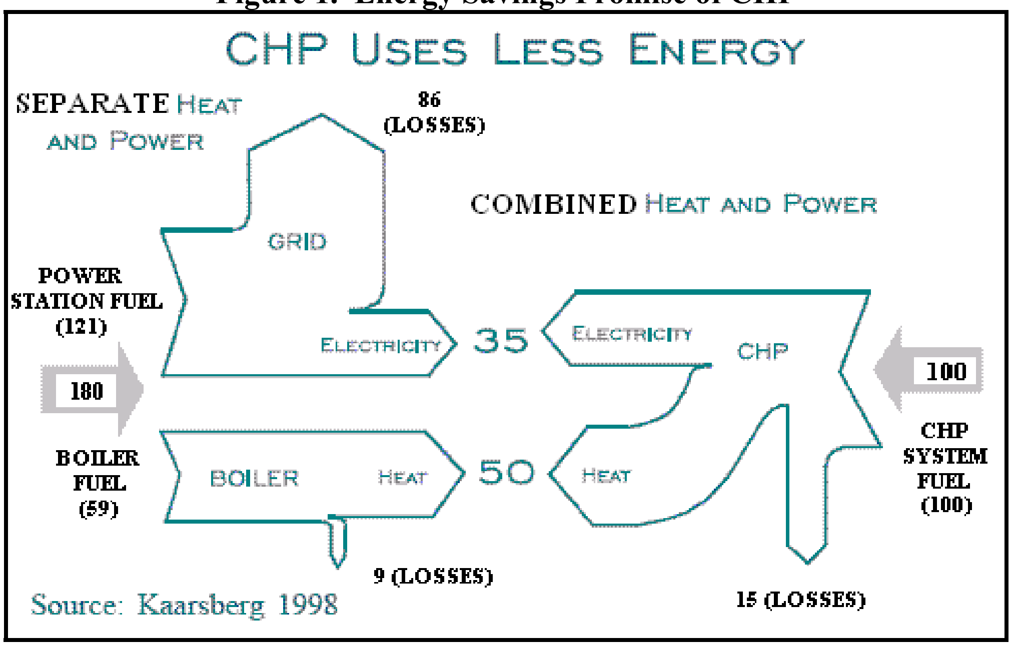
Program impacts evaluation studies have been undertaken each year to measure the actual performance and impacts of systems installed through the SGIP (RER 2002, Itron 2003-2008). The goal of this paper is to summarize impacts evaluation results in a way that will help key stakeholders who will be developing and operating the next generation of CHP DG systems for industrial applications.

Background

The promise of industrial CHP is frequently found depicted graphically in energy balance diagrams such as that presented in Figure 1. While Figure 1 was taken from a National CHP Roadmap (National CHP Roadmap 2001), virtually identical diagrams appear in other references (Bryson et al. 2001, Catalogue of CHP Technologies 2002). This energy balance provides a side-by-side comparison of Separate Heat and Power (i.e., business as usual) and Combined Heat and Power. The presence/absence of a boiler is a key factor differentiating the two alternatives. Recovery and use of waste heat produced by electricity production activities enables elimination of the boiler in the CHP scenario. Important assumptions embedded in this summary include:

- CHP electrical conversion efficiency is 35%.
- Heat recovery efficiency is 59%.
- CHP overall energy efficiency is 85%.
- The ratio of heat recovery to electricity production is 4.9 MBtu/kWh.

Figure 1. Energy Savings Promise of CHP



While this diagram is useful, there are several caveats that should be considered when using the theoretical promise of CHP as a measure of individual project performance. First, achieving text book efficiency levels is not a trivial exercise. If great care is not given to system design, construction, and operation then actual energy savings could be smaller, or total energy consumption could even increase. Second, energy efficiency is a necessary but not sufficient element of project success. Regardless of the overall energy efficiency level, if a CHP system does not operate a certain number of hours per year it will not deliver attractive financial performance. Lastly, transparency in fuel energy input specifications (i.e., HHV vs. LHV[1]) is an important consideration as new stakeholders enter the market.

The performance benchmark summarized in Figure 1 focuses on average efficiencies. To make this promise of industrial CHP a reality, system designs must conform to at least two best practices design principles: high electrical capacity factor, and heat/electric coincidence.

Even a well designed and properly functioning CHP DG system delivers cost savings only during those hours when it is operating. These systems require investment in physical assets (e.g., steel, concrete, copper). To offset that investment there is some minimum number of hours that such a system must operate each year. Failure to operate at least that many hours will result in financial underperformance regardless of system efficiency during those operational hours. A common proxy for operating hours is electrical capacity factor, which expresses the ratio of actual electrical energy generation to the amount of electricity that would be generated if the system operated at full load during all hours of the year. Electrical capacity factors exceeding 70% are desirable (CHP Resource Guide 2005).

To achieve the high average efficiencies indicated in Figure 1 the waste heat generated as a byproduct of electricity generation must be either recovered and used immediately, or recovered and stored for later use (e.g., hot water storage tank). Many CHP DG systems do not include heat storage capacity. In these instances system performance hinges on both the timing and relative magnitudes of electricity generation and use of recovered heat. If the timing of demand for recovered heat does not coincide with its availability then it will be dumped to atmosphere instead of contributing to the heat recovery efficiency identified in Figure 1. Similarly, if the magnitude of demand for recovered heat is insufficient to use all available waste heat then the surplus heat also will not contribute to the heat recovery efficiency identified in Figure 1.

Overview

A total of 53 industrial CHP DG projects representing nearly 34 MW of installed generating capacity have been completed through the SGIP to date. The prime mover technologies used by these projects are summarized in Table 1. Ninety five percent of the total rebated industrial CHP capacity uses IC engines. The average size of microturbine projects is approximately 170 kW, whereas that of IC engines is approximately 730 kW. The microturbine projects range in size from 70 kW to 240 kW while the IC engine projects range in size from 75 kW to 1,500 kW.

Table 1. Summary of Prime Movers

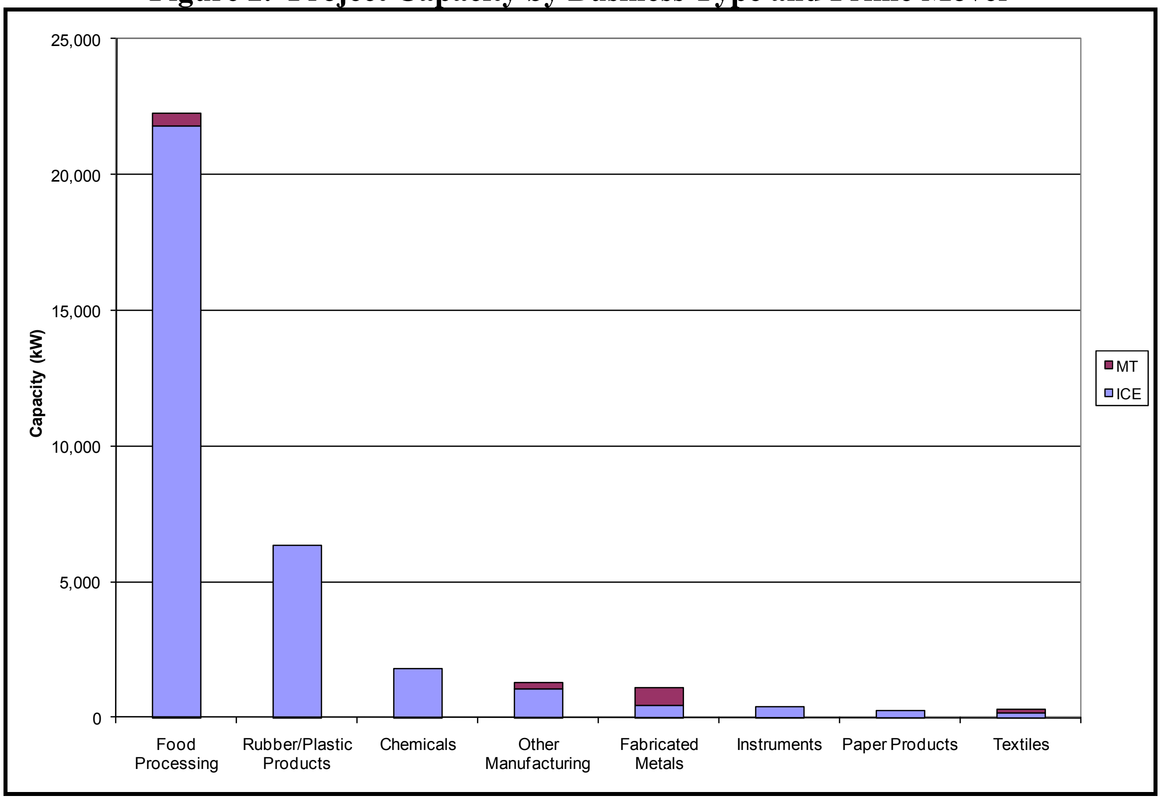
Prime Mover	No. Projects (n)	Rebated Capacity (kW)
ICE	9	1,522
MT	44	32,262
Total	53	33,784

MT = microturbine; ICE = internal combustion engine

[1] Utility companies refer to natural gas energy content in terms of higher heating value (HHV), which includes the heat that could be recovered if products of combustion were allowed to condense. Engine manufacturers refer to natural gas energy content in terms of lower heating value (LHV), which is based on products of combustion remaining in a gaseous or vapor state.

SGIP participants represent a variety of business types as summarized in Figure 2. Two thirds of the project capacity is devoted to food processing. This distribution is not surprising for California, where agriculture plays a large role in the state's economy. Even in other parts of the country where agriculture plays a smaller role in the overall economy there is considerable interest in deploying CHP in food processing applications (Bourgeois et al. 2005). At the national level most of the untapped potential for CHP exists in other industries (Bryson 2001, ONSITE SYCOM 2000).

Figure 2. Project Capacity by Business Type and Prime Mover



Data Collection

Electricity generation, fuel consumption, and recovered heat data are being collected from a sample of completed CHP systems. The scope of metering of the industrial CHP systems is summarized in Table 2. The calculated percentages presented in Table 2 are with respect to the MT and ICE project participation levels presented in Table 1.

Table 2. Summary of Metered Data Availability

Prime Mover	Point	Metered Sites (n)	Metered Sites (MW)	Metered Sites as % of Total (n)	Metered Sites as % of Total (MW)
ICE	ENGO	28	21.5	64%	67%
	FUEL	25	21.5	57%	67%
	HEAT	13	9.1	30%	28%
MT	ENGO	8	1.4	89%	93%
	FUEL	6	1.1	67%	72%
	HEAT	4	0.7	44%	49%

The metering rates for recovered heat are low. The SGIP impacts evaluation was not designed to produce statistically significant results for the subset of industrial CHP systems. In this paper the available metered data are summarized and presented, but no claims are made as to the ability of the metered data to support statistically significant impacts estimates for the population of industrial CHP systems. The results of analysis of metered data are very valuable nonetheless given the dearth of publicly available metered data for these types of systems.

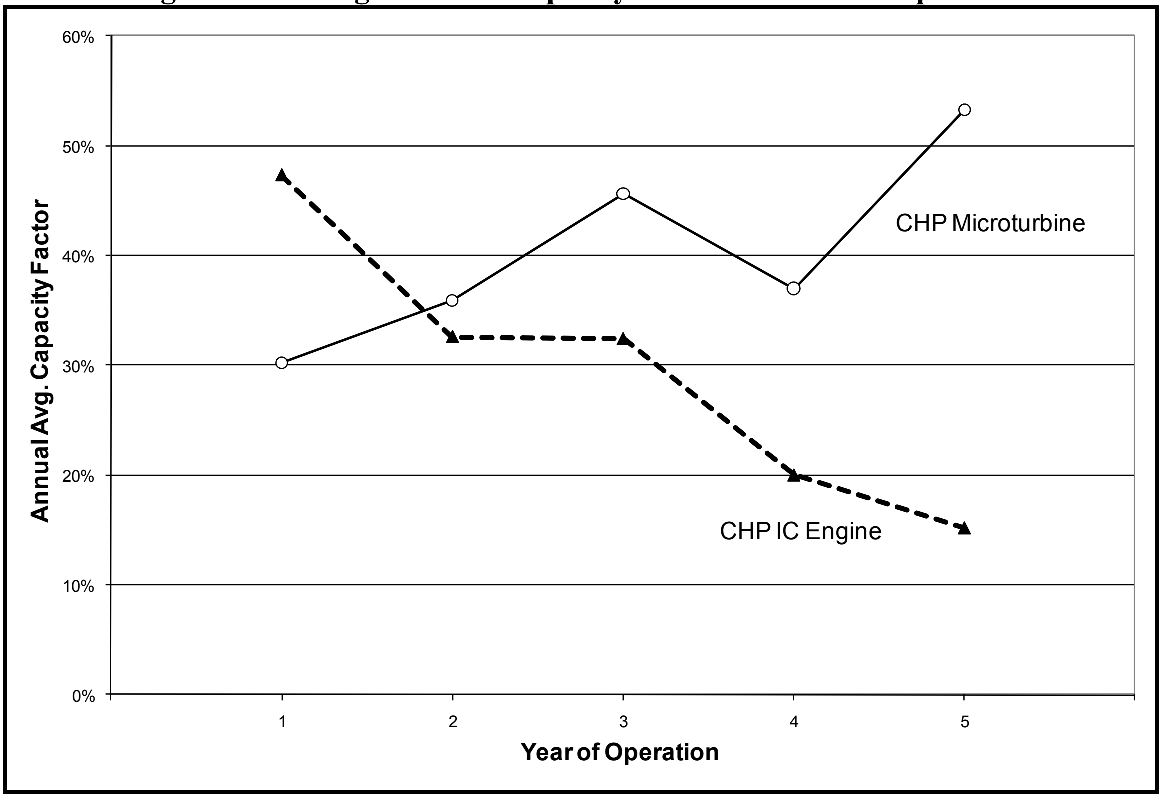
Results

Results of analysis of available metered data are presented below. A discussion of electric capacity factors is followed by presentation of electric conversion efficiencies and heat recovery rates.

Electric Capacity Factor

Annual average electric capacity factors for IC engines and microturbines are presented in Figure 3. The annual capacity factor of IC engines tends to decrease as systems age, and the systems were installed over the course of several years. For this reason the results in Figure 3 are presented separately for each individual year of operation (rather than for specific calendar years).

Figure 3. Average Electric Capacity Factor vs. Year of Operation



The SGIP employs an incentive scheme comprising installed capacity payments ($/kW) with no performance component.[2] Numerous other CHP program incentive schemes exist and have been described (Bourgeois et al. 2007). A CHP program implemented by NYSERDA employs an incentive scheme that includes two (2) installed capacity payments ($/kW) that are subject to minimum performance requirements (NYSERDA CHP Systems Manual 2008). The annual installed capacity payments, which comprise up to 30% of the overall incentive, are reduced to zero for projects failing to achieve a Power Ratio of at least 0.60.[3]

Even though SGIP incentives include no performance component, electric system peak demand reduction is one of several key program objectives. When the program was originally designed the expectation was that participants would have sufficient economic incentive to operate their systems during summertime afternoons. Measurements of actual electric system demand reduction during summertime afternoons is an area of great interest (Lilly 2003, SGIP Annual Impact Evaluations 2002-2008).

While the programs in New York and California are different in numerous respects there may be interest in assessing performance of their respective CHP systems using similar

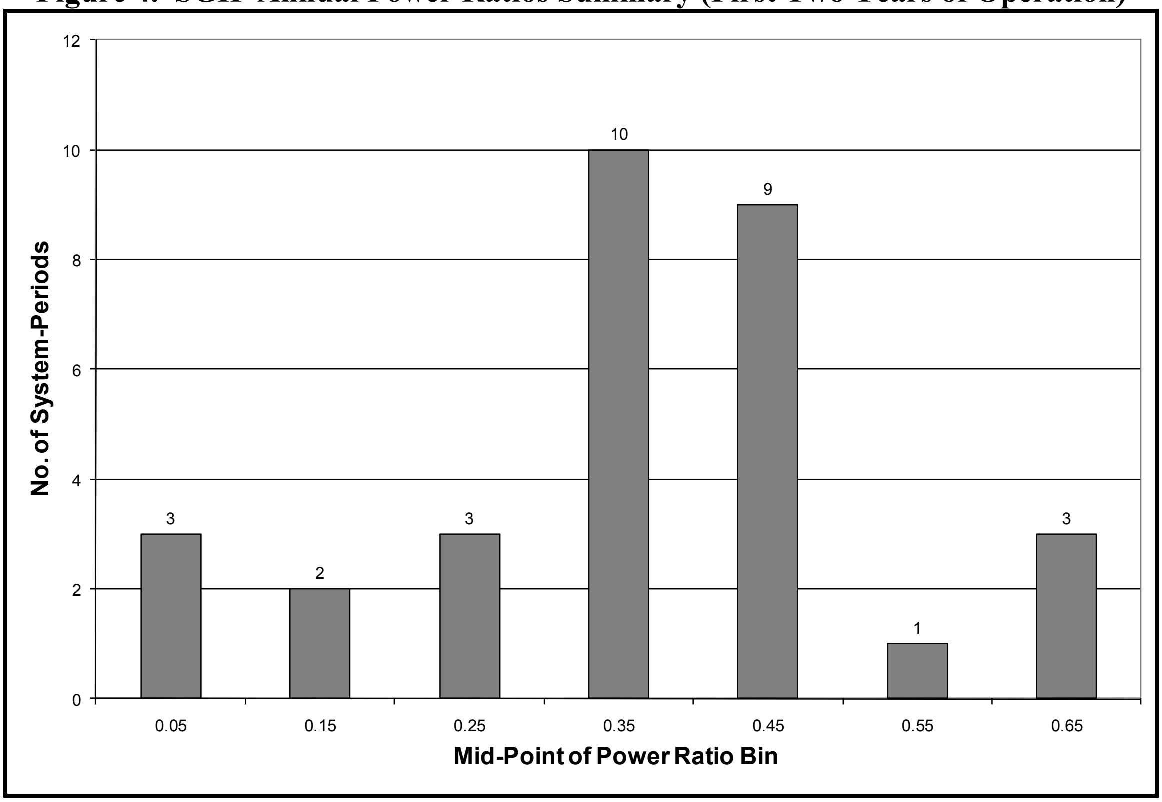
[2] The rationale underlying this program design element was described in the California Public Utilities Commission's March 27, 2001, Decision 01-03-073 regarding Rulemaking 98-07-037 : "We are not persuaded that it is necessary or reasonable to impose operating requirements or incentives related to on-peak operation for this program. We believe that customers willing to invest in self-generation already have sufficient economic incentive from energy prices to employ time-of-use meters to measure their usage and to operate their self-generation systems during peak periods."

[3] This Power Ratio is calculated as the average net power actually produced during the summer capability period (between the hours of 12 pm and 6 pm, Monday through Friday, from May 1 through October 31, excluding legal holidays) divided by the system's projected peak demand reduction.

performance metrics. To facilitate this type of comparison the metered average net power data for the SGIP systems were used to calculate annual power ratios for the first two years of operation. Metered data covering 31 system-periods were available.[4]

Results are summarized in Figure 4. Sixty-one percent of the annual Power Ratios fell within the range of 0.3 to 0.5. Three (10%) of the annual Power Ratios exceeded 0.6. In three cases the annual Power Ratio was equal to zero. Three different CHP systems accounted for these zeros. In two cases the cause of the system being idled is known: contractual dispute or facility ownership change. Only very limited amounts of additional, anecdotal information about operation of the metered CHP systems is available. Other challenges that have been encountered by these program participants have included disruption of CHP operations caused by an absorption chiller tripping offline, and higher than expected natural gas prices.

Figure 4. SGIP Annual Power Ratios Summary (First Two Years of Operation)



Electric Conversion Efficiency

Results of an analysis of cogeneration system electrical conversion efficiencies are presented in Table 3. ENGO and FUEL usage data were used to calculate these electric conversion efficiencies. In the case of reciprocating engines (ICE), actual electrical conversion efficiencies of approximately 30% were measured. The median efficiency actually observed for microturbines was 23%. Statistics summarizing results at the project level are presented in Table

[4] For purposes of calculating annual Power Ratios for the SGIP each system's projected peak demand reduction was assumed equal to the system size upon which the incentive calculation was based. The summer capability period defined in Footnote 3 was also used in the calculation of SGIP annual Power Ratios. Each system contributed up to two data points to Figure 4 depending on availability of metered data.

3. The reason for presenting so many different summary statistics is that this information about inter-site variability may help others with their sample design and uncertainty analysis work in the future. A calculation of efficiencies by system type resulted in overall weighted average efficiencies of 29% for ICE and 22% for MT.

Table 3. Actual Electric Conversion Efficiencies (LHV)

Statistic	ICE	MT
N	14	4
Minimum	21%	19%
Maximum	35%	24%
Median	30%	23%
Mean	29%	22%
Std. Deviation	4%	2%

Heat Recovery Rate

Substantial quantities of metered recovered heat data are available for only four industrial CHP systems. Performance data for these systems are presented in Table 4. While these projects cannot be expected to represent the heat recovery performance of all 53 industrial CHP systems, they do serve as interesting and illustrative case studies.

Table 4. Illustrative Heat Recovery Rates

Performance Metric	ICE #1	ICE #2	MT #1	MT #2
Heat Recovery Rate (MBtu/kWh)	4.7	4.0	8.3	3.0
Electric Efficiency (%, LHV)	34%	29%	19%	23%
Overall Efficiency (%)	80%	64%	66%	44%
Electric Capacity Factor (%)	72%	77%	28%	22%

Conclusions

CHP installed in the industrial sector offers the promise of increased energy efficiency, lower costs, and reduced air pollutant emissions. However, several challenges must be surmounted for this promise to deliver actual benefits. Actual measured values of several performance metrics indicate that for the metered subset of SGIP CHP DG projects in California:

- Average electrical capacity factors are relatively low.
- Average electrical conversion efficiencies vary depending on prime mover technology, and may be lower than values found in some articles, papers, and studies

If the promise of industrial CHP is to be realized as quickly as possible future adopters of the technology must be aware of and manage risks to project success. One means of increasing awareness is to share the experiences of early adopters. That is the purpose of this paper.

Recommendations

The actual experiences of customers installing industrial CHP between 2002 and 2008 through California's SGIP indicate several recommendations for prospective customers and those that would seek to influence them:

Customers

Industrial customers considering installation of CHP DG should incorporate as much actual performance information as possible into their pro forma financial analyses, system designs, and performance calculations.

- Prime Mover Performance. Just as "your mileage may vary" in your automobile, so to the actual performance of microturbines and internal combustion engines may deviate from readily available nominal values. Before relying exclusively on readily available nominal values customers should assess their suitability for use for their specific project's design.
- Electric demand and heat load. The magnitude and timing of both electric demand and heat load need to be examined very closely during the CHP system design process. Instrumentation capable of developing interval-metered data for these two key design parameters is readily available for rental. While development of these primary data is not without cost, the potential value of the data is substantial.

Customers considering a CHP project should rigorously apply project management tools to the project. In particular, project risk management plans should explicitly address threats to project success, including:

- Operations staff expertise and turnover
- Electricity and natural gas price variability
- Equipment reliability

Program Implementers

Utility companies and other program implementers should account for the fact that actual CHP performance may fall short of readily available best-case scenarios such as that included as Figure 1.

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