A FEASIBILITY STUDY OF FUEL CELL COGENERATION IN INDUSTRY

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ABSTRACT

Up until now, most of the literature on fuel cell cogeneration describes cogeneration at commercial sites. In this study, a PC25C phosphoric acid fuel cell cogeneration system was designed for an industrial facility and an economic analysis was performed. The US DOE Industrial Assessment Center (IAC) database was examined to determine what industry considers a good investment for energy saving measures. Finally, the results of the cogeneration analysis and database investigation were used to project the conditions in which the PC25C might be accepted by industry.

Analysis of IAC database revealed that energy conservation recommendations with simple paybacks as high as five years have a 40% implementation rate; however, using current prices the simple payback of the PC25C fuel cell exceeds the likely lifetime of the machine. One drawback of the PC25C for industrial cogeneration is that the temperature of heat delivered is not sufficient to produce steam, which severely limits its usefulness in many industrial settings. The cost effectiveness of the system is highly dependent on energy prices. A five year simple payback can be achieved if the cost of electricity is $0.10/kWh or greater, or if the cost of the fuel cell decreases from about $3,500/kW to $950/kW. On the other hand, increasing prices of natural gas make the PC25C less economically attractive.

OVERVIEW OF FUEL CELLS

A fuel cell (Figure 1) takes chemical energy from the oxidation of a gas fuel and converts it directly into electrical energy in a continuous exothermic process (Hirschenhofer et al., 1994). It differs from a battery in that the reactant is supplied from an external source and is continually replenished. Fuel cells use hydrogen as the oxidation agent and oxygen as the reduction agent. The hydrogen and oxygen gases are bubbled into separate compartments connected by an electrolyte. Inert electrodes, mixed with a catalyst such as platinum, separate the hydrogen and oxygen from the electrolyte. When the two electrodes are connected, the oxidation and reduction reaction takes place in the cell. Hydrogen gas is oxidized to form water at the cathode (negative pole). Electrons are liberated in this process and flow through the external circuit to the cathode (positive pole), where the electrons combine with the oxygen and the reduction reaction takes place. This process creates heat and a current across the electrodes.

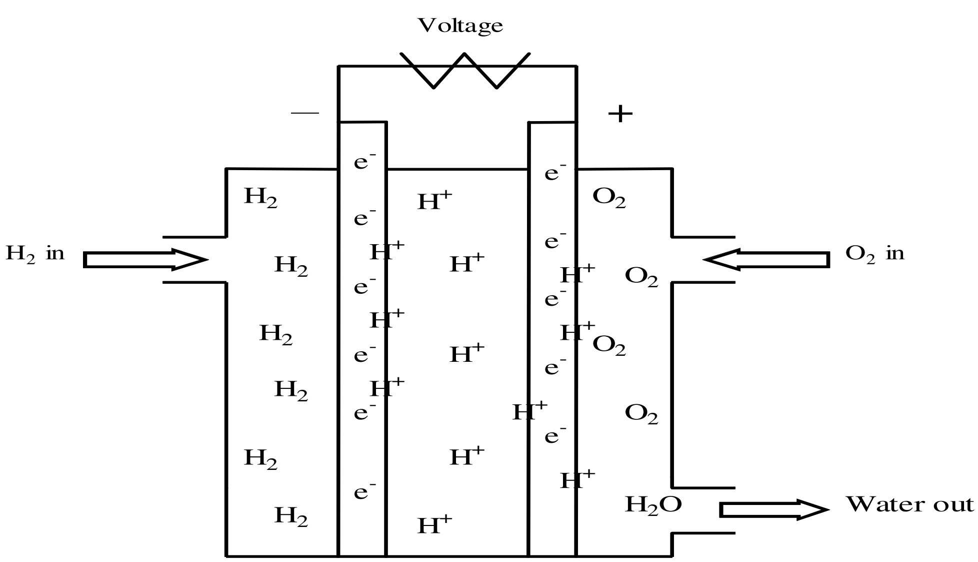

Figure 1. Schematic of a proton exchange membrane fuel cell

Anode: $H_2 \rightarrow 2H^+ + 2e^-$
Cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$
Overall: $\frac{1}{2} O_2 + H_2 \rightarrow H_2O$

Fuel cells have several compelling advantages over combustion based power generation devices. They generate electricity at efficiencies better than or comparable to the most advanced combustion systems while producing nearly no pollutant emissions. Their lack of moving parts makes them quiet and vibration free. Their modular design allows fuel cells to be stacked to meet nearly any load. Finally, the combined thermal and electrical efficiency of fuel cells used in a cogeneration system can be as high as 85% based on the HHV of the fuel.

Four primary types of fuel cells have thus far emerged. They are classified by the type of electrolyte: Proton Exchange Membrane Fuel Cell (PEMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC) (see Table 2). The different fuel cells operate at different temperatures. Each fuel cell has advantages and disadvantages that must be weighed when deciding which fuel cell to use for a particular application.

The PC25C Phosphoric Acid Fuel Cell

The PC25C phosphoric acid fuel cell (ONSI Corp., 1995) was chosen for use in this case study because it was commercially available, able to use natural gas as fuel, and has demonstrated over 900,000 hours of field service, characteristics which make it appealing to the industrial sector. It exceeds the American Gas Association's emission requirements (Table 3) and has a maximum sound level of 60 dB at 30 feet. The emissions of the PC25C are so low that they have been exempted from permitting requirements in The South Coast, Santa Barbara and Bay Area Air Quality Management Districts in California (Whitaker, 1995). The PC25C produces 200 kW of 3-phase electric power at 480 Volts, provides 700,000 Btu/hr of thermal energy, and is able to be connected to the utility's electric grid. The power generation specifications of the PC25C are shown in Table 4.

Table 2. Characteristics of fuel cells (Hirschenhofer et al., 1994)

Fuel Cell	Operating Temperature	Electrolyte
PEMFC	80-100°C	ion exchange membrane
PAFC	150-220°C	phosphoric acid
MCFC	600-700°C	molten carbonate
SOFC	650-1000°C	solid metal oxide

Table 3. Emission and sound pressure levels of PC25C (ONSI Corp., 1995)

Emissions	Emissions at 200 kW (ppmv, 15% O_2, Dry)	California Standards for Combustion Engines
NO_x	1	36
SO_x	Negligible	-
Particulates	Negligible	-
Smoke	None	-
CO	5	2000
Non-methane Hydrocarbons	1	250 (Reactive Organic Gases)
Noise	62 dBA at 30 ft	

Table 4. C25C Performance Specifications

Natural gas consumption	1.9 MMBtu/hr
AC power generation	200 kWh/hr (0.6826 MMBtu/hr)
Heat generation	0.7 MMBtu/hr
Electrical Efficiency	35.9%
Total Conversion Efficiency	72.8%

As of March, 1996, PC25Cs have been installed at 65 sites and have accumulated 981,505 hours of operation. (ONSI Fuel Cell Times, April 1996). Twenty-three of these units have operated continuously for over six months, and three units have operated continuously for over 8,000 hours. The early data indicate that the PC25C may have the reliability and low maintenance characteristics important for cogeneration applications. PC25Cs have been installed at hospitals, hotels, senior citizen centers, offices building, universities and airports. The fuel cell heat has been used for domestic hot water, laundry, space heating, boiler preheat, and other applications. A few sites have chosen not to use the PC25C's cogeneration capabilities and are only generating electricity. Of the 65 PC25C units installed as of March, 1996 only three are at industrial sites.

Case Study

The first step in performing the case study was to find an industrial site for analysis. A search was performed to find a site that matches the PC25C's 200 kW and 700,000 Btu/hr energy output. The site's lowest electrical demand had to be greater than 200 kW in order to fully utilize the electric generation capabilities of the fuel cell. In order to most effectively utilize the thermal energy generated by the fuel cell, the site needed to have continuous thermal processes. The thermal energy from the fuel cell could be used for space heating; however, because space heating is only needed five months of the year, thermal energy would be wasted during the rest of the year.

Using the University of Dayton Industrial Assessment Center's database of local manufacturing facilities, a local manufacturing firm was selected and agreed to be the subject of the case study. The facility is a three shift operation with peak electrical demands of about 600 kW. They run one or more boilers year round for process and space heating. The minimum electrical demand is greater than 200 kW year round (Figure 2).

Next, a thermal interface between the PC25C and the plant was designed (Figure 3). The PC25C is capable of providing hot water at a maximum temperature of 170°F hot water at 15 gallons per minute (Wheat, 1996). This temperature is insufficient to create steam and less than the condensate return temperature. Hence, in this plant, the fuel cell's thermal energy could be used only to preheat the boiler make-up water. A heat exchanger is required to transfer heat to the make-up water because the flow rate of make-up water was below the 15 gpm recommended for safe operation. This arrangement limited the amount of fuel cell heat that could be used by the facility. Only 6.5% of the available thermal energy from the fuel cell could be utilized.

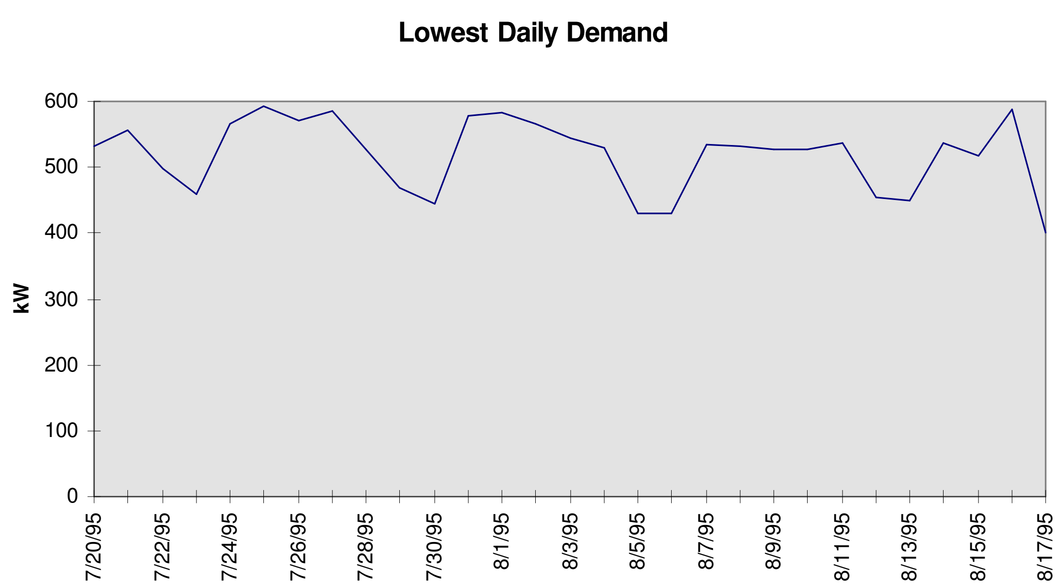

Figure 2. Minimum electrical demand at case study site from 7/20/95 to 8/17/95.

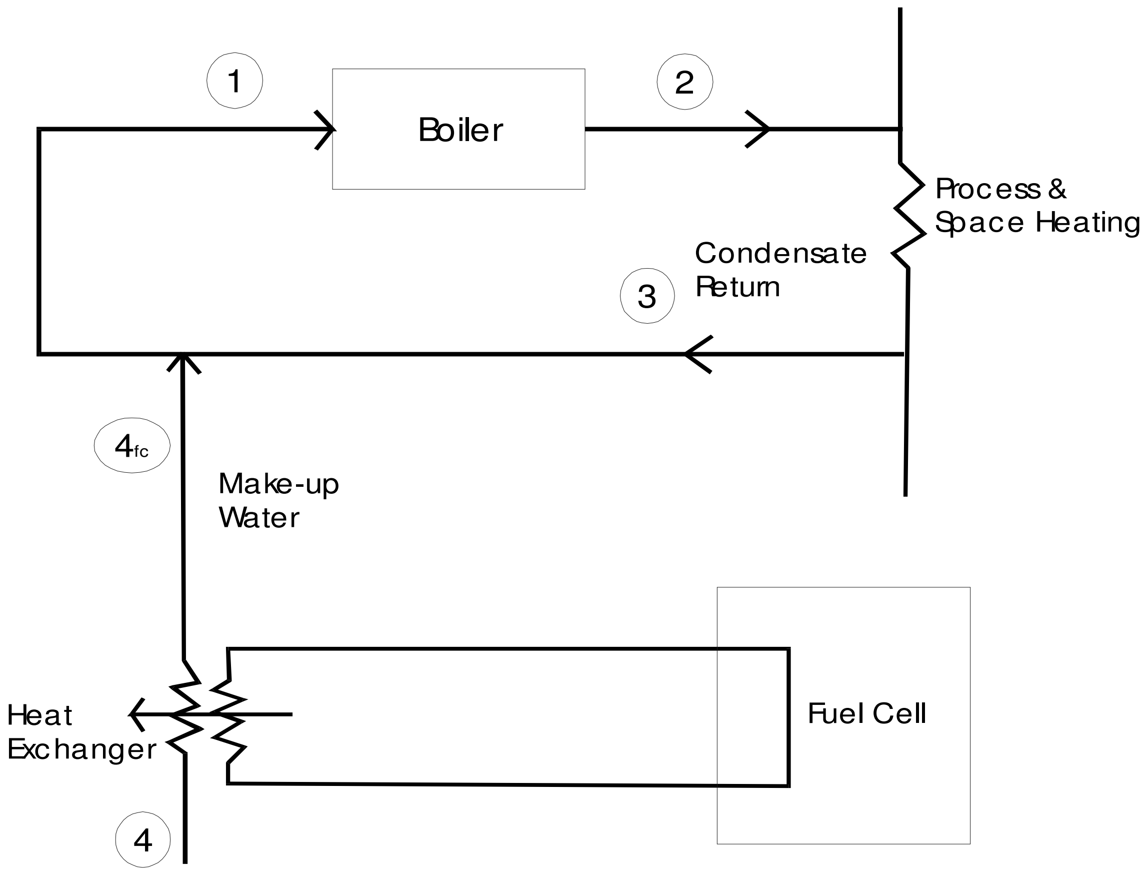

Figure 3. Thermal interface between the PC25C and the plant.

Using PC25C performance specifications (Table 4), local utility rates (Table 5), and a mathematical model of the cogeneration system, the annual cost of fuel, the electric demand savings, and the electric usage savings were calculated. The results of the analysis are shown in Table 6.

Table 5. Local marginal utility rates.

Electric Demand	$15.665/kW/month
Electric Usage	$0.02/kWh
Natural Gas	$3.10/MCF

Table 6. Fuel and maintenance savings.

	Annual	Savings
Electric Demand	200 kW	$37,596
Electric Usage	1,752 MWh	$35,040
Boiler Fuel	3,980 CCF	$1,234
PC25C Fuel	-166,440 CCF	-$51,596
Maintenance	-$0.0013 /kWh	-$1,234
Net		$19,996

According to Wheat (1996), the PC25C has a maintenance cost of $0.015/kWh. This includes scheduled and unscheduled maintenance, as well as a fuel cell stack replacement every five years. This breaks down to $0.0013/kWh for maintenance and $160,000 every five years for stack replacement. The stacks need to be replaced every five years because the phosphoric acid reserve is depleted.

The initial cost of a PC25C is about $600,000 and installation costs about $90,000. Recently the US DOE has appropriated $15 million for fuel cell rebates. The rebates are $1,000/kW, which amounts to about $200,000 for the PC25C. The net cost of PC25C is, therefore, about $490,000 plus a $160,000 stack replacement every five years. Assuming an discount rate of 10%, the present value of the capital cost is:

$$\text{Cap Cost} = \$490{,}000 + \$160{,}000 \times [(1+0.1)^{-5} + (1+0.1)^{-10} + (1+0.1)^{-15}] = \$689{,}337$$

The simple payback from the investment would be:

Simple Payback = Initail Cost / Annual Savings
Simple Payback = $689,337 / $19,996/yr = 34.5 years

FUTURE FEASIBILITY OF FUEL CELLS IN INDUSTRY

It is clear that the PC25C fuel cell is currently not a sound investment for the industrial facility in this case study. Several questions now arise. What does industry consider a sound investment for facility changes? How would the cost of electricity and natural gas effect the feasibility of the fuel cell? What industrial facilities will be able to fully utilize the fuel cell's cogeneration capabilities? Once these questions have been answered the potential for cogeneration at industrial facilities will be more clear.

The Department of Energy funds thirty Industrial Assessment Centers (IAC) at universities across the US These centers perform integrated assessments of medium-size industrial facilities, trying to find ways to reduce energy and waste and improve productivity. Each center performs follow-up interviews six to twelve months after the assessment to determine which recommendations were implemented. The recommendation and implementation data are stored in a database for public use (IAC, 1996).

These data were analyzed to see what industry considered a sound investment (Figure 8). The majority of the recommendations had simple paybacks of six months or less. Interestingly, even with simple paybacks as long as five years, 40% of the recommendations were implemented.

The simple payback for the PC25C fuel cell in an industrial facility is dependent upon the cost of: the fuel cell, stack replacements, maintenance, electric demand, electric usage, and natural gas. In order to determine how these variables affect the economic feasibility of the system, the number of variables was reduced from 6 to 4. The initial cost and stack replacement cost were combined as the present worth of the capital cost. Next, the peak demand, and electric usage cost were combined to generate the average cost of electricity in $/kWh. These reductions give simple payback as a function of only four cost variables: purchase, maintenance, electricity, and natural gas. Keeping the cost of maintenance constant, the simple payback was calculated for each of the three variables while the other two were held constant. The annual savings were calculated assuming the ideal case where all available heat from the fuel cell is utilized and including the $200,000 US DOE rebate.

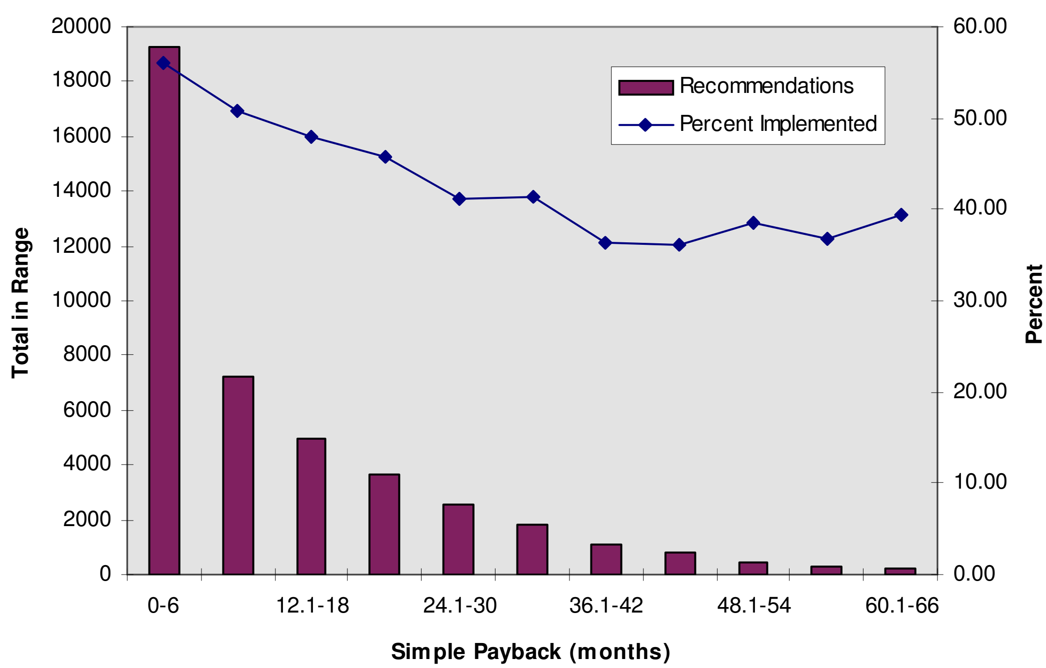

Figure 4. Simple payback vs. percent of energy saving recommendations implemented (IAC, 1996).

The simple payback is a linear function of capital cost when all other variables are held constant. For a simple payback of five years the capital cost would need to be reduced by approximately 70%.

The cost of electricity turns out to be the most promising in terms of the fuel cell's economic acceptance. While the average cost of electricity for industry is approximately $0.047/kWh, a cost of $0.07/kWh, which is common in New York and California, gives a simple payback of under eight years (Hochanadel & Aitken, 1996). A cost of $0.10/kWh reduces the simple payback to only five years (Figure 5). The simple payback increases dramatically as the cost of natural gas increases (Figure 6). Thus regions with high electricity and low natural gas prices are economically favorable for fuel cell cogeneration.

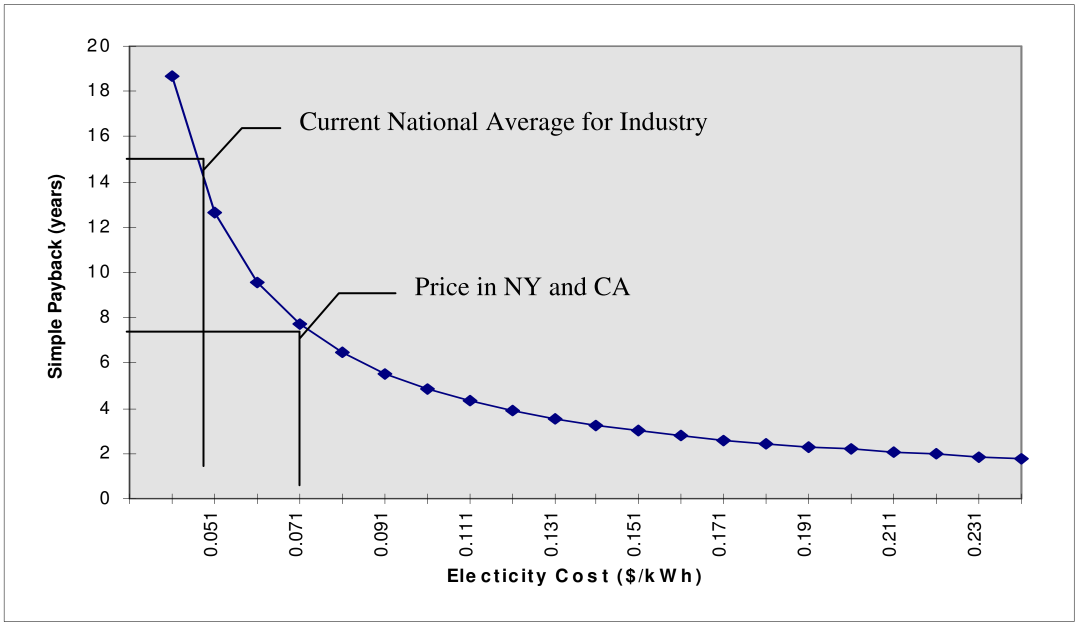

Figure 5. Simple payback vs. cost of electricity, with other costs held constant.

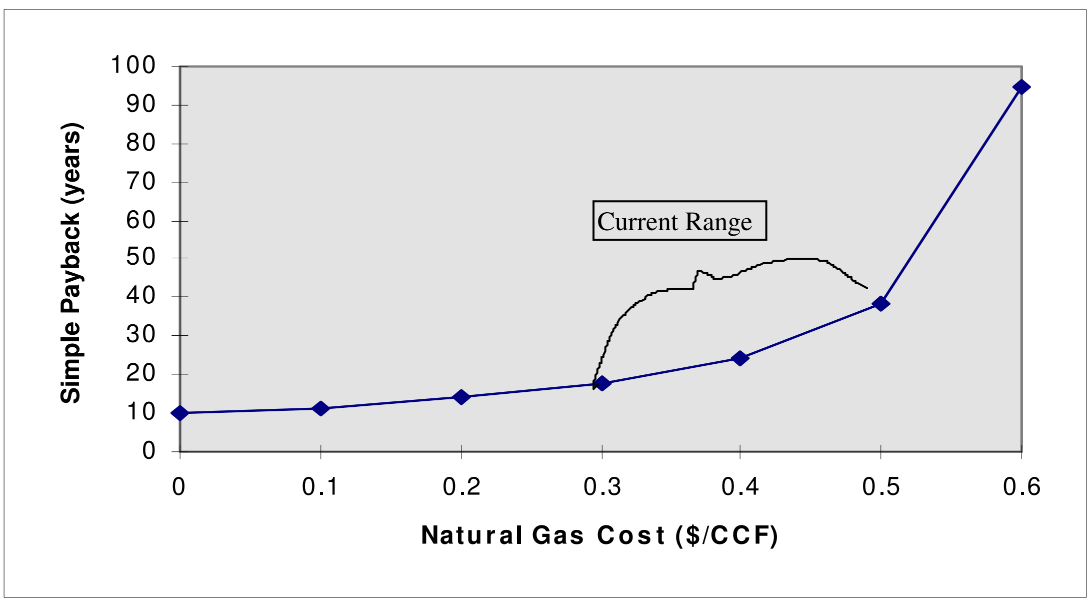

Figure 6. Simple payback vs. cost of natural gas, with other costs held constant.

Another common metric used to compare energy conversion technologies is the capital cost per kilowatt generated. From the present worth and simple payback calculations we determined that an initial cost of $950 per kilowatt would allow the system to payback in five years. This does not seem to be unattainable because the fuel cell industry is still on a steep learning curve and, just like any emerging technology, the manufacturing costs should decrease with increased sales. For example, it has been projected that a mass produced proton exchange membrane fuel cell could cost as little as $40 to $60 per kW (AGTD, 1994; Wilson et al., 1995).

CONCLUSIONS

Several important results arose from this study. The first is that industries which rely primarily on steam for their thermal requirements will only be able to use a small fraction (about 6.5%) of the total thermal energy generated by this fuel cell. To utilize more than this, an industry would need to have one or more continuous processes that can use heat at 185°F or less. Second, the simple payback for a cogeneration system is highly sensitive to the cost of natural gas; the lower the cost of natural gas the better. The opposite is true for electricity. A reasonable payback of five years can be achieved if the cost of electricity is only $0.10/kWh with natural gas at $3.10/MCF. Finally, given current energy prices, the capital cost of the fuel cell (including stack replacements every five years) would need to decrease to about $950/kW for fuel cells to become economically attractive.

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