

The Electrical Cost Threshold As a Measure of Economic Viability for Combined Heating and Power Applications

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ABSTRACT

“Spark spread” refers to the difference between the cost of electricity and the cost of fuel on a per-MMBtu basis. This metric is often used when considering the economic feasibility of Combined Heat and Power (CHP) systems. A spark spread of at least \$12 per MMBtu is considered the threshold for economic viability of CHP systems. However, this study shows that increases in the electric or fuel utility rates have an impact on the spark spread required to achieve economic viability of a CHP project. This challenges the paradigm that a single value for spark spread can be used as a “rule of thumb” for determining the economic viability of CHP projects. There are five factors that must be considered when using the spark spread threshold: (1) thermal energy cost, (2) thermal energy recovery efficiency, (3) generator heat rate, (4) installed equipment cost, and (5) desired payback. The combination of these values into an electrical cost threshold provides a more reliable indicator of the economic viability of a CHP system for a first-order analysis. The minimal effort spent on better-defining the electrical cost threshold is well worth the avoided cost of a CHP load analysis for a system that turns out to have marginal economics.

Keywords: Spark spread, CHP, economic viability

NOMENCLATURE

$Cost_E$	electrical cost (\$/kWh)
$Cost_{Equip}$	installed equipment cost-per-unit load (\$/kW)

$Cost_I$	implementation cost (\$)
$Cost_T$	thermal energy cost (\$/MMBtu).
$Load_E$	electrical load (kW)
$Load_{E-peak}$	peak electrical load (kW)
$Load_T$	thermal load (MMBtu/hr)
OC_{CHP}	operational cost for combined heat and power system (\$/hr).
OC_{CU}	operational cost for conventional system (\$/hr)
OC_{DG}	operational cost for distributed generation (\$/hr)
Payback	simple payback period (hr).
Spark Spread	the difference in electricity and fuel costs on an MMBtu basis
WHR	rate of waste heat recovered (MMBtu/hr)
X_{WHR}	fraction of useable waste heat to available waste heat
ϕ	generator heat rate (Btu/kWh)
η_E	electrical efficiency of the prime mover
η_{HR}	heat recovery efficiency
η_T	efficiency of the thermal energy conversion equipment

INTRODUCTION

When considering the use of combined heating and power (CHP) or distributed generation (DG) in a facility, the two main areas of evaluation are load analysis and economic analysis. Analyzing the match between electrical and thermal loads in a facility often requires a significant investment in time and data gathering. Before making such an investment, a first-order economic analysis is often performed to determine whether or not the utility costs are favorable for the implementation of CHP. Such an analysis has typically taken the form of evaluating the "spark spread." Spark spread is defined as the difference between the electrical cost and the thermal energy cost on a per-MMBtu basis. If the spark spread exceeds a threshold, then the evaluation proceeds to a detailed analysis of the facility loads.

From 1999 to 2009, the annual average retail price for electricity to industrial customers in the United States increased by 58%; from 4.43 cents per kWh to 7.01 cents per kWh [1]. This increase caused many industries to consider alternative forms of electrical power generation, including CHP and DG technologies. However, during the same period

of time, the annual average natural gas cost increased by 208%; from \$3.12 per million cubic feet (MCF) to \$9.61 per MCF [2]. Since 2001, natural gas costs have fluctuated from a monthly low of \$3.18 per MCF to a monthly high of \$12.11 per MCF. The fluctuations and overall increase in natural gas prices have resulted in the cancellation of several prospective CHP and DG projects as well as the shutting down of existing CHP and DG installations [3]. An understanding of the spark spread and its implication are critical to the success of a CHP application.

A literature survey revealed a number of case studies which presented economics along with detailed load studies [4-7]. One case study even provides an evaluation of the natural gas price for which the savings disappear [8]. However, these case studies focus on particular installations and represent a significant investment in engineering effort. While these case studies present a method of analyzing the economics, the level of effort required to use them is much greater than that for a first-order analysis. Engineering firms that specialize in CHP projects note that spark spread analysis does not account for the increased efficiencies of CHP system components [9, 10]. However, these companies discredit traditional spark spread analysis without explaining how a spark spread analysis compares with a more detailed analysis which considers equipment efficiencies. The Federal Energy Management Program has developed a CHP screening form that presents an analysis of utility rates and payback [11]. While the results of this analysis are similar to the results presented in this report, the methodology is not explained. No publications were found that quantitatively explained how the spark spread threshold relates to economic factors such as simple payback, equipment cost, and equipment efficiencies.

This article will demonstrate how a spark spread threshold fits within the context of thermoeconomic energy considerations for a facility. The goal is to understand the context in which this parameter is valid, not to discredit the use of the spark spread threshold.

DEVELOPMENT AND ANALYSIS

In order to evaluate the economics of a CHP system, a baseline for the performance of the conventional method of utility delivery must be established. The cost per hour of operation (OC_{CU}) of a conventional industrial facility which utilizes fuel for process heat (including steam)

and electricity for all other processes can be evaluated as the sum of the electricity and fuel cost per hour or

$$q cog_{m,i,g,j,k} = Kt1_{m,i} \cdot pel_{m,g,i,j,k} + Kt2_{m,i} \cdot th_{m,g,i,j,k} + Kt3_{m,i} \cdot y_{m,g,i,j,k} \quad [kJ] \quad (1)$$

η_T accounts for the thermal efficiency of a fired system to meet the thermal load. Energy rates (power) are convenient to use since the simple payback period is a goal of this analysis.

Expressed in Btu/hr, the electrical power required is $Load_E \cdot 3412 \frac{Btu}{kWh}$ and the fuel required to generate that power is the electrical power required divided by the electrical efficiency of the prime mover or

$Load_E \cdot 3412 \frac{Btu}{kWh} \frac{1}{\eta_E}$. Since the heat rate,, for a prime mover is defined as, the cost per hour for fuel to generate the electricity becomes $Load_E - \phi - Cost_T$. The cost per hour of operation of a facility with a fuel-fired generator in a distributed generation scenario, expressed in terms of the heat rate, is

$$OC_{DG} = (Load_E \cdot \phi \cdot Cost_T) + \left(\frac{Load_T \cdot Cost_T}{\eta_T} \right) \quad (2)$$

When the waste heat is recovered from the electrical generator exhaust, as in a typical CHP application, the rate of waste heat available is the fuel energy rate minus the electrical rate (expressed in Btu/hr). The rate of waste heat recovered, WHR , is the heat recovery efficiency (the fraction of available thermal energy recovered), η_{HR} , times the rate of waste heat available, times the useable waste heat fraction, X_{WHR} or

$$WHR = [(Load_E \cdot \phi) - Load_E] \cdot \eta_{HR} \cdot X_{WHR} \quad (3)$$

Using this definition for waste heat recovered, the cost saving per hour of operation of a CHP system is the cost of fuel for the prime mover plus the cost of fuel for process use (thermal load minus the WHR) or

$$OC_{CHP} = (Load_E \cdot \phi \cdot Cost_T) + \left[\frac{(Load_T - WHR) \cdot Cost_T}{\eta_T} \right]$$

The system requires $Load_T$ to operate. If $WHR = Load_T$, the waste heat recovered satisfies the thermal load; if $WHR < Load_T$, then additional fuel is needed to satisfy the thermal load. $WHR > Load_T$ means that more thermal energy is recovered than can be utilized by the facility. In this case, $X_{WHR} < 1$ as appropriate to account for the excess available waste heat. See Hodge [12] for further details on operating modes of CHP systems. Using waste heat recovered, Equation 4 becomes

$$OC_{CHP} = (Load_E \cdot \phi \cdot Cost_T) + \left[\frac{(Load_T - [(Load_E \cdot \phi) - Load_E] \cdot \eta_{HR} \cdot X_{WHR}) \cdot Cost_T}{\eta_T} \right] \quad (5)$$

$$\begin{aligned} Savings &= OC_{CU} - OC_{CHP} \\ &= (Load_E \cdot Cost_E) + \left(\frac{Load_T \cdot Cost_T}{\eta_T} \right) \\ &\quad - \left[(Load_E \cdot \phi \cdot Cost_T) + \left[\frac{Load_T - [(Load_E \cdot \phi) - Load_E] \cdot \eta_{HR} \cdot X_{WHR}}{\eta_T} \cdot Cost_T \right] \right] \end{aligned} \quad (6)$$

The implementation cost is determined using the cost-per-kW for estimating the installed cost of electrical generation equipment with heat recovery. Cost-per-kW is a commonly used metric for pricing CHP systems, with values that currently range from \$800/kW for large turbine systems to in excess of \$5,000/kW for fuel cell systems [13]. The cost-per-unit load is multiplied times the peak electrical load that will be served by the CHP system. The implementation cost can be expressed as

$$Cost_I = Load_{E-peak} \cdot Cost_{Equip}$$

The analysis is done on a per-hour basis, in effect meaning that the system is operated at the peak load. For this reason, the peak electrical load is the same value as the electrical load ($Load_E$) in the previous

expressions, and Equation 7 can be rewritten as

$$Cost_I = Load_E \cdot Cost_{Equip}$$

Dividing the implementation cost (Equation 8) by the savings per unit time (Equation 6) yields the simple payback period (in hours of operation) for the system.

$$Payback = \frac{Load_E \cdot Cost_{Equip}}{\left((Load_E \cdot Cost_E) + \left(\frac{Load_T \cdot Cost_T}{\eta_T} \right) \dots \right) - \left[(Load_E \cdot \phi \cdot Cost_T) \dots \right] + \left[\frac{Load_T - [(Load_E \cdot \phi) - Load_E] \cdot \eta_{HR} \cdot X_{WHR} \cdot Cost_T}{\eta_T} \right]} \quad (9)$$

For continuous operation (24/7), the simple payback period in years is obtained by dividing the payback period in hours by 8760 hr/year. Combining the appropriate terms reduces Equation 9 to the form

$$Payback = \frac{Cost_{Equip} \cdot \eta_T}{(Cost_E \cdot \eta_T) - (\phi \cdot Cost_T \cdot \eta_T) - [\eta_{HR} \cdot X_{WHR} \cdot Cost_T + (\phi \cdot \eta_{HR} \cdot X_{WHR} \cdot Cost_T)]} \quad (10)$$

The simple payback period is a metric that is often used to determine if a project warrants further investigation. The shorter the simple payback period, the more attractive the measure is economically. However, the point of this study is not to show the simple payback for a system, but rather to examine the effects of varying utility costs on the spark spread required for a CHP system to exhibit economic viability.

For this analysis, simple payback will be treated as a constant. The value used will depend on the particular payback period that is deemed suitable by a facility. With the payback defined, Equation 10 can be rearranged to provide the relationship between fuel cost and electric cost

required to maintain a constant simple payback. The relationship for the electric cost per unit load becomes

$$\begin{aligned}
 Cost_E = \frac{Cost_T}{\eta_T} \cdot \left(\frac{\phi \cdot \eta_T}{10^6 \frac{Btu}{MMBtu}} + \frac{\eta_{HR} \cdot X_{WHR}}{293.071 \frac{kWh}{MMBtu}} - \frac{\phi \cdot \eta_{HR} \cdot X_{WHR}}{10^6 \frac{Btu}{MMBtu}} \right) \\
 + \frac{Cost_{Equip}}{Payback} \quad (11)
 \end{aligned}$$

where the units conversion terms for ϕ and η_{HR} are explicitly included. The lack of load-dependence, $Load_T$, in Equation 11 is worth noting. If all fuel-fired thermal components have the same thermal efficiency, η_T , then the additional fuel required if $WHR < Load_T$ cancels out of the CHP payback expression. This is the "best-case load scenario" for the financial case. *A more rigorous load-dependent study of economic payback can be avoided if the "best-case load scenario" does not satisfy the economic requirements of the facility.*

For a given payback period and fuel cost, Equation 11 provides the electricity cost required. If the cost is greater than that required, then the CHP system economics become more favorable. In that context, the electrical cost resulting from Equation 11 represents a threshold value for the economic viability of CHP. The relationship between the fuel cost and the electrical cost threshold in Equation 11 is linear. The offset of this linear relationship is determined by the equipment cost per kW and the payback period. The slope of this relationship is determined by the generator heat rate, the thermal efficiency, the heat recovery efficiency and the usable waste heat fraction. Figure 1 illustrates the electrical cost threshold versus the thermal energy cost for 2-year, 5-year, and 10-year payback periods. The values for ϕ , η_T , η_{HR} , X_{WHR} , and $Cost_{Equip}$ used in this illustration are 10,000 Btu/kW-hr, 85%, 60%, 100% and \$1,000/kW, respectively.

The values for ϕ , η_T , η_{HR} , X_{WHR} , and $Cost_{Equip}$ are typical values for a large system that utilizes the waste heat to make process steam. The range of thermal energy costs from \$0 per MMBtu to \$15 per MMBtu

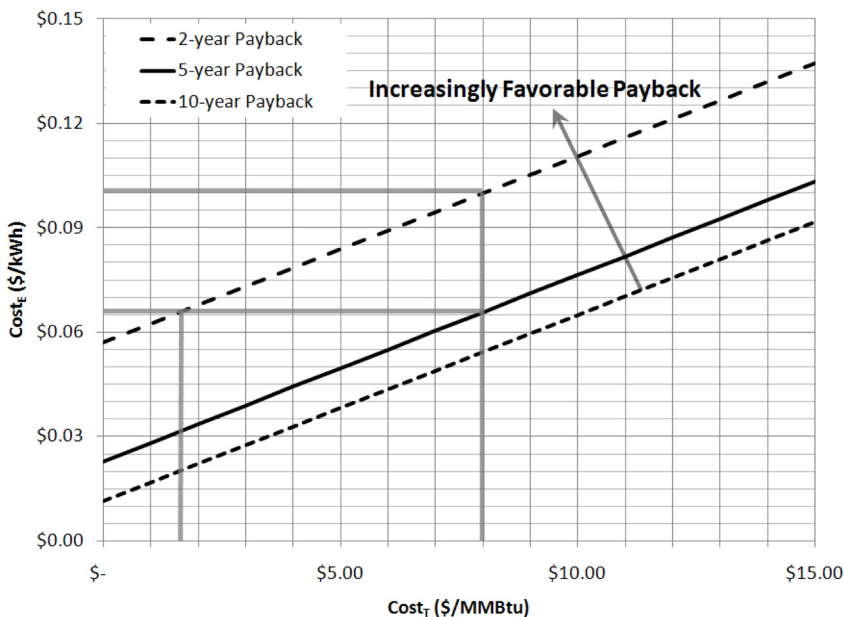


Figure 1. Electrical Cost (Threshold) versus Thermal Energy Cost.

captures the fluctuations of the annual average natural gas cost in the United States over the past 10 years. At a thermal energy cost of \$8/MMBtu, a 5-year simple payback can be achieved if the electrical cost is in excess of \$0.065/kWh. At the same thermal energy cost, a 2-year simple payback can only be achieved if the electrical cost is in excess of \$0.10/kWh. A drop in thermal energy price to \$1.75/MMBtu would allow a 2-year simple payback if the electrical costs were at \$0.065/kWh. The electrical cost threshold lines represent the boundary for the desired payback. For movement upwards or to the left of this boundary line, the economics for CHP become increasingly favorable.

The electrical cost threshold values in Figure 1 represent an economic indicator that takes into account generation efficiency and heat recovery efficiency. However, spark spread is the economic indicator usually referenced when considering the first-order economic viability of a CHP system. Spark spread is defined as the difference between the electrical cost and the thermal energy cost on a per-MMBtu basis and can be expressed as

$$Spark\ Spread = \left(Cost_E \cdot 293.071 \cdot \frac{kWh}{MMBtu} \right) - Cost_T \tag{12}$$

The spark spread does not include equipment efficiencies, equipment cost or payback in the calculation. An underlying assumption is that one unit of thermal energy has equal thermodynamic value to one unit of electrical energy. Nevertheless, a spark spread threshold remains the most common metric for performing a preliminary economic evaluation of a CHP system. The current “rule-of-thumb” states that the spark spread must be at least \$12/MMBtu for a CHP system to have a “the potential for a favorable payback” [14]. While the calculation of spark spread does not explicitly account for CHP system efficiencies, the efficiency is implicitly accounted for by the specification of the \$12/MMBtu spark spread threshold. Figure 2 presents the electrical cost versus the thermal energy cost for a \$12/MMBtu spark spread threshold.

The electrical cost threshold values from Figure 1 are retained in

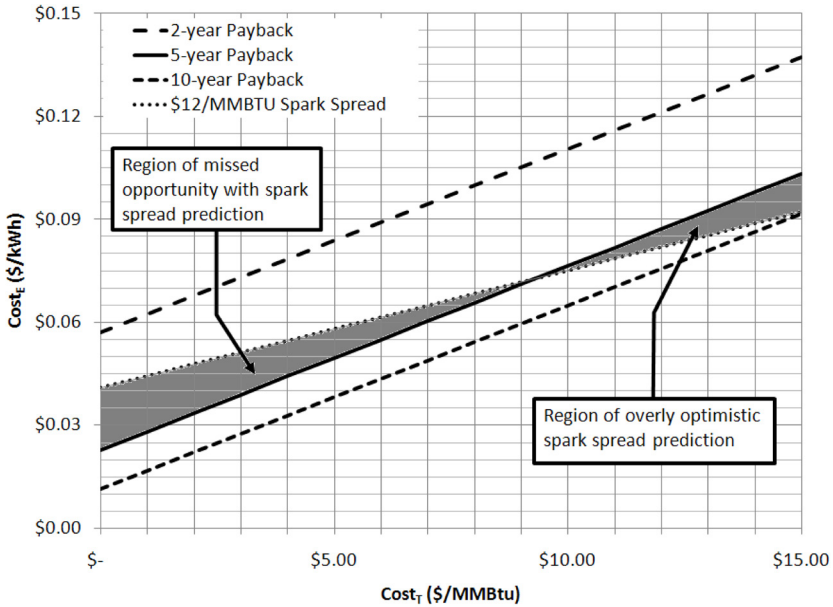


Figure 2. Electrical Cost Threshold versus Thermal Energy Cost for a \$12/MMBtu spark spread.

Figure 2. Since the values presented in Figure 1 are for a meaningful nominal set of parameters, general trends are useful but drawing specific quantitative conclusions from the comparison of the lines in Figure 2 is not warranted. However, conclusions may be drawn for the particular system in question with regard to the spark spread threshold. If a simple payback of 5 years or less is deemed "favorable," then the use of the spark spread threshold will work for thermal energy costs below \$9/MMBtu. Above \$9/MMBtu thermal energy cost, however, the spark spread threshold analysis begins to predict a favorable payback for the particular system in question. The intersection of the 5-year simple payback electrical cost threshold and the spark spread threshold is the point where the validity of the spark spread threshold begins to break down.

The slope of Equation 11 is defined by the generator heat rate, the thermal efficiency, the heat recovery efficiency and the usable waste heat fraction. In order to produce a graph that will allow a more general comparison of the electrical cost threshold and the spark spread threshold, limits must be imposed on the generator heat rate, the heat recovery efficiency and the usable waste heat fraction. A "best-case efficiency" scenario would include a generator with a low heat rate, a thermal energy recovery efficiency of 100% and a useable waste heat fraction of 100%. A "worst-case" efficiency scenario would include a generator with a high heat rate, no thermal energy recovery efficiency and a useable waste heat fraction of zero. The thermal energy conversion efficiency is 85% for both cases. A generator heat rate of 7,500 Btu/kWh will be considered as an upper bound for generator efficiency. This equates to a thermal efficiency of 45.5% and is representative of fuel cell efficiencies. A generator heat rate of 15,000 Btu/kWh ($\eta = 23\%$) will be considered as a lower efficiency bound and is representative of reciprocating engine efficiencies. Heat recovery efficiency may range from 0% in the case of distributed generation applications to near 100% for CHP applications with well-insulated condensing heat recovery units. For a 5-year simple payback, the limiting cases will be the 15,000 Btu/kWh generator with no heat recovery and the 7,500 Btu/kWh generator with 100% heat recovery. Figure 3 presents a graph of the electrical cost threshold for a 5-year payback for the two limiting cases as well as the \$12/MMBtu spark spread threshold.

In Figure 3, the \$12/MMBtu spark spread threshold is very nearly parallel to the 100% thermal energy recovery line. This behavior stands

to reason since all of the energy used to power the generator is being recovered in the form of either electricity or heat. The heat rate no longer affects the slope of the line and only serves to define the proportion of the energy input recovered as electricity. The difference in slope is due to the efficiency of the thermal energy conversion equipment, η_T .

If η_T , η_{HR} and X_{WHR} are all taken to be 100%, the threshold produced by Equation 11 is exactly parallel to the \$12/MMBtu spark spread threshold. Since the offset of Equation 11 is a function of payback period and equipment cost per unit load, the difference between the spark spread threshold and the 100% thermal energy recovery electrical cost threshold can be described in terms of either parameter. If the 5-year payback period is retained, the \$12/MMBtu spark spread threshold represents an installed equipment cost of \$1,795/kW. If the \$1,000/kW installed equipment cost is retained, the \$12/MMBtu spark spread threshold represents a 2.8-year payback.

However, for the case of 0% thermal energy recovery, the electrical cost threshold for a 5-year payback rapidly exceeds the spark spread

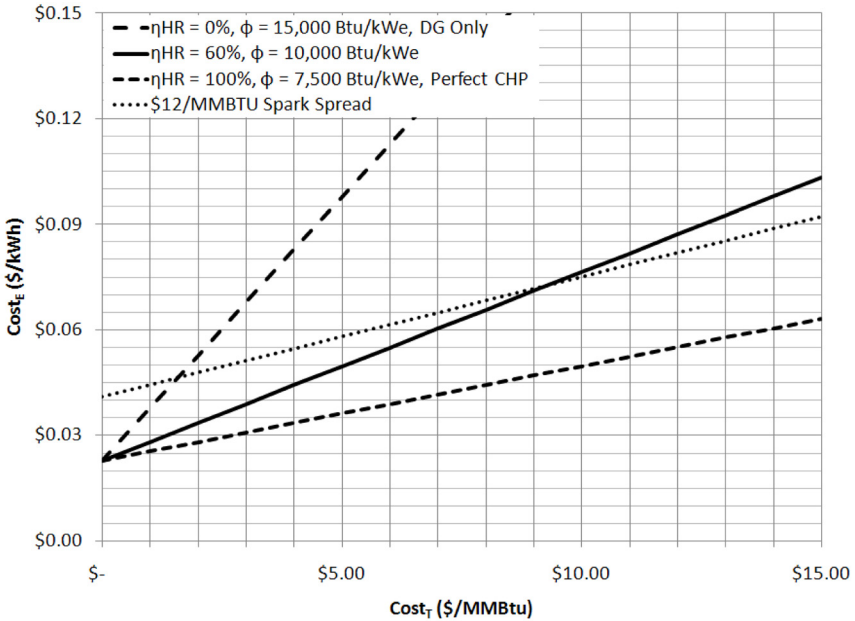


Figure 3. Bounded 5-year Electrical Cost Threshold and \$12/MMBtu spark spread threshold.

threshold. As in Figure 2, the intersection of the 0% thermal energy recovery electrical cost threshold and the spark spread threshold represents the point where the validity of the spark spread threshold begins to break down. While a single “rule-of-thumb” value for the spark spread threshold value may be established for a distributed generation system, this value will quickly become unusable with fluctuations in the thermal energy cost. Any value of thermal energy recovery efficiency below 100% will change the slope of the electrical cost threshold so that it intersects the spark spread threshold. The intersection of these two lines is the point where the validity of the spark spread threshold begins to break down as a reliable economic indicator of the viability of CHP.

Another method for gauging the economic viability of a CHP system is presented by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in their literature on cogeneration systems: “...if the cost of electricity expressed in \$/kWh is more than 0.013 times the cost of fuel expressed in \$/106Btu, a study should be considered. If it is 0.026 times or more, the chances are excellent for simple payback in three years or less” [15]. This method consists of multiplying the thermal energy cost times a constant coefficient to arrive at an electrical cost threshold much like the one presented in Equation 11. A plot of the ASHRAE electrical cost thresholds is presented in Figure 4.

The electrical cost thresholds established by the ASHRAE procedure provide an extremely conservative view of the viability of a CHP system. The ASHRAE electrical cost threshold is so conservative that, for thermal energy costs greater than \$3/MMBtu, the simple payback may be as little as 2 years before the ASHRAE threshold would even recommend a study. A significant region of CHP opportunity is missed by the ASHRAE electrical cost threshold predictions.

The ASHRAE electrical cost thresholds were developed nearly two decades ago during a period when thermal energy prices were much lower than the current values. Over the range of thermal energy prices during that period, the values of the electrical cost threshold predicted by ASHRAE are close to the value produced by Equation 11. The variation in thermal energy prices has rendered the coefficients used in these equations obsolete. The slope of the lines in Figure 4 compared with the case of 0% thermal energy recovery in Figure 3 indicates that, for DG systems, a threshold developed with a constant coefficient will be more appropriate than a spark spread threshold. As this pertains to only DG

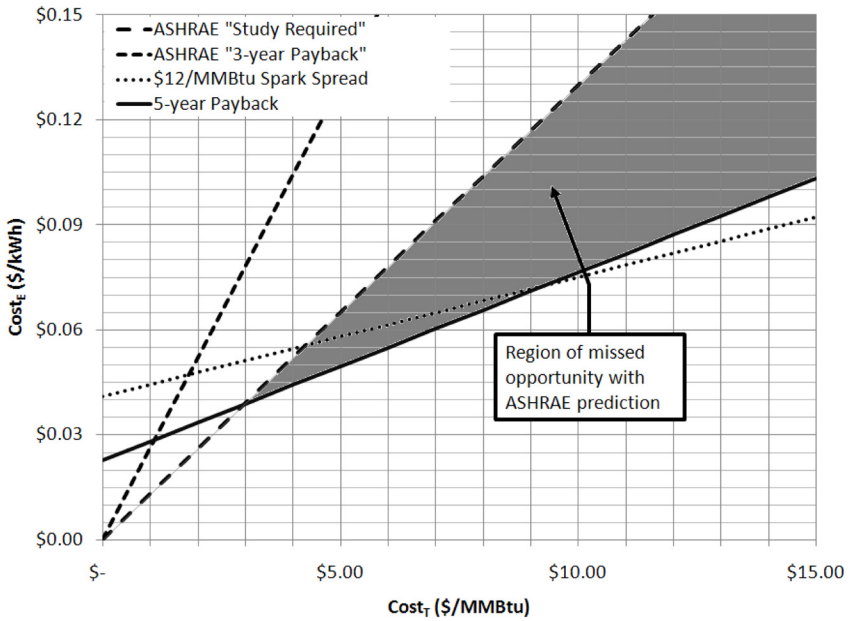


Figure 4. ASHRAE Electrical Cost Thresholds.

systems, development of this coefficient is beyond the scope of this article. With regard to CHP systems, the use of a threshold developed with a constant coefficient suffers from the same malady as the spark spread threshold: the reliability of the threshold breaks down with variations in thermal energy cost.

CONCLUSION

No single parameter can be used to accurately gauge the economic viability of a CHP system. If a single parameter must be selected, the spark spread threshold does provide the best gauge of economic viability. The current $\$12/MMBtu$ "rule-of-thumb" for spark spread will yield at least a five year payback for $\$800/kW$ systems up to a thermal energy cost of $\$15/MMBtu$ for thermal energy recovery efficiencies greater than 78% and generator heat rates less than 10,000 Btu/kW-hr. There are five factors that must be considered when using the spark spread threshold: (1) thermal energy cost, (2) thermal energy recovery

efficiency, (3) generator heat rate, (4) installed equipment cost, and (5) desired payback. The user of the spark spread threshold should keep these factors in mind before applying the “rule of thumb.”

However, the electrical cost threshold presented in Equation 11 presents a much more reliable indicator of the economic viability of a CHP system for a first-order analysis. The thermal energy cost must be defined in order to use any of the metrics for a first-order analysis. The customer should be able to define an acceptable payback period. The remaining parameters of generator heat rate, thermal recovery efficiency, and equipment cost are values that can be estimated with minimal effort. Because the equipment cost and payback are independent variables, the use of this method does not constrain itself to the current cost of energy or equipment. Neither does it constrain itself to someone else’s notion of a “reasonable payback.” The combination of these values into an electrical cost threshold will allow the evaluator to determine if the customer’s economic desires can be achieved before embarking on a more rigorous study of the facilities loads. The minimal effort spent on better-defining the electrical cost threshold is well worth the avoided cost of a CHP load analysis for a system that turns out to have marginal economics.

References

- [1] Energy Information Administration. “Electric Power Monthly—Average Retail Price of Electricity to Ultimate Customers: Total by End-Use Sector.” Energy Information Administration Web site. June 2009. http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html (accessed May 2008).
- [2] Energy Information Administration. “United States Natural Gas Industrial Price (Dollars per Thousand Cubic Feet).” Energy Information Administration Web site. <http://tonto.eia.doe.gov/dnav/ng/hist/n3035us3M.htm> (accessed June 2009).
- [3] Western Governors’ Association Clean & Diversified Energy Initiative. “Meeting the Potential Capacity of Combined Heat & Power in the WGA States.” Western Governors’ Association website. Western Governors’ Association Clean & Diversified Energy Initiative. January 2006. <http://www.westgov.org/wga/initiatives/cdeac/CHP-full.pdf> (accessed May 2008).
- [4] Jalalzadeh-Azar, A.A. “A Comparison of Electrical- and Thermal-Load-Following CHP Systems.” ASHRAE Transactions (American Society of Heating, Refrigeration and Air-Conditioning Engineers) 110, Part 2 (2004): 85-94.
- [5] Colpan, C.O., and T. Yesin. “Energetic, exergetic and thermoeconomic analysis of Bilkent combined cycle cogeneration plant.” International Journal of Energy Research (John Wiley & Sons, Ltd.) 30, no. 11 (September 2006): 875-894.
- [6] Luz-Silveira, J., A. Beyene, E.M. Leal, J.A. Santana, and D. Okada. “Thermoeconomic analysis of a cogeneration system of a university campus.” Applied Thermal Engineering (Elsevier Science Ltd.) 22, no. 13 (September 2002): 1471-1483.
- [7] Sun, Zhi-Gao. “Energy efficiency and economic feasibility analysis of cogeneration system driven by gas engine.” Energy and Buildings (Elsevier Ltd.) 40, no. 2

- (2008): 126-130.
- [8] Moran, Alan, Pedro J. Mago, and Louay M. Chamra. "Thermoeconomic modeling of micro-CHP (micro-cooling, heating, and power) for small commercial applications." *International Journal of Energy Research*. Online Article. Wiley InterScience. John Wiley & Sons, Ltd., 2008.
 - [9] Minett, Simon. "Spark Spreads for Combined Heat and Power." Delta Energy and Environment Web site. Delta Energy and Environment. November 2005. http://www.delta-ee.com/downloads/Spark%20Spreads_DeltaResBrief.pdf (accessed February 2008).
 - [10] Jackson, Jerry. "Turning Utility DG Threats into Business Opportunitites: Part I. Assessing the Threats." DG Marketplace Web site. Jackson Associates. 2004. <http://www.dgmarketplace.com/wpdgeval.html> (accessed February 2008).
 - [11] Federal Energy Management Program. "ADD CHP Sample Screening Report." Federal Energy Management Program Web site. February 25, 2002. http://www.ornl.gov/sci/femp/pdfs/example_gt.pdf (accessed February 2008).
 - [12] Hodge, B. K., *Alternative Energy Sources and Applications*, Wiley, Hoboken, NJ, 2010.
 - [13] U.S. Environmental Protection Agency Combined Heat and Power Partnership. "Catalog of CHP Technologies." Environmental Protection Agency Web site. April 2002. <http://www.epa.gov/CHP/basic/catalog.html> (accessed February 2008).
 - [14] Midwest CHP Application Center and Avalon Consulting, Inc. *Combined Heat & Power (CHP) Resource Guide*. Chicago: University of Illinois Chicago, 2003.
 - [15] American Society of Heating, Refrigeration and Air Conditioning Engineers. *Heating, Ventilating, and Air Conditioning Systems and Equipment*. Atlanta, GA: American Society of Heating, Refrigeration and Air Conditioning Engineers, 2004.

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