Available online at www.sciencedirect.com

ScienceDirect

Journal of Power Sources 165 (2007) 300–306

JOURNAL OF POWER SOURCES

www.elsevier.com/locate/jpowsour

Economic analysis of a combined heat and power molten carbonate fuel cell system

Derek W. Hengeveld[a,*], Shripad T. Revankar[b]

[a] Purdue University, Herrick Laboratories, 140 South Intramural Drive West Lafayette, IN 47907, United States
[b] School of Nuclear Engineering, Purdue University, West Lafayette, IN 47907, United States

Received 10 November 2006; accepted 18 December 2006
Available online 22 January 2007

Abstract

Fuel cells can be attractive for use as stationary combined heat and power (CHP) systems. Molten carbonate fuel cell (MCFC) power plants are prime candidates for the utilization of fossil based fuels to generate high efficiency ultra clean power. However, fuel cells are considerably more expensive than comparable conventional technologies and therefore a careful analysis of the economics must be taken. This work presents analysis on the feasibility of installing both a FuelCell Energy DFC® 1500MA and 300MA system for use at Adams Thermal Systems, a manufacturing facility in the U.S. Midwest. The paper examined thoroughly the economics driving the appropriateness of this measure. In addition, a parametric study was conducted to determine scenarios including variation in electric and natural gas rates along with reduced installation costs.

Keywords: Combined heat and power (CHP); Molten carbonate fuel cells; Manufacturing; FuelCell Energy

1. Introduction

The direct conversion of chemical into electrical energy with high efficiency, no noise or hazardous emissions has been an engineer's dream since the discovery of the fuel cell concept in the 19th century [1]. Fuel cells of today have many technological advances including: high fuel efficiency, ultra-clean emissions, improved reliability, quiet operation, scalability, operation from readily available fuels and the ability to provide both electricity and heat [2]. Because of these reasons, fuel cells can be attractive for use as stationary combined heat and power (CHP) systems. Molten carbonate fuel cell (MCFC) power plants are prime candidates for the utilization of fossil based fuels to generate high efficiency ultra clean power. However, these systems are considerably more expensive than comparable conventional technologies and therefore a careful analysis of the economics must be taken.

Previous assessments of MCFC technologies have focused on the commercial viability of these technologies in generating electricity. As expected, these analyses revealed that the primary barrier towards increased market acceptance has been capital costs, which in some cases can lead to payback periods in excess of the life of the plant [3]. Based on historical cost trends and increased market penetration of MCFC technologies, these barriers will become less pronounced [4]. As a result of expected decreases in capital costs, analyses are often carried out utilizing a fixed utility structure and allowing the capital costs to fluctuate [5]. This can provide a forecast of the future potential of MCFC technologies. Further, analyses are often based upon areas in which the potential application of MCFC technologies is the greatest. That is, areas with high utility rates and emissions penalties. One area that quite often gets overlooked for the application of fuel cell technologies is the U.S. Midwest [2]. Here, utility rates are significantly lower and emissions penalties are traditionally less severe. The following provides an analysis of installing a FuelCell Energy MCFC system at a manufacturing plant in the U.S. Midwest.

FuelCell Energy has developed a unique MCFC termed direct fuel cell (DFC®). The DFC® design incorporates an internal reforming feature that allows utilization of a hydrocarbon fuel directly in the fuel cell without requiring any external reforming reactor and associated heat exchange equipment. This approach upgrades waste heat to chemical energy and thereby contributes to a higher overall conversion efficiency

---

* Corresponding author. Tel.: +1 605 690 1612; fax: +1 765 494 0787.
E-mail address: dhengeve@purdue.edu (D.W. Hengeveld).

0378-7753/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jpowsour.2006.12.053

Nomenclature

ATS	Adams thermal systems
CE	corrected efficiency (%)
CHP	combined heat and power
CPO	corrected power output (kW)
CS	cost savings ($ year^{-1})
DFC	direct fuel cell
FU	fuel usage (kW)
H	local elevation (435 m)
HR	heat recovered (kW)
IC	implementation cost ($)
MCFC	molten carbonate fuel cell
PEL	plant electric load (kW)
PL	part load ratio (%)
RE	rated efficiency (47%)
RER	rated energy recovery, 410.3 kW (1,400,000 Btu h^{-1})
RFC	rated fuel consumption, 2126.1 kW (7,254,000 Btu h^{-1})
RPO	rated power output (1000 kW)
RWU	rated water usage, 0.3155 L s^{-1} (5 gpm)
SP	simple payback period (years)
T_{amb}	local ambient temperature (°C)

of fuel energy to electricity with low levels of environmental emissions [6]. FuelCell Energy has developed direct fuel cells in three capacities: DFC® 300MA, DFC® 1500MA and DFC® 3000MA with capacities of 250, 1000 and 2000 kW, respectively.

This work presents analysis on the feasibility of installing both a DFC® 1500MA and 300MA system for use at ATS, a manufacturing facility in the U.S. Midwest. The paper thoroughly examined the economics driving the appropriateness of the feasibility of DFC® power systems. Significant economic parameters analyzed included: electrical savings, natural gas costs, maintenance savings, emissions savings and implementation costs. In addition, a parametric study was conducted to determine scenarios including variation in electric and natural gas rates along with reduced installation costs.

2. Baseline power systems

ATS is a South Dakota manufacturer of engine cooling systems for off and on-highway vehicles [7]. Housed in a 12,077 m^2 (130,000 ft^2) manufacturing facility, production occurs 8760 h year^{-1} and as a result, the facility consumes a considerable amount of resources including both electricity and natural gas [7]. The following section summarizes electric, natural gas, water and sewer usage over the course of one calendar year. These results were critical in the analysis of the feasibility of a CHP fuel cell system installation at the facility.

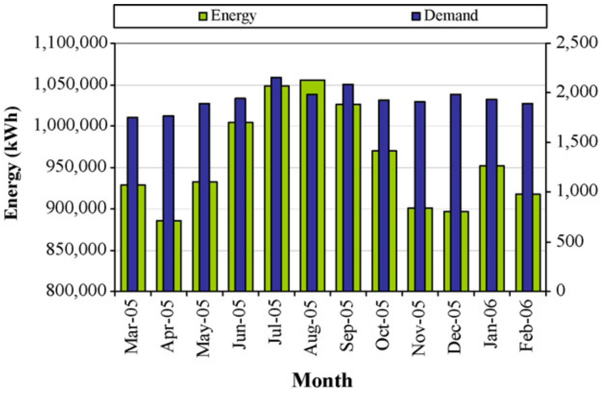

Fig. 1. Electrical summary.

2.1. Electric system

Electrical consumption can be attributed to such items as: lighting, air compressors, fans, pumps, cooling and process equipment. Demand rates are $8.50 kW^{-1} with energy rates averaging 3.2 cents kWh^{-1}.

Electrical demand and usage along with the associated charges, fees and taxes were obtained from billing statements for the months of March 2005 through February 2006 [7]. During the survey period, the facility consumed 11,516,318 kWh year^{-1} with a maximum demand reaching 2156.76 kW in July. The total charges incurred by the facility were $614,622 year^{-1}. Monthly energy and demand amounts were then plotted as shown in Fig. 1.

Fig. 1 shows a relatively consistent year-round demand slightly peaking in the summer, which gives support to some space cooling at the facility. Conversely, the energy usage varies considerable and peaks during summer months. This tends to show that the facility has varying production throughout the year, where times of increased production in the summer are joined by increased electrical energy usage.

2.2. Natural gas system

As discussed previously, the facility utilizes natural gas for a variety of heating processes. A survey of significant natural gas consuming equipment was analyzed to find prospective uses for waste heat generated from the anticipated fuel cell system.

Natural gas information was obtained from the facility for a period from May 2004 through April 2005 [7]. Due to availability of the information, this period does not coincide with electric information. This is not problematic since only a representative overall natural gas cost is needed.

The facility consumed 64,506,076 MJ year^{-1} (611,432 therms year^{-1}) during the survey period with an average value of 5375506.3 MJ month^{-1} (50,953 therms month^{-1}). The facility was charged $380,396 year^{-1} for the purchase and use of natural gas. An overall average energy rate was obtained in the amount of $0.0059 MJ^{-1} ($0.62 therm^{-1}). This rate was used for cost savings analyses.

2.3. Water and sewer system

Water and sewer information was obtained from the facility for a period from May 2004 through April 2005 [7]. As before, due to availability of the information, this period does not coincide with electric information. This is not problematic since representative overall water and sewer costs are only needed.

Analysis of this information reveals overall average water and sewer usage rates of \$0.0005 L^{-1} (\$0.0020 gal^{-1}) and \$0.0009 L^{-1} (\$0.0035 gal^{-1}), respectively. These figures were utilized in the subsequent fuel cell analyses. The electric, natural gas and water and sewer analyses were used in the subsequent economic analysis.

3. DFC® performance

The performance of the DFC® 1500MA was obtained from FuelCell Energy [8] and summarized in Table 1. Several factors contribute to reduced performance including: ambient temperature, elevation, fuel composition and heat recovery parameters [9].

3.1. Ambient temperature

Ambient temperature affects the fuel cell performance by impacting the amount of air needed by the power plant. For ambient temperatures in the range of 4.4 °C (40 °F) to 26.7 °C (80 °F) no correction was necessary.

For ambient temperatures in the range of −28.9 °C (−20 °F) to 3.9 °C (39 °F), less air is needed to maintain system thermal balance (i.e. lower air blower power), but dilution of cathode O_2 reduces cell performance. Further, electrical heaters also turn on at low temperatures to protect electrical equipment and prevent freezing. Because of this, corrections were made to power output as follows:

$$\mathrm{CPO} = \mathrm{RPO} - 9 \times \left(\frac{1 - T_{\mathrm{amb}}}{40}\right) \quad (1)$$

Corrections are also made to efficiency as follows:

$$\mathrm{CE} = \mathrm{RE} - 0.0405 \times (40 - T_{\mathrm{amb}}) \quad (2)$$

Table 1
Performance characteristics of DFC® 1500MA [8]

Description	DFC 1500MA
Power output, ISO conditions	
Power at plant rating	1000 kW
Standard output voltage	480 V
Standard frequency	60 Hz
Efficiency at rated output at ISO conditions	
LHV efficiency	47% ± 2%
Fuel consumption at rated output	
Natural gas 34,689 kJ m^{-3} (930 Btu ft^{-3})	61.347 sL s^{-1} (130 scfm)
Water consumption at rated output	
Average	0.3155 L s^{-1} (5 gpm)
Water discharge at rated output	
Average	0.1893 L s^{-1} (3 gpm)
Available heat at rated output	
Exhaust temperature	343.3 °C (650 °F)
Exhaust flow	1.449 kg s^{-1}(11,500 lb h^{-1})
Emissions	
NO_x	0.009072 kg MWh^{-1} (0.02 lb MWh^{-1})
SO_x	0.0004536 kg MWh^{-1} (0.001 lb MWh^{-1})
CO	0.02268 kg MWh^{-1} (0.05 lb MWh^{-1})

3.2. Elevation

Due to operation at elevations above sea level (lower barometric pressure) the performance is affected since at lower barometric pressure, the air supply blower has to deliver more volume to provide the required mass flow for thermal balance and the fuel cell reactions are slightly less efficient at lower pressure. Because of this, corrections to both power and efficiency were made for all altitudes above sea level as follows:

$$\mathrm{CPO} = \mathrm{RPO} - (H \times 0.00479) \quad (3)$$

Corrections were also made to efficiency as follows:

$$\mathrm{CE} = \mathrm{RE} - (H \times 0.000863) \quad (4)$$

3.3. Fuel composition

So long as the fuel composition falls within the robust design range of FuelCell Energy's fuel specification, no adjustment need be made to the efficiency or power output. It was assumed that no modifications of efficiencies were necessary due to the relatively conservation ranges of constituents and contaminants.

3.4. Heat recovery

The DFC® 1500MA exhaust is a humid flue gas consisting of about 4–5% CO_2, 9–10% O_2, 19–20% water and the balance nitrogen at approximately 343.3 °C (650 °F) [10]. This high grade waste heat can be extracted from the exhaust in an amount depending on how the heat is recovered. FuelCell Energy typically specifies heat recovery on a system that cools the exhaust to 121.1 °C (250 °F) which provides reasonable approach temperatures.

If a more aggressive heat recovery approach is taken, additional waste heat can be obtained. This is problematic since approaching the dew point of the exhaust (about 60 °C (140 °F)) produces condensed water which is slightly acidic (due to the dissolved CO_2 in the flue gas water). There is a significant amount of heat available from the condensation of the flue gas water if economics and the value of heat warrant the extra equipment cost.

4. Economic analysis

Based on the utility and fuel cell information previously discussed, an economic analysis was performed to ascertain the feasibility of installing a fuel cell system to provide both electricity and waste heat. The following analysis and results are based

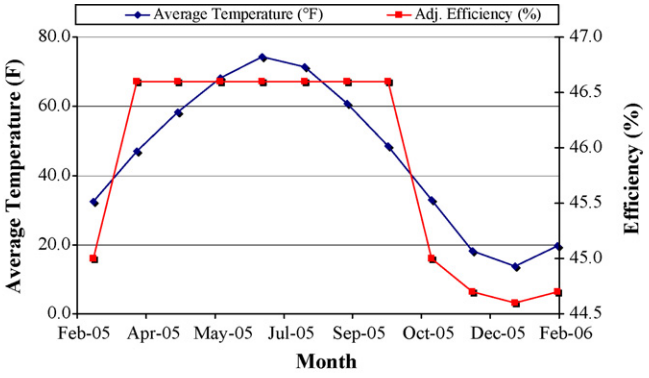

Fig. 2. Corrected efficiency values.

on installation and operation of a DFC® 1500MA. The results of installing and operating a DFC® 300MA are subsequently summarized.

Demand data recorded every 15 min from March 2005 to February 2006 were obtained yielding over 35,000 lines of data [7]. The following outlines the procedure used in analyzing these data and illuminates key results from this analysis.

4.1. Cost savings (DFC® 1500MA)

The first step was to correct both rated power output and efficiency values due to ambient temperature, elevation and fuel composition effects. Average monthly temperatures and local elevation were used to adjusted power and efficiency for each month. Adjustments for fuel composition were not made due to insufficient information. Fig. 2 shows a graphical representation of these adjustments.

Values from this figure were used to determine the proposed operating conditions for each line of data for the respective month. Discussion with representatives from FuelCell Energy revealed that the power output, fuel consumption, heat recovery, water usage and sewer discharge were all a linear function with plant load down to 30% part loads [11]. Utilizing this key trait along with performance parameters, the following provides a description into the various calculations made.

4.1.1. Electrical savings

For each demand reading, the part load operation of the proposed fuel cell was first calculated as follows:

$$\mathrm{PL} = \frac{\mathrm{PEL}}{\mathrm{CPO}} \tag{5}$$

Obviously, if the plant electric load was greater than the corrected power output, the part load ratio of the fuel cell would automatically be set to 100%. Utilizing this part load ratio, the electric power reduction was obtained which was used to calculate the proposed electric demand. Since demand readings were taken every 15 min, this new demand value was multiplied by this factor to obtain energy usage for that period. Fig. 3 illustrates current versus proposed electrical and demand values which shows that demand will be reduced by approximately 1000 kW each month. Energy reductions are not constant each month due to part load ratio variations. The proposed energy usage for the facility was estimated to be 3,047,640 kWh year^{-1}. Based on the facilities utility rate, fees and taxes were also adjusted to account for the new electric charges. A total of 8,468,678 kWh year^{-1} and \$400,267 year^{-1} would be saved in electrical consumption and charges through the use of the DFC® 1500MA system. Further a demand reduction of approximately 1000 kW would be found each month as previously discussed.

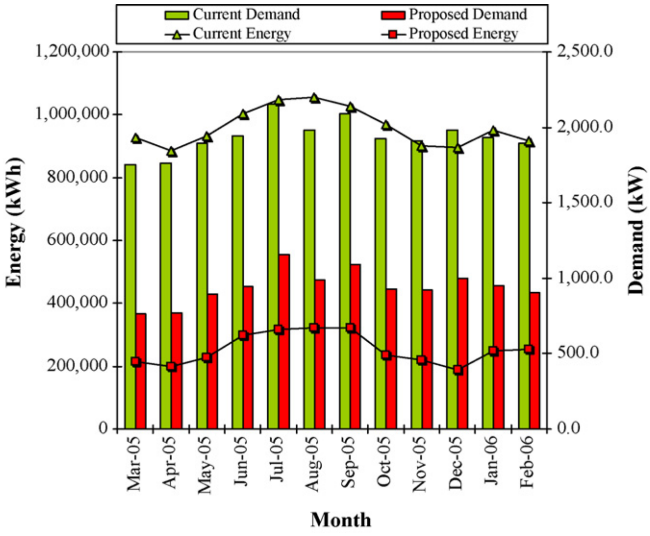

Fig. 3. Current vs. proposed electrical parameters.

4.1.2. Fuel usage

Fuel usage utilized the rated fuel consumption along with the part load ratio previously calculated. The fuel consumption for each 15 min interval was calculated as follows:

$$\mathrm{FU} = \mathrm{PL} \times \mathrm{RFC} \times \left(\frac{15}{60}\right) \tag{6}$$

4.1.3. Heat recovery savings

Heat recovery utilized the rated heat recovery values along with the part load ratio previously calculated. The heat recovered for each 15 min interval was calculated as follows:

$$\mathrm{HR} = \mathrm{PL} \times \mathrm{RER} \times \left(\frac{15}{60}\right) \tag{7}$$

4.1.4. Water and sewer usage

Water and sewer usages utilized the rated heat recovery values along with the part load ratio previously calculated. The water usage for each 15 min interval was calculated as follows:

$$\mathrm{WU} = \mathrm{PL} \times \mathrm{RWU} \times 900 \tag{8}$$

A similar procedure was used to determine sewer usage except the rated sewer usage was 0.1893 L s^{-1} (3 gpm).

4.1.5. Maintenance charges

Equipment maintenance is a considerable portion of fuel cell costs. Discussion with FuelCell Energy representatives revealed that these costs are typically estimated to be \$0.04 kWh^{-1} [11]. These charges are the result of periodic replacement of the following equipment and consumables:

- Fuel cell stack.
- Water treatment chemicals.
- Sulfur sorbent (fuel cleanup).
- Bottled nitrogen.
- Preconverter catalysts.
- Miscellaneous (filters, lube oil, etc.).

The previous calculations for fuel usage, heat recovery savings, water and sewer usage and maintenance charges were applied to each 15 min interval over the course of each month. From this and utilization of the electric, natural gas, water, sewer and maintenance rates, all costs and savings were summarized. Results revealed that although savings contributions from electric and heat recovery savings are significant (\$492,811 year^{-1}) the costs associated with increased natural gas usage, maintenance charges and water/sewer usage are considerably greater (\$732,855 year^{-1}). A negative net savings of −\$240,044 year^{-1} shows that the installation of the DFC® 1500MA at the facility would in fact increase costs at the facility, thus making this measure unattractive.

4.2. Emissions savings (DFC® 1500MA)

In addition to electrical reductions, emissions reductions would potentially reduce facility costs. Of the emissions at the facility, NO_x, SO_x and CO were analyzed. Electric emissions are a result of blended emissions from typical powerplants in the region of the facility. Emissions for natural gas are from the facility's combustion processes. The calculations yielded total current emissions of 22657.8 kg year^{-1} (49,951 lb year^{-1}), 14387.3 kg year^{-1} (31,718 lb year^{-1}) and 1255.6 kg year^{-1} (2768 lb year^{-1}) of NO_x, SO_x and CO, respectively. Proposed emission rates for the facility's electric, natural gas and fuel cell systems yielded total current emissions of 8116.7 kg year^{-1} (17,894 lb year^{-1}), 3819.3 kg year^{-1} (8420 lb year^{-1}) and 851.0 kg year^{-1} (1876 lb year^{-1}) of NO_x, SO_x and CO, respectively. The majority of emissions reductions occurred as a result of reduced utility electric consumption at the facility.

Estimated savings due to reduced emissions were based on permitting costs for each pollutant. These values were \$1.08 kg^{-1} (\$979 t^{-1}), \$0.18 kg^{-1} (\$166 t^{-1}) and \$0.10 kg^{-1} (\$87 t^{-1}) for NO_x, SO_x and CO, respectively [12]. From this information, a total savings of \$15,962, \$1934 and \$39 year^{-1} for NO_x, SO_x and CO, respectively was calculated. This yields a total cost savings due to emissions reductions of \$17,935 year^{-1}. These savings were not included in subsequent analyses but included as reference and illustrate the impact of emissions charges. These values are dependent on the region in which the fuel cell will be installed. The facility currently incurs no charges (permitting or otherwise) for the generation of electricity or combustion of natural gas.

4.3. Implementation costs (DFC® 1500MA)

Implementation costs for this measure include fuel cell equipment and installation along with mechanical equipment costs. The following describes these in more detail.

4.3.1. Fuel cell equipment and installation

Equipment and installation costs were estimated to be \$4300 and \$1000 kW^{-1}, respectively [11,13]. Based on a rated power output, the cost of a DFC® 1500MA is \$5,300,000 for both equipment and installation.

4.3.2. Mechanical equipment

The purchase of heat exchange and distribution equipment is required to recover waste heat generated by the fuel cell. The implementation cost of this recommendation is a result of the purchase and installation of two stainless steel gas-to-gas heat exchangers and one gas-to-water heat exchanger along with miscellaneous costs such as ductwork and fittings to recover heat.

Costs were obtained through discussion with equipment suppliers along with mechanical estimating references [14–16]. Heat recovery equipment and installation costs totaled \$60,760. Based on the previous analysis, the total installed cost of the DFC® 1500MA is \$5,360,760.

4.3.3. Incentives

There are attractive incentives available which help offset fuel cell equipment and installation costs. For example, the 2005 U.S. Energy Policy Act created a Federal Investment Tax Credit worth \$1000 kW^{-1}. In addition, it provides 5 year accelerated depreciation [17]. These incentives could reduce the DFC® 1500MA plant overall cost by approximately one million dollars via the Investment Tax Credit and the net present value of the accelerated depreciation would also approach 1 million dollars [11]. Of course each case is unique and the numbers provided and realized may be different.

There are other incentive programs available. For example, California provides additional funding through the Self-Generation Incentive Program (SGIP) fund. This provides a \$2500 kW^{-1} credit for fuel cells operating on natural gas [18]. Pacific Gas and Electric Company® provides a complete listing of public information on installed SGIP systems [19].

4.4. DFC® 300MA summary

A similar analysis was performed for installation of a DFC® 300MA at the facility. At this capacity, equipment and installation costs are \$4600 and \$1000 kW^{-1}, respectively [11]. The results of this analysis showed electric and heat recovery savings of \$123,595 year^{-1} with combined costs of \$187,318 year^{-1}. A negative savings of −\$63,723 year^{-1} shows that the installation of the DFC® 300MA at the facility would in fact increase costs at the facility, thus making this measure unattractive.

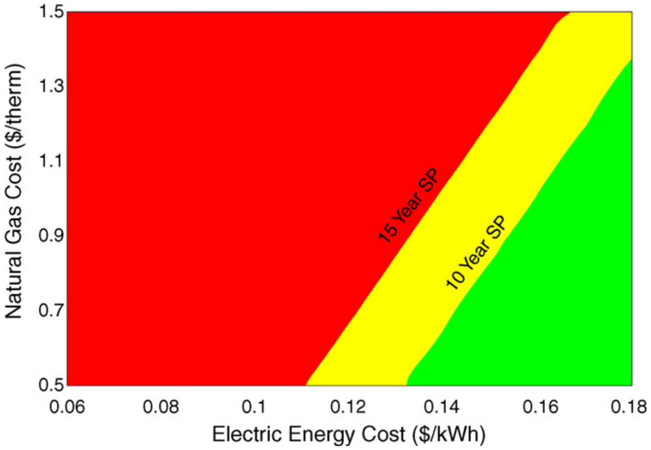

Fig. 4. Simple payback period vs. natural gas and electric rates ($5300 kW^{-1}).

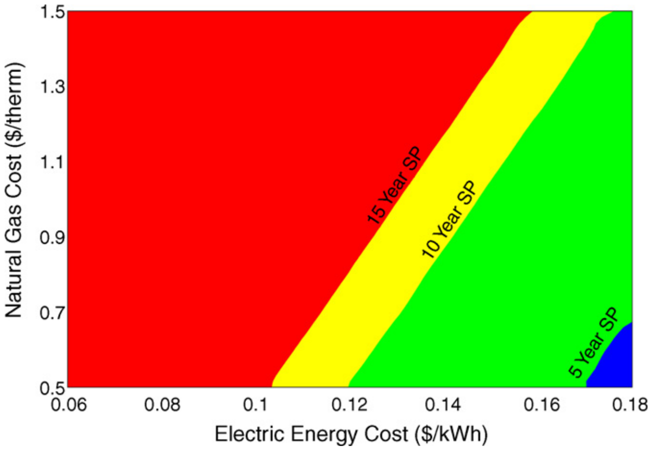

Fig. 5. Simple payback period vs. natural gas and electric rates ($4300 kW^{-1}).

5. Parametric study

As a result of the poor economic performance of a stationary fuel cell system at the facility, a parametric study was performed to identify combinations of natural gas and electric energy rates that would make the installation of a DFC® 1500MA attractive. A simple payback period analysis was utilized as an economic indicator and was calculated as follows: SP = IC/CS. The results of this analysis were summarized in a contour plot generated utilizing EES (Engineering Equation Solver). Figs. 4 and 5 show simple payback periods for a variety of utility combinations.

It is shown that at average electric energy rates below $0.11 kWh^{-1}, the simple payback period approached and exceeded the rated life of the unit (20 years). Only at extremely high electric energy rates and low natural gas rates does this measure become attractive. Considering an attractive simple payback period of 10 years, only when the electric energy rate reaches $0.13 kWh^{-1} do stationary fuel cell products become attractive for this facility (at very low natural gas rates).

The facility had a blended electrical rate (energy and demand) of $0.053 kWh^{-1} and a natural gas rate of $0.0059 MJ^{-1} ($0.62 therm^{-1}). Figure shows that this combination of utility rates makes the installation of a DFC® 1500MA unfeasible.

A further analysis was provided which included projected costs of stationary fuel cells. Information obtained from FuelCell Energy revealed that projected costs are anticipated to be reduced by $1000 kW^{-1} [11]. A similar parametric study was achieved with this updated cost as shown in Fig. 5.

Figure shows that reduction of fuel cell costs by $1000 kW^{-1} does have an impact on the attractiveness of stationary products. In fact, it is shown that at average electric energy rates below $0.10 kWh^{-1}, the simple payback period exceed the rated life of the unit. Considering an attractive simple payback period of 10 years, only when the electric energy rate reaches $0.12 kWh^{-1} do stationary fuel cell products become attractive (at very low natural gas rates).

6. Conclusions

The economic analysis of a stationary MCFC for a combined heat and power system at the industrial facility previously described revealed several conclusions.

(1) Installation of a DFC® 1500MA (1000 kW capacity) would cost the facility $240,044 year^{-1}. The majority of these costs are attributed to maintenance of the fuel cell plant. The cost for this system was estimated to be $5,360,760.
(2) Installation of a DFC® 300MA (250 kW capacity) would cost the facility $63,723 year^{-1}. The majority of these costs are attributed to maintenance of the fuel cell plant. The cost for this system was estimated to be $1,740,760.
(3) Emissions penalties could provide additional savings making fuel cell installations appear more attractive. These are dependent upon the region in which the installation will be located.
(4) At an average cost of $5300 kW^{-1}, stationary fuel cells become attractive for onsite generation at approximately $0.13 kWh^{-1}. High average electrical rates and low natural gas costs are most favorable for this type of application.
(5) At an average cost of $4300 kW^{-1}, stationary fuel cells become attractive for onsite generation at approximately $0.12 kWh^{-1}. High average electrical rates and low natural gas costs are most favorable for this type of application.

In general, the use of a fuel cell at this facility would not be economically feasible at this time. Although savings contributions from electric and heat recovery savings are significant, the costs associated with increased natural gas usage, maintenance charges and water/sewer usage are considerably greater. In certain areas, emissions reductions would help this measure but not enough to make it attractive for this facility. The parametric study indicated that in the future as electric and natural gas rates change and fuel cell costs are reduced, this technology would become more attractive for the facility.

Acknowledgements

The authors would like to acknowledge the contributions from Adams Thermal Systems and FuelCell Energy.

References

[1] W. Münch, H. Frey, M. Edel, A. Kessler, J. Power Sources 155 (2006) 77–82.

[2] M. Bischoff, J. Power Sources 154 (2006) 461–466.

[3] G. Bizzarri, G.L. Morini, Appl. Therm. Eng. 24 (2004) 383–400.

[4] A.M. Appleby, J. Power Sources 69 (1996) 153–176.

[5] E.M. Leal, J.L. Silveira, J. Power Sources 106 (2002) 102–108.

[6] H. Ghezel-Ayagh, A.J. Leo, H. Maru, M. Farooque, Overview of direct carbonate fuel cell technology and products development, in: ASME International, First International Conference on Fuel Cell Science, Engineering and Technology, April 21–23, 2003.

[7] Private communication, Adams Thermal Systems, 2006.

[8] Direct FuelCell® DFC1500MA™ Standard Powerplant Specification Summary, FuelCell Energy, February 2006.

[9] Powerplant Output and Efficiency Correction Factors to Standard Conditions, #5841, FuelCell Energy, May 2004.

[10] Waste Heat Availability from FuelCell Energy Direct FuelCell® Powerplants, FuelCell Energy, September 15, 2005.

[11] Private communication, FuelCell Energy, 2006.

[12] Emission Factors and Energy Prices for the Cleaner and Greener Environmental Program, Prepared by Leonardo Academy Inc. for the Multiple Pollutant Emission Reduction Reporting System (MPERRS), April 2004.

[13] FuelCell Energy Company Overview, FuelCell Energy on-line publication: http://www.fce.com/site/investor/presentation_05_06/sld018.htm [accessed August 11, 2006].

[14] Private communication, Exothermics, Inc., 2006.

[15] Private communication, Xchanger, Inc., 2006.

[16] Mechanical Cost Data, R.S. Means Company Inc., Kingston, MA, 2004.

[17] S. Nadel, The Federal Energy Policy Act of 2005 and its Implications for Energy Efficiency Program Efforts (Report Number E053), American Council for an Energy-Efficient Economy on-line publication: http://www.aceee.org/pubs/E053.pdf [accessed August 11, 2006].

[18] Self-Generation Incentive Program, Pacific Gas and Electric Company® on-line publication: http://www.pge.com/selfgen/ [accessed August 11, 2006].

[19] Self-Generation Incentive Program Statistics, Pacific Gas and Electric Company® on-line publication: http://www.pge.com/docs/word_xls/suppliers_purchasing/new_generator/incentive/SGIP_Statewide_Data_Aug06.xls [accessed August 11, 2006].