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Life cycle analysis of stationary fuel cells

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ABSTRACT

Stationary fuel cells have the ability to produce electricity at efficiencies much higher than those of traditional power plants. In doing so, the fuel cell all but eliminates the harmful effects on the environment. Recent technological advancements to the fuel cell have made it a viable source of energy in certain niche markets. It is not known at this time when full market entry will occur but there must be a significant drop in the $4,000-$5,000 / kW for the fuel cell to provide economic benefit to the owner. The focus of this report is to conduct a financial analysis of the fuel cell life cycle with the purpose of determining when market entry may occur. The analysis has been performed on the life cycle of a 200 kW fuel cell unit including initial costs, future energy savings, future costs, and stack replacements. An economic spreadsheet produced by the Department of Defense is the starting point of the study and has been expanded upon to determine present value. The analysis is conducted using the time value of money approach that involves finding the net present value, the discounted payback rate, and the project's rate of returns. Government incentives for fuel cells and other distributed generation technology are discussed along with the effect they have on market entry.

CHAPTER 1: INTRODUCTION

Over the past few decades the world, particularly the western world, has become increasingly more dependent on electricity for day-to-day activities. Whether relying upon electricity to heat your home during the winter (or cool it during the summer), turning on the television to watch your favorite program, or using the oven to make a meal, you rely on electricity to be there. Unfortunately there are times when the power is not there as you expect it to be. While this is an inconvenience, it is generally assumed that limited power outages will occur from time to time.

Now image that this power outage of 2 minutes causes you to loose somewhere in the range of six million dollars. Is this "inconvenience" still as insignificant as in the example above? Of course not! Suddenly the 97% reliability provided by the electric grid proves to not be enough. This example is what happened to the First National Bank of Omaha when it's building experienced a momentary voltage sag in 1997. The outage that lasted mere seconds ended up costing the bank over $6 million per hour of downtime in lost transactions and wires. In the current times of 24/7 account access 365 days a year, higher reliability is required by institutions who offer these services. Studies have shown that power fluctuations cause annual loses of $12-26 billion nationwide. [(1)]

The solution First National Bank of Omaha chose was to install four 200 kW fuel cells onto the building power system. A fuel cell is a device that produces electricity from a chemical reaction, very similar to a battery. The system runs on external sources or energy, hydrogen and oxygen, so unlike the battery, a fuel cell never stops working as long as the fuel source is available. The fuel cells for the bank were attached in parallel with the grid power system, which means both sources were used simultaneously to provide the building's power needs. The cells, purchased from Sure Power Corp., provided 99.9999%

reliability to meet the bank's around-the-clock account access. The added 800 kW of power not only increased reliability but it lowered the peak demand charges the bank incurred from the electric municipal. In the end, the fuel cell was the best solution to meet the dependability needs of the banking systems as a cost effective, economic solution.

In regions where power economics are controlled by the high costs of electricity, fuel cells provide a cost efficient way to offset the electric costs. Electric utilities allow for lower rates but generally with a loss of reliability, which, as stated above, is not an option for a lot of companies these days. As electricity costs continue to rise, the fuel cell will help pay for itself with the annual cost savings on electricity. This is true except in areas where gas prices are considerably higher than the cost of electricity.

The second main issue at hand, other than reliability, is the need to greatly increase electric capacities in both domestic and international markets. According to the U.S. Department of Energy, it is estimated that the domestic demand for new power and replacing lost capacity will be 363 gigawatts by 2020 [(2)]. On top of that, international forecasts show that total worldwide electricity consumptions rising to 22 trillion kilowatts-hours by 2020, which almost doubles the 12 trillion kilowatts-hours consumption in 1996.

Just as producing new power is important, it is also necessary to install and erect new infrastructure as a means of transmitting and distributing (T&D) electricity. With the current infrastructure operating at its maximum capacity, problems will occur when the demand exceeds T&D abilities. As you may recall in summer of 2001, California experienced rolling blackouts throughout much of the southern part of the state. As stated in the earlier example, outages can cause businesses to loose millions of dollars because of downtime or costs associated with the startup of manufacturing processes. Installing new T&D lines to relieve this problem is both timely and costly to the electric utilities and ultimately the consumers.

The Fuel Cell Solution

One solution to the reliability and infrastructure problems is the use of fuel cells to meet energy needs. A fuel cell is a type of energy solution that falls under distributed generation (DG). These units are characterized as "small, self-contained electric generating plants that can provide power to a single home, business, or industrial facility." [(3)] DG provides power to a single site rather than the site getting power from typical power plants or electric utilities. Distributed generation includes fuel cells, reciprocating engines generators, gas turbines, photovoltaic cells (solar), and wind generators as the basic options.

Fuel Cell Advantages

Fuel cells have some distinct advantages over the other forms of distributed generation. First, they use a chemical reaction to transform fuel into electric power. There are virtually no moving parts so the machine is very quite, and with proper operation they produce virtually no pollutants. Permitting can be done very quickly for these two reasons.

The potential for fuel efficiencies go far beyond even the most advanced generators or microturbines, another reason fuel cells are alluring. Combined cycle applications are the reason for the high efficiencies. When the chemical reaction takes place the resultants are water, heat, and a very small amount of pollutants considered to be of no concern. The heat can be collected and used to for other applications such as heating water. Of course there is one major drawback to fuel cells at this time, cost per kW.

Another potential benefit of fuel cells is their use of fuels such as natural gas, kerosene, methane, or propane for operation. With the ongoing concerns in the Middle East and the nations oil supply, fuel cells could lessen our reliance on foreign oil. Doing so could help the United States economy if war or related actions would stop our oil supply. The Energy Policy Act of 1992 stated that one of the Department of Energy's (DOE) primary goals was to decrease the nation's dependence on foreign oil and increase energy security through the use of domestically produced alternative fuels. [4]

The Electrical Industry

Why is this technology important to the electrical industry? How can they benefit from fuel cell research and development? The answer is simple – more products and more services. If the industry obtains control of the market look for more products, parts, and equipment to run through the distributors and that means more revenue. As fuel cells continue to grow, more expertise will be needed to install and maintain the units. By 2004, California alone will install 500 MW of additional power from fuel cells. A California Stationary Fuel Cell Collaborative will facilitate the project. [5] Why shouldn't the service be provided by electrical contractors?

Uninterruptible power supplies (UPS), including fuel cells, will also be used to meet added electrical requirements across the nation. In a report compiled by the Darnell Group, Inc., a publishing and consulting company that specializes in power electronics, it was shown that worldwide UPS will have an annual growth rate of 6.1% and reach $7,203 million by 2006. That number is up from their 2001 forecast of $5,348 million. It should be noted that UPS will have a slower growth rate the first few years and then accelerate upward towards the end of the period. [6]

When it comes to distributed generation, a good comparison can be made to developing countries and their use of cell phones instead of landlines. Installing landlines is costly and time consuming, so instead these countries are in the process of placing cellular towers to meet their communication needs. Doing so saves lots of time and money unlike the United States where the lines already exist. By using distributed power (i.e. fuel cells) in the same manner as cell phones are being used, those countries can avoid the transmission and distribution costs while increasing the reliability of the power source.

Another good reason for electrical contractors to get involved with fuel cells is the government appears committed to developing the technology. There are many government incentives for companies wanting to be leaders in the use of fuel cell technology and even more money for those researching and improving fuel cells. The research and competition will certainly drive down the cost per kW of the units.

The final incentive for electrical contactors to get involved with fuel cells is that no one industry currently controls the technology. Many different industries will be vying for control of the fuel cell market. Since the fuel cell is ultimately an electrical unit, it makes sense for electrical contractors to do the checks and scheduled maintenance. The electrical industry has just recently gained control of the low voltage power systems such as computers, phone, and voicemail-video systems that is should have had from the beginning. It is better to be proactive with new technologies than reactive years later.

Research Goals

The goal of this paper is to give a background of fuel cells and produce a life cycle analysis of the system. The first step was to expand the economic cost savings spreadsheet provided by the Department of Defense into a lifecycle analysis. Initial costs, annual maintenance, annual savings, salvage value and incentive programs are all incorporated in the analysis. A sensitivity study is to be conducted to find out the effects of changing the values of gas, electricity, contractor's cost of capital, and most importantly the fuel cell cost.

The life cycle analysis is done with the main goal of determining at what cost per kW fuel cells will fully enter the market. Electrical contractors can use this information to determine if it is a good business strategy for their industry to get involved with fuel cell installation and maintenance. Another goal was to find out if government incentive programs will have an impact on when fuel cells will initially enter the marketplace.

CHAPTER 2: TECHNOLOGY BACKGROUND

The fuel cell is an energy solution that falls under Distributed Generation (DG) or Uninterruptible Power Supply (UPS). In order to fully understand what a fuel cell is, one must first understand a little bit about DG. This chapter is designed to give a brief overview of distributed generation, it advantages, disadvantages, and then more about the fuel cell.

Distributed Generation

Distributed generation is characterized as "small, self-contained electric generating plants that can provide power to a single home, business, or industrial facility." [3] Power is provided to a single site by DG instead of receiving it from the electric utilities. Distributed generation includes fuel cells, reciprocating engines, gas turbines, photovoltaic cells (solar cells), and wind generators as the main technologies. Table 1 tells a little about each system's capability and efficiency.

Table 1 - Summary of Distributed Generation Technologies

	IC Engine	Microturbine	Solar Cells	Fuel Cells
Dispatchability	Yes	Yes	No	Yes
Capacity Range	50 kW - 5 MW	25 kW – 25 MW	1 kW - 1 MW	200 kW - 2 MW
Efficiency	35%	29-42%	6-19%	33-57%
Capital Cost ($ / kW)	200-350	450-1000	6,600	3,750-5,000
O & M Cost ($ / kWh)	0.01	0.005-0.0065	0.001-0.004	0.0017
Nox (lb / Btu)				
Natural Gas	0.3	0.10	---	0.003-0.02
Oil	3.7	0.17	---	---
Technology Status	Commercial	Commercial in Large Size	Commercial	Commercial Scale demos

Distributed generation never became a practical energy source until recently. The reason was the economy of scale was never in the favor of DG. When larger generators where installed there was an overwhelming advantage of these units to be more cost efficient. Recent advances in technology have greatly reduced the economy of scale where the small units are quite competitive as shown in Figure 1.

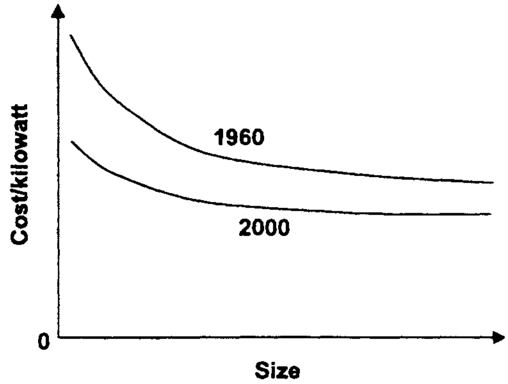


Figure 1 - Economy of Scale

Distributed generation systems are generally considered to be more reliable than the electric grid. This reliability continues to improve when connected in grid-parallel mode, which means that both the DG and the electric power grid are supplying the site with electricity. One major advantage of DG has over the power gird is the ability to supply energy independently. The modularity of the systems allows power to be provided quickly and easily to remote locations without waiting on transmission lines to be installed.

The deregulation of electric utilities opened the door for more distributed generation opportunities. Beginning with the *Energy Policy Act* (EPAct) of 1992, there are fewer barriers than ever for DG to become a viable electric solution. The act required interstate transmission line owners to allow all independent electric generators access to their lines. Interconnection of DG allowed electricity to be introduced to the grid with the opportunity to sell it back to the utility. Disagreements have arisen over net metering and other interconnection issues over the past few years. Although no one knows how deregulation will ultimately end up, the outlook for DG is promising because of it.

Eventually it is believed that distributed generation will win the battle over central generation for supplying the world's power. The DG systems will prevail because of proximity to the site, not overall efficiency. The avoided T&D costs of having the power generated on site is so vast that central generation should never be able to keep up. The current infrastructure has a high initial capital cost, continuing O&M, and reliability issues all caused by T&D costs. Given distributed generation costs continue to drop while T&D costs continue to rise will help DG to be more widely used in the future.

Distributed Generation Concerns

Concerns have arisen regarding the use of fuel cells and other distributed generation with the existing power grid and infrastructure. The first main concern regards technical barriers such as negative energy flow into existing T&D lines. There must be safety measures taken to be sure a dead line does not suddenly become charged when workers are present. Most of the technical issues can, and are, being approached with additional switchgear and more research.

Another issue regarding DG is the amount of investment that has already been put into the existing power plants and how the electric municipals will recoup the cost of their investments. There was an initial investment on someone's part and they have the right to recoup the cost of another person using their investment. Building on this idea are the barriers that will come from the existing infrastructure with tariffs, extra costs, and other barriers either actual or perceived.

Fuel Cells

Now the focus is going to switch to the fuel cell. Fuel cells are energy conversation devices that continuously transform the chemical energy of a fuel and an oxidant into electrical energy. They act like a continuously fueled battery to produce DC power using an electrochemical process. While the technology has been around for a while it never gained popularity because of the arrival of the combustion engine in the 1800's. Recent technology advances have re-fueled interest in fuel cell systems. This chapter will discuss the origins of fuel cell technology, how it works, how the efficiency is produced, future energy trends, and concern for the new technology.

Origins

Fuel cells are by no means a new technology. The origins can be traced back to the late 1830's to an English barrister and amateur physicist, Sir William Grove. Grove took the well know chemistry principal of electrolysis, reversed the process, and created electricity. The discovery never took hold during that era because the internal combustion engine was being developed in Germany concurrently with the discovery of oil reserves around the world. People quickly realized how the engines could make their life better at a relatively small price and felt that fossil fuels would never run out. No one understood what harmful effects would later result from the combustion of earth's fossil fuels. (7)

It wasn't until the years of the Gemini and Apollo space missions that the fuel cell was revitalized. NASA used fuel cell systems onboard the space shuttles as a means to generate energy and produce water for the astronauts to use. These exotic applications paved the way for future expansion of fuel cells to the consumer.

Today fuel cells are becoming the focus of many research and development groups as well as government agencies. Technology improvements are the basis for the newfound interest and the reason costs are beginning to come down. The main changes involve the reduction in the amount of platinum used in each system and the introduction of a reformer to supply hydrogen to the fuel cell. A reformer changes petroleum-based fuels, such as natural gas, to hydrogen and allows the current infrastructure to supply fuel to the fuel cell.

Fuel cells can be used in many different types of applications and on most types of buildings even though the cost currently limits them to niche markets. Fuel cells provide power solutions in many situations similar to the ones listed here.

- Stand Alone Power Generation
- Standby or Peak Shaving
- Quality Power Generation
- Combined Heat & Power Generation
- Reliable Power Generation

Fuel cells are particularly useful when reliability is a key issue such as the example of First National Bank of Omaha in the introduction. In this project the fuel cells were used alongside the power grid to increase dependability of the power source for their computing systems.

How Fuel cells Work (2)

Fuel cells produce power electrochemically by passing a hydrogen-rich gas over an anode and air over a cathode, and introducing an electrolyte in between to enable exchange of electrical changes called ions. Since hydrogen has a natural tendency to react with the oxygen in the air, one of the streams becomes charged. The ions flow then causes an electrical current in an external circuit. Figure 2 on the next page is a good illustration to show how the process works.

The byproducts of the reaction are heat, carbon dioxide, and water with no solid waste being produced. The heat can be recaptured and used in other applications thus increasing efficiency of the fuel cell. Carbon dioxide is on a very minute scale and in a concentrated form ideal for recapturing. Water is the final byproduct and comes out of the system suitable for drinking.

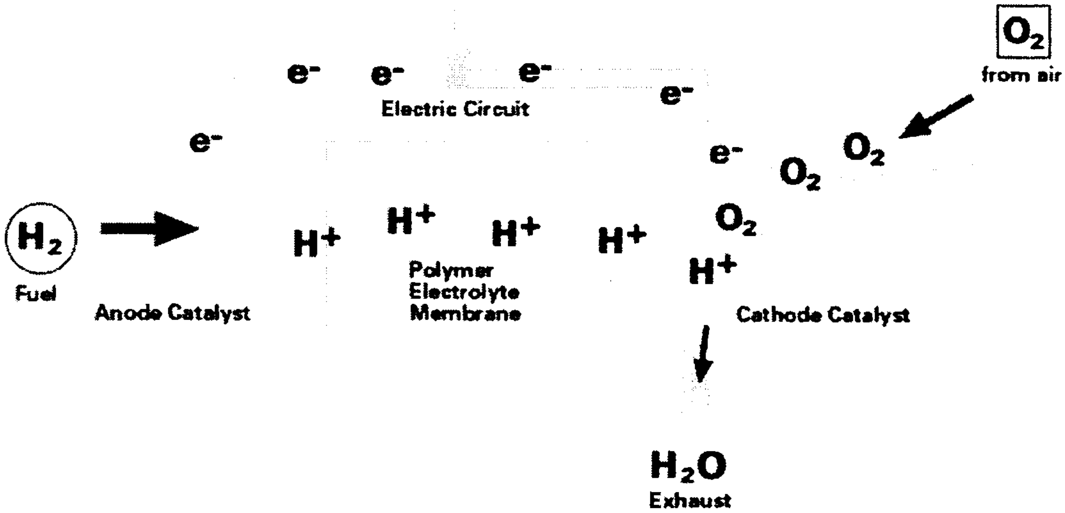


Figure 2 – Reverse Electrolysis

Fuel cells produce DC power much in the same way as traditional batteries. Therefore, a complete fuel cell system made for power distribution includes a converter. A converter takes DC power produced by the fuel cell and converts it to AC power. The converter is included upon delivery of the fuel cell unit.

Stacks

In reality a fuel cell is a small unit that produces 0.5 to 0.9 volts per cell. Cells are then combined into stacks to obtain a usable voltage and power output. The cells are assembled in stacks and connected in series to build up the energy. The system converts the majority of the chemical energy stored in the fuel to electricity creating a high efficiency. Unlike conventional power systems that require larger sizes to gain efficiency, a fuel cell's size has little effect on efficiency when generating power or when changing the applied load.

Reformers [8]

If you recall, fuel cells run on hydrogen and oxygen to produce clean and efficient energy. The problem is bottled or piped hydrogen is expensive and difficult to deliver so we turn to fossil fuels to supply the energy. Natural gas is the most common fuel used in stationary applications but any hydrocarbon can be used. When using fossil fuels, the fuel must undergo "reforming" to release the hydrogen from the carbon bonds. The job of the reformer (catalytic converter) is to provide relatively pure hydrogen to a fuel cell by stripping it out of a hydrocarbon fuel.

Natural gas is composed mostly of methane (CH_4) and is processed using the following reactions. Water vapor reacts with the methane in the natural gas to form hydrogen and carbon monoxide gases.

$$\mathbf{CH_4 + H_2O \Rightarrow CO + 3H_2}$$

Equation 1

The water vapor then splits into hydrogen gas and oxygen, the oxygen combining with the CO to form CO_2.

$$\mathbf{H_2O + CO \Rightarrow CO_2 + H_2}$$

Equation 2

Naturally some of the natural gas and carbon monoxide escape without reacting since reactions are not perfect. The material that gets through is burned by the fuel cell catalyst, which turns the remaining CO to CO_2 and the remaining methanol to CO_2 and water. Various other devices may be used to clean up any other pollutants that may be in the exhaust stream.

Today commercially available fuel cells have an external reformer. The fuel passes through this reformer, is cleaned up, and then delivered to the power generator. The waste is then either recycled back through the reformer or exhausted from the system as shown in Figure 3.

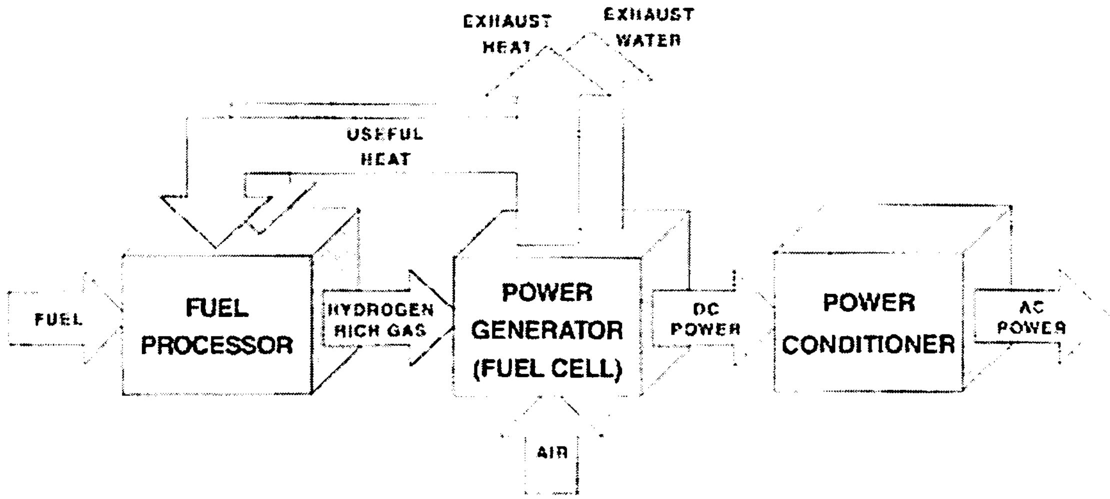


Figure 3 – Fuel Cell System

A major problem of the reforming process is the decrease in overall fuel cell efficiency caused by the reformer. Many consider this to be the key item that will lead to the acceptance of this technology and the reduction in price of fuel cells. Hopefully the onset of internal reformers will help alleviate this issue.

The newer generation fuel cells are being equipped with an internal reformer so the fuel can be delivered directly to power generator. The reformer is itself a catalyst converter so it and the reactions of the catalytic oxidizer of the power generator will occur simultaneously. Even though controlling two catalytic processes at the same time is more difficult, convenience is expected to propel self-reforming fuel cells ahead of the rest.

Types of Fuel Cells [3]

The type of catalyst used in the electrochemical reaction characterizes the fuel cell. There are four main types that are being focused upon for generating power in the stationary market: proton exchange membrane fuel cells (PEMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), and solid oxide fuel cells (SOFC). Each fuel cell operates at a different temperature which correlates to the total efficiency that can be obtained. The Carnot Cycle states that the higher the high temperature, the greater the efficiency or the cooler the low temperature, the higher the efficiency. (Equation 3)

$$\text{Upper limit on engine efficiency} = \frac{T_{high} - T_{low}}{T_{high}}$$

Equation 3 – Carnot Cycle

Table 2 shows the characteristics of the major fuel cell types mentioned above. Notice the higher efficiencies associated with the increased internal temperature of the fuel cell. A more detailed description of each fuel cell will be addressed after the chart.

Table 2 - Summary of Fuel Cell Types

	PEMFC	PAFC	MCFC	SOFC
Electrolyte	Polymer membrane	H_3PO_4 Lithium carb.	$LiKaCo_3$ Zirconia	Stabilized
Typical construction	plastic, metal	Steel	titanium	ceramic
Self-reforming?	No	No	Yes	Yes
Oxidant	Use air	Use air	Use air	Use air
Internal Temp.	85°C	190°C	650°C	1000°C
Basic cell efficiency	30%+	≈ 40%	≈ 42%	≈ 45%
Typical application	car, spacecraft	DG	large DG	very large DG

Proton Exchange Membrane Fuel Cell (PEMFC)

PEMFCs have the lowest temperature of the fuel cells, operating around the boiling point of water. They are generally used in cars and spacecraft because of the low operating temperature and long life but do have some applications to residential consumers. A solid polymer electrolyte is used as the catalyst but the low operating temperature means the efficiency is also the lowest. Another main disadvantage of the PEMFC is that it is highly intolerant to carbon monoxide and the reaction will stop if the incoming hydrogen is polluted.

At this time Plug Power LLC is testing the PEMFC technology for use in residential applications. The company has just recently commercially released a system capable of producing 5kW of electricity and 9kW of heat captured during the electricity production. The systems are expected to be sold globally through a joint venture with General Electric and DTE Energy Technologies.

Phosphoric Acid Fuel Cell (PAFC)

PAFCs are the most mature and tested fuel cell technology appropriate for stationary applications. The units use phosphoric acid as the electrolyte and platinum as a catalyst. Waste heat can easily be collected for use in other applications thus improving the efficiency of the system. PFACs are considered to be commercially available but because of the high cost the units are only practical in a few specialty markets. The use of platinum and the intolerance to impurities are the main disadvantages of the PAFC.

At this time UTC Fuel Cells has delivered over two hundred ONSI PC25 200 kW units for operation in the United States and around the world. The units have logged over 5 millions hours of operating experience in various environments. The Department of Energy (DOE) is heavily involved in research and development and has a partnership with UTC.

The fuel cells produced by UTC are the focus of the study. They are the being researched by the DOE and a lot of information available to review. [9]

Molten Carbonate Fuel Cell (MCFC)

MCFCs use molten carbonates as an electrolyte and have a number of advantages over the PAFC units. One advantage of the MCFC is that reforming can take place internally meaning natural gas is converted to hydrogen directly within the fuel cell. MCFC units operate at higher temperatures which translates into better efficiency and more heat production for co-generation applications. The temperature can cause problems because of the considerable heat required to "start" the units and the realization they are not suitable for small modular manufacturing.

Field-testing of these units is being conducted and the DOE has gotten involved to assist manufacturers with the development and commercialization of the MCFC. Two leaders in this field are Energy Research Corporation (ERC) and M-C Power (MCP) who are both in the testing stages. ERC has an efficiency goal of 55% for large-scale plants and MCP is conducting tests on a 250kW system at Miramar Naval Air Station near San Diego.

Solid Oxide Fuel Cell (SOFC)

The highest of the operating temperatures is found within the SOFCs. This type of fuel cell is made out of ceramic material due to the fact that most metals would weaken at the high operating temperature. Similar to the MCFC, the SOFC has higher efficiencies, more usable waste heat, and the ability to have internal reformers.

The SOFC is the least developed of the fuel cell technologies and is not close to commercial use. Many improvements are needed before the product will be commercially available. SOFCs have tremendous potential with companies such as Siemens Westinghouse Power Corporation, and Ztek Inc leading the research and development.

Fuel Cell Benefits [1]

"The cleanest, most efficient electric power plants on the market." This is how the U.S. Department of Energy describes fuel cells in a packet on fuel cells. They go on to say the technology "is on the verge of revolutionizing the electric power industry". Whether this is true or not is yet to be seen, and many demonstration projects are in the process of finding out. There are many known benefits of fuel cells and these will be briefly addressed.

- Negligible air emissions
- Higher efficiencies than conventional plants
- Added efficiency with heat recovery
- Customer choice
- Reliable, uninterruptible generation
- No moving parts - quiet
- Fuel variety
- Extreme mobility
- Eliminate T & D costs

Negligible Air Emissions

The world today is concerned with the environment and the impact humans are having on the planet. The ultimate goal for electricity is to produce more energy without emitting more pollutants, which in most cases is almost impossible. Fuel cells allow for the production of energy with almost no hazardous emissions and generate no solid waste. The fuel cell is so environmentally friendly that it has received blanket exemptions from regulations in many parts of the country including environmentally sensitive states such as California, Connecticut and Massachusetts.

Efficiency

Fuel cells offer efficiencies competitive with other forms of distributed generation and power plants. The efficiency continues to increase when heat recovery is included in the process. These numbers are consistent and not a function of unit size or applied load. The heat recovery is ideal for commercial, industrial, and residential applications and has the ability to raise total efficiencies up to 85%.

Customer Choice

The customer has the ability to meet any electrical load that is desired. Fuel cells can be designed at any size, to meet any capacity, without any change in efficiency. Modular units will likely be the norm since economy of scale comes into play with manufacturing. The number of modules will have no effect of productivity meaning one 800 kW unit would have same efficiency as four 200 kW units connected together.

Reliability

Fuel cells promise to be one of the most reliable sources of energy in the future. On-site power generation eliminates voltage spikes and typical problems associated with the power grid making the fuel cell ideal for sensitive equipment such as computers and hospital equipment. While this hasn't been proved at this time, research continues and demonstration projects are underway to test reliability.

System Requirements

Fuel cells are very flexible when it comes to operating requirements. They can run on various fossil fuels, such as natural gas or methanol gas, that are reformed to produce the hydrogen the system runs on. Sources of alternative fuel include biogas, landfill gas, or other hydrocarbon fuels.

The variety of fuels lends a high degree of mobility of the fuel cell units to places that normally wouldn't be able to receive cost effective power solutions. Remotely located buildings can now remove the cost of transporting the energy to meet their needs.

Technology Development and Barriers

The benefit of fuel cells seem to be endless and makes one wonder why the technology hasn't become more prevalent in the current market. While there are numerous reasons at this time the main ones are listed below. (10)

- Cost per kW
- Fuel Flexibility
- System Integration
- Endurance and Reliability
- Industry Barriers

The obvious issue that comes up is the enormous capital investment of purchasing a fuel cell. Manufacturing costs are in the range of $4,000-$5,000 / kW and aren't expected to become competitive until the cost is reduced by at least $1,000-$2,000. Competition and mass production will help reduce this cost.

Fuel flexibility seems to be a non-issue with the fuel cell since most fossil fuels can be used to create hydrogen. The problem occurs when there isn't a primary source of the fuel leading to the system or the source of hydrogen is not pure enough for the cell. By making the technology able to handle different types of fuel or impurities within the fuel source, the fuel cell will increase market penetration.

System integration is a concern not only for the fuel cell but all types of distributed generation (DG). When contributing electricity to the power grid, the DG source must match the wave, voltage, and other requirements to ensure the integrity of the grid. The electric industry is currently looking at interconnection requirements and once a system has been agreed upon the technology will be allowed to meet the power grid needs.

Fuel cells have demonstrated the ability to deliver quality power at remarkably high efficiency with very little, if any at all, environmental implications. The problem is that the reliability and endurance of the systems have not yet been proved. There are many demonstration programs up and running to test the fuel cell's ability to perform with the same efficiency during long-term testing as they have seen during short-term testing.

The last barrier could ultimately be the hardest to overcome. The current power grid has been set up and developed with tremendous financial investment on the part of investors. When electricity is purchased from a utility, the price reflects the cost of not only generating the electricity but also getting it to the consumer. If fuel cells or other forms of distributed generation are used, how is the investment of T&D going to be recovered by the utilities? People's reluctance to change is difficult to overcome in such situations.

Energy Trends – A Hydrogen Future?

Energy needs will continue to rise as will the need for clean, more efficient sources of energy. As previously stated, it is estimated that the domestic demand for new power and replacing lost capacity will be 363 gigawatts by 2020 and international forecasts show that worldwide electricity consumptions rising to 22 trillion kilowatts-hours by 2020 [(2)]. Looking at the world's energy history one will see a basic progression up the hydrocarbon chain. Humans started by burning wood, then coal, then oil, and now natural gas. Each step helped to reduce the amount of pollutants that are emitted by reducing the amount of carbon associated with each change. Ultimately to produce energy with the least amount of pollutants the world will need to transform to hydrogen based energy system.

Since the 1930s, hydrogen has been receiving a lot of attention within academic, scientific and political circles. As a nonpolluting and renewable form of energy, the possibilities of using hydrogen seem endless. When hydrogen is burned in an internal-combustion engine, it releases a practically harmless water-vapor exhaust and doesn't emit pollutants when burned, reports the "Futurist." Hydrogen is also a major element of fuel cells for cars and other uses. Hoffman says that fuel-cell engines can be more than twice as efficient as internal-combustion engines. Daimler Chrysler is spending $1 billion in the next 10 years on fuel-cell work and is joining forces with Ford and Ballard Power Systems to sell fuel-cell buses in Europe later this year.

Hydrogen's major advantage is that is can store large amounts of electricity for future use while remaining clean and efficient. Currently hydrogen is removed from fossil fuels, a process that lessens the efficiency. There is the ability to change to a hydrogen market at this time, but it is commonly believed that fuel cells vehicles are going to pave the way towards a hydrogen-based energy system. Once technology and the infrastructure improve, look for hydrogen to be the fuel of choice.

CHAPTER 3: FINANCIAL BACKGROUND [11]

Lifecycle analysis is a main key for determining if a building owner is interested in using a new technology. The following information covers the method of analysis using the time value of money approach. The first topic of importance when discussing time value of money is that money today will not be worth the same amount in the future. As you go out further and further the present worth becomes less and less. There are many reasons that this happens but it basically comes down to if you had the money today, you could invest it and earn interest thus giving you more money in the future. It is a requirement to take this into consideration when determining the life cycle of a potential project.

A key input in lifecycle analysis is determining what it costs a company to borrow money or raise capital. This will be referred to as the weighted average cost of capital (WACC) through the remainder of the paper. Companies typically obtain financing through a mixture of debt, preferred stock, and common stock if they are publicly owned. Private companies may only be able to raise money through loans or other private sources. Either way leaders of a firm should be aware of the firm's optimal capital structure as well as their WACC. Both will be used in the financial evaluation of the fuel cell and are assumed known throughout the remainder of the report.

The analysis conducted of fuel cell lifecycle costs will include the calculation of the net present value of all future cash flows, the discounted payback rate, the internal rate of return, and the modified rate of return. Each item will be discussed in the following pages.

Net Present Value

Net present value (NPV) is used to find out how much money the project is anticipated to earn (or lose) during the life of the project. To find NPV, first determine the future cash flows for the project on a periodic basis such as yearly, monthly, or quarterly. These could be actual or projected if the costs/savings are not completely known. Once the costs are determined, calculate what the net value is for that particular period. Take that new value and apply Equation 4 to find what the present value is of the future cash flow.

$$PV = \frac{FV_n}{(1+i)^n}$$

Equation 4 - Net Present Value Equation

Next add all the future values together to find the present value. Remember to use the weighted average cost of capital (company's cost of borrowing money) for the interest number (i) and the year it occurs (n). Figure 4 has been included to give you an idea of how the results could be worked out.

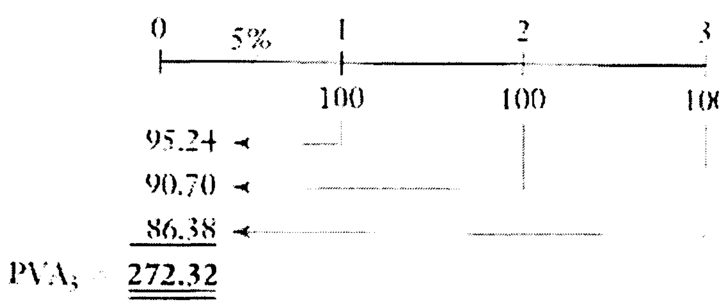


Figure 4 – Net Present Value Example

The different values in the present value equation (Eq. 4) have a tremendous effect of the NPV when they are altered. Figure 5 shows how the value of $1 will drop off given differing interest rates and time. As can be seen, the higher the interest (WACC) the less the money is worth today.

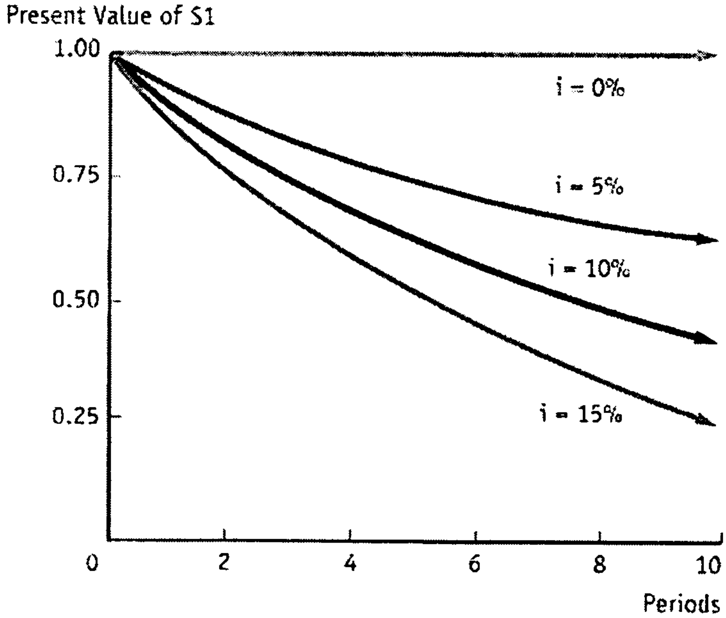


Figure 5 – Relationships among PV, Interest Rates, and Time

The method described will end up giving the present value of a future cash flow or the value the money has today. To find the NPV, simply add the present values of each future cash flow together. The number calculated is the projected value the project has today. Figure 6 on the next page is a good example of how to find the NPV for differing cash flows over an extended amount of time.

Net present value is the second step towards determining if the fuel cell system is good for a building. (The first step is finding out if it will save on your energy costs.) Simply stated, if the NPV is positive then the project will return money to the owner and provide value to the company. If the NPV of the project is negative, the fuel cell unit is not a good system to use or the cash flows need to be reexamined more. Once a positive NPV is established then more checks can be applied to determine the validity of the system. Generally owners want (require) a more detailed look at the project to justify it to a board of directors or to compare it to another type of project. These checks will be the covered next.

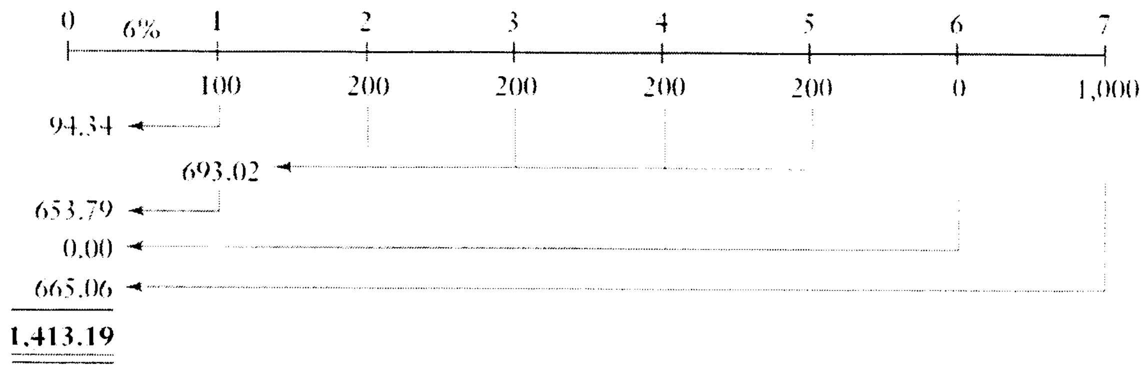


Figure 6 - Uneven Cash Flows Example

Discounted Payback Period

The discounted payback period establishes the length of time it will take to pay off an investment and start making money on a project. Future cash flows are determined (as in the net present value approach) and the sums are altered to reflect current amounts or the net present value. The NPVs are then added year by year until the project begins to make money. Shown in Figure 7 are a couple examples of how the discounted payback period is determined. The net cash flow establishes the future cash flow, the next line discounts the cash flow to the present value, and then the final line sequentially adds the numbers together to find when the project will start making money. Note that Project L has more future cash flow but because the locations and the time value of money principle it will make less than Project S.

	0	1	2	3	4
Project S:					
Net cash flow	−1,000	500	400	300	100
Discounted NCF (at 10%)	−1,000	455	331	225	68
Cumulative discounted NCF	−1,000	−545	−214	11	79

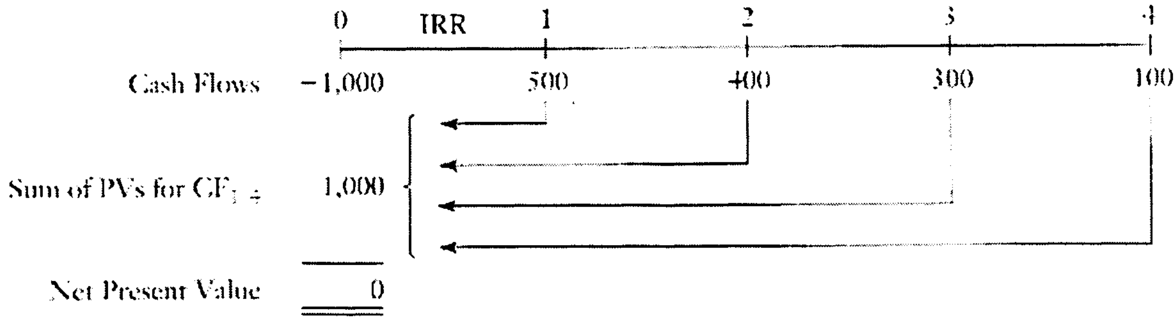
	0	1	2	3	4
Project L:					
Net cash flow	1,000	100	300	400	600
Discounted NCF (at 10%)	1,000	91	248	301	410
Cumulative discounted NCF	1,000	−909	−661	360	50

Figure 7 - Discounted Payback Period

Internal Rate of Return

The discount rate that forces the present value of a project's inflows to equal the present value of its cost is called the project's internal rate of return (IRR). It can also be described as the rate that forces the NPV to equal zero. The method is a way of ranking projects based on the rate of return, which is useful in comparing projects of differing lengths. Although it was fairly easy to find the NPV without much assistance, it is a lot more difficult to find the IRR without the help of a calculator or computer. Figure 8 shows the calculation of the internal return rate.

The rational behind using the IRR method is fairly simple. The IRR is the expected return rate for the project. When the internal rate of return exceeds the weighted average cost of capital the project will have excess funds when completed. These funds then enhance the firm's wealth. What this means is any project whose IRR is above the WACC is increasing the firm's, and ultimately the stockholder's, wealth. If the IRR is less than the WACC the project is decreasing the company's worth and probably not a good project to take on.



$$-1{,}000 + \frac{500}{(1 + \mathrm{IRR})^1} + \frac{400}{(1 + \mathrm{IRR})^2} + \frac{300}{(1 + \mathrm{IRR})^3} + \frac{100}{(1 + \mathrm{IRR})^4} = 0.$$

Figure 8 - Internal Rate of Return

Modified Internal Rate of Return

There is an ongoing debate regarding the use of NPV and IRR in financial evaluation. The academic preference is to use NPV but most executives prefer to use IRR method of examination. Businesses tend to evaluate in terms of percentages rather than the overall dollar amount used in NPV. The issue between the two is how the cash flows should be reinvested. The present value approach says the cash flows are reinvested at the WACC but the internal rate of return states that cash flows are reinvested at the project's rate of return. The best reinvestment rate assumption concludes that the cash flows are reinvested at the WACC, which leans towards using NPV. The problem is that executives still like the percentage approach.

The solution to this discrepancy is the modified internal rate of return (MIRR). The MIRR modifies the IRR to make it a better indicator of relative profitability. Instead of turning the future cash flows into their present value, the MIRR takes these projections and determines a terminal value of each flow. The terminal value is found by assuming each future cash flow will be reinvested at the company WACC instead of reinvesting at the project's own rate of return. Reinvestment will typically take place at the cost of capital making the MIRR a better indicator of true profitability. In the example showing how MIRR works, the k-value is the same as the WACC previously described. (Figure 9) As with the IRR, the MIRR is not easily determined and the use of a calculator or computer will most likely be needed.

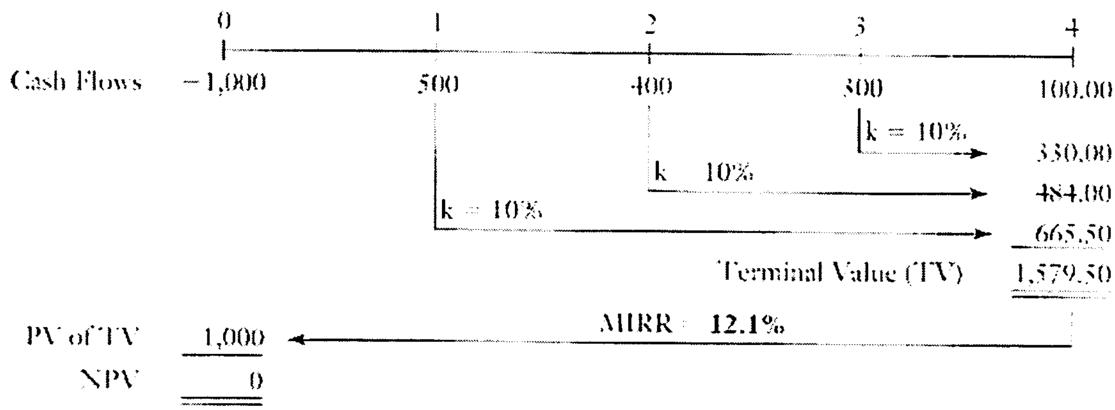


Figure 9 - Modified Internal Rate of Return Example

CHAPTER 4: FUEL CELL FINANCIAL ANALYSIS

Money drives the decision making process in the world today. Even if environmental issues are the main concern, the final decision will ultimately be made on the least cost alternative to meet the requirements. Money is king and will continue to be for some time to come, so it is important to evaluate any project from that standpoint. Even with all the positives presented earlier, fuel cells are no different and must be reviewed accordingly.

Financial evaluation of the fuel cell lifecycle will be the focus in this section of the thesis. In conducting the review, all expenses that pertain to buying, installing, and maintaining the fuel cells are considered. The initial economics of the fuel cell was taken from the Department of Defense (DoD) Fuel Cell Demonstration website. [12] The analysis shows the annual cost savings of using a fuel cell run on natural gas in lieu of the electricity from the power grid. From the DoD report and input from email and talks with Mike Binder of the DoD and John Trocciola of UTC Fuel Cells, a lifecycle analysis was completed. [13][14] Described in the rest of this chapter are the different variables, where they come from, and how the financial factors are determined. The financial analysis is done using methods discussed in Chapter 3 such as net present value (NPV), internal rate of return (IRR), and modified rate of return (MIRR). "What-if" scenarios have also been conducted to see what changes will take place if a given variable is changed from the inputted value.

The Construction Engineering Research Laboratory (CERL) at the US Army Corps of Engineers began a fuel cell installation program for the Department of Defense in 1993. CERL has managed the installation of 200 kW fuel cells at over 30 sites. As a result of this project, CERL developed a set of application guidelines. These guidelines cover fuel cell size calculation and economics. The CERL data will provide the starting point for this study.

The CERL guidelines are based on 200 kW phosphoric acid fuel cells (PAFC) produced by UTC Fuel Cells.

Input Variables

The first step in the lifecycle analysis is to determine the different cost variables included throughout the life of the fuel cell. The variables will include energy savings, construction costs, stack replacement, salvage value, and incentive programs.

Energy Savings

The first step in deciding upon the purchase of a fuel cell is to find out if it will save money on the energy costs of a building. As stated before, an analysis spreadsheet from the DoD has already been completed showing if a fuel cell will save on energy costs. The spreadsheet uses inputs provided to show the amount of money that can be save. The inputs include the building electric consumption (actual or anticipated), the building thermal requirements, boiler temperature, fuel cell size and efficiency, and most importantly the cost of gas and electricity in the local area. From these inputs the program calculates the overall savings. Broken out in the analysis is the annual energy production of the fuel cell, the energy displaced using the new system, the annual savings, the annual costs including maintenance, and then the annual net savings of the fuel cell unit(s). Another good option in the program is the possibility of selling excess electricity back to the power grid at a reduced cost. Table 3 shows the inputs used in calculating the annual savings of a fuel cell. The numbers are also included in Appendix A.

Table 3 - Economic Inputs

INPUTS

Building Electric Load		
Building Annual Peak Demand:	**950**	KW
Annual kWh Consumption:	**2,980,000**	kWh/Yr.
Building Minimum Demand:	**250**	KW
Building Thermal Load		
Building Annual Gas Load:	**6,000**	MMBtu/Yr.
Annual Displaceable Gas Load %:	**50%**	
Annual Displaceable Gas Load:	**3,000**	MMBtu/Yr.
Thermal Interface Temperature:	**130**	°F
Boiler Efficiency:	**75%**	
Fuel Cell		
Size:	**200**	KW
Availability:	**90%**	
Months of Demand Reduction:	**12**	mos./year
Average Operating Load:	**200**	KW
Electrical Efficiency:	**36%**	HHV*
Thermal Efficiency:	**40%**	HHV*
Sell Back to Utility?:	**2**	Y=1/N=2
Fuel Cell Installed Cost:	**$900,000**	
Energy Rates**		
Electric Demand:	**$7.00**	/kW/Month
Electricity:	**$0.10**	/kWh
Input Fuel:	**$4.00**	MMBtu
Maintenance Costs:	**$0.020**	/kWh

From the listed inputs above the spreadsheet calculates the energy produced, the energy displaced, annual savings, and net savings of the fuel cell. The most important of these outputs for the lifecycle analysis are the annual cost savings and the amount set aside for yearly maintenance. Both of these numbers are inserted automatically as yearly inputs in the analysis. See Table 4 for these numbers as well as Appendix A.

Table 4 - Economic Outputs

OUTPUTS		
Annual Fuel Cell Energy		
Electric Output:	1,576,800	kWh
Thermal Output:	5,980	MMBtu
Input Fuel:	14,949	MMBtu
Displaced Site Energy		
Annual Demand Reduction:	2,400	kW/Yr.
Displaced Electricity:	1,576,800	kWh/Yr.
Electricity Sold Back to Utility:	-	kWh/Yr.
Displaced Site Thermal:	2,250	MMBtu/Yr.
Annual Savings		
Electricity Savings:	$174,480	
Thermal Savings:	$12,000	
Subtotal:	$186,480	
Annual Costs		
Input Fuel:	$59,796	
Maintenance:	$31,536	
Subtotal:	$91,332	
Annual Net Savings	**$95,148**	

Construction Costs

There is a tab within the lifecycle spreadsheet that addresses the construction costs of installing the fuel cell. Each site is going to be different, but it is generally assumed that installation costs will run between $50,000 and $200,000 depending on location on the site, the cost of transporting the 40,000 lb unit on a lowboy trailer from Connecticut, the length of the wire, gas, and thermal runs, and other site preparatory needs. Contractor markup has been included in the cost of installation and can be altered on the summary/sensitivity page. It should be noted at this time that the fuel cell cost within the construction page is just the cost of manufacturing the units.

Stack Replacement

As the fuel cell continues to produce energy, the amount of the catalyst driving the reaction is slowly depleted. The overall system is still operable so a stack replacement is needed halfway through the 10 years life of the system. In year 5, the owner will incur a cost to replace the stack. At the time of writing this paper John Trocciola of UTC Fuel Cells quoted the cost for the replacement at $315,000. When conducting a future lifecycle analysis be sure to correct the value for updated technology and costs.

Salvage Value

While there is a salvage value for the fuel cell unit, the cost is quite minimal especially when you look at the time value of money. Since this analysis is being done assuming a 10-year useful value, the benefit drops tremendously. I have inputted a value of $50,000 for the salvage value mainly for the value of scrap metals.

Incentive Programs

Incentive programs are one of the main reasons fuel cells are being developed and researched. The programs will be discussed later in this section but are one of the largest variables to be included in the lifecycle analysis. The Federal Government is currently offering a $1,000 per kW incentive for the installation of a fuel cell, and this benefit has been included in the analysis. As there are many other programs out there it is not feasible to try and include them all. Because of this room has been left within the spreadsheet to include these cost savings. See Appendix A for a look at the lifecycle inputs for the spreadsheet.

Summary / Sensitivity Review

When the inputs have been finalized, it is time to run the calculations, review the results, and determine what will happen if some of the variables change from the predicted values. The spreadsheet used to conduct the lifecycle analysis has been inserted in Appendix A. Included are each of the input sheets, the construction costs, the lifecycle inputs and the summary/sensitivity review.

After initially completing the economics study of the energy system for the fuel cell, including the inputs on the economics worksheet, additional variables need to be provided. As discussed earlier, a company has a certain weighted average cost of capital (WACC) percentage it can borrow money. This number needs to be entered into the summary sheet for the spreadsheet calculations to be done correctly. The contractor must also provide the markup percentage they intend to use on the work to be installed. The final input is the manufacturing costs of the fuel cell without installation costs. All of these variables are required in order for this spreadsheet to correctly calculate the time value of money results. Table 5 is a copy of the input section for lifecycle analysis.

In running the spreadsheet in an example, numbers were selected to simulate the $4,000-$5,000 per kW cost of the fuel cell. The analysis was completed using a 200 kW unit with the manufacturing costs set at $4,300 per kW, the contractor markup set at 10% and the WACC set at 12%. In order to make the rates of return positive, the federal government incentive of $1,000 per kW was included and another $400,000 of incentives has been introduced as well. Incentives are initially included to give the project a positive NPV and positive rates of return to extend the amount of analysis that could be done. The incentives will be discussed in more detail later in the chapter.

Table 5 – Inputs Required for Analysis

Inputs..........

Construction Costs

Averages from the DoD demonstration project have been entered into the spreadsheet analysis.

Specific site conditions are to be adjusted for on the Construction Cost worksheet.

Fuel Cell Manufacturing Costs

Average Cost per kW	$4,300	Excluding construction

Contractor Cost of Money

Weighted Average Cost of Capital	12%	(WACC) Cost of money

Contractor Markups

Construction	10%

Analysis will be based upon the results calculated using the numbers previously shown and the economic variables. All deductions will be drawn from the net present value, internal rate of return and modified rate of return for the project. Results are shown in the Table 6. Given the inputs and the incentives used in this example, the fuel cell would most likely be installed since the NPV is positive and the rates of return are greater than the WACC of the company. Basically the fuel cell would make the owner money.

Table 6 – Initial Lifecycle Analysis

Results..........

NPV	**$68,458**
IRR	**17.16%**
MIRR	**13.66%**

The next sections discuss what will happen to the results when the main variables change. The spreadsheet lends itself to changing the variables one at a time. The ones to be discussed here are the weighted average cost of capital, the contractor's markup, the cost per kW of manufacturing the fuel cell, gas prices and of course electric prices.

Cost per kW Changes

The most important issue with fuel cells being commercially accepted is the cost per kW of the units. The following table shows how the net present value and rate of returns are affected by reducing the manufacturing costs. Note that the internal rate of return (IRR) is greatly affected as the cost per kW is lowered, which is why the modified rate will be more telling of the projects true return on investment. Table 7 shows how cost is a main factor towards fuel cell projects becoming integrated into the existing power grid.

Table 7 – Results of Lowering $/kW

	-$2,000	***-$1,500***	***-$1,000***	***-$500***	***$0 Difference***
$ / kw	$2,300	$2,800	$3,300	$3,800	**$4,300**
NPV	$508,458	$398,458	$288,458	$178,458	$68,458
IRR	NA	NA	88.25%	32.44%	17.16%
MIRR	32.51%	29.97%	22.07%	17.06%	13.66%

The NPV continues to increase with the reduction of manufacturing costs, which makes the rates of return superior as well. The change is so great that the $1,500/kW reduction in cost makes the IRR so large that it cannot be calculated. Reviewing the MIRR shows an increase benefit as the manufacturing costs decrease. Since the units are showing good profitability with a cost reduction, the next logical step is to find out at what manufacturing cost will government incentives no longer be needed.

Comparison Without Incentives

In order for fuel cells to become a useful source of energy they must be capable of creating a positive net present value without the help of government incentives. The following table displays the results that occur when all the government incentives (including the $1,000/kW) are removed. The results show a cost reduction between $2,400 and $2,450 off the initial $4,300 is needed for fuel cell to become viable without incentives. The corresponding manufacturing cost of the fuel cell would then be in the range of $1,800-$1,900 per kW to the owner plus the additional of the cost of construction.

Table 8 - Results without Gov't Incentives

	-$2,750	***-$2,500***	***-$2,450***	***-$2,400***	***$0 Difference***
$ / kw	$1,550	$1,800	$1,850	$1,900	**$4,300**
NPV	$73,458	$18,458	$7,458	-$3,542	-$531,542
IRR	17.62%	13.22%	12.48%	NA	NA
MIRR	13.79%	12.42%	12.17%	NA	NA

Prior to starting the analysis it was assumed that the cost per kW would have to drop at least $1,000/kW to become a good energy source. From the table above is appears the reduction needed is about double the original assumption. According to the Direct Technologies, Inc., an independent research agency located in Arlington, Virginia, fuel cell costs will be greatly reduced once the number of units produced increases. They estimate that mass-producing 100 units will reduce the cost to $1,701 / kW and to $778 / kW once 10,000 units are mass-produced [15]. The increase in production appears to be in the distance since fuel cells are still in the research, development, and testing phases. There are limited applications where stationary fuel cells may be used and this fact may reduce the mass-production efforts for a few more years.

Figure 10 is a graph of how the cost of manufacturing will change the NPV for the fuel cell. The range starts at $4,300 per kW and is reduced to under $1,000 per kW. The graph is an extension of Table 8 and shows the entire range for manufacturing costs effects without the benefit of government incentives. Again notice new present value of the system doesn't become positive until the cost of manufacturing is below $2,000

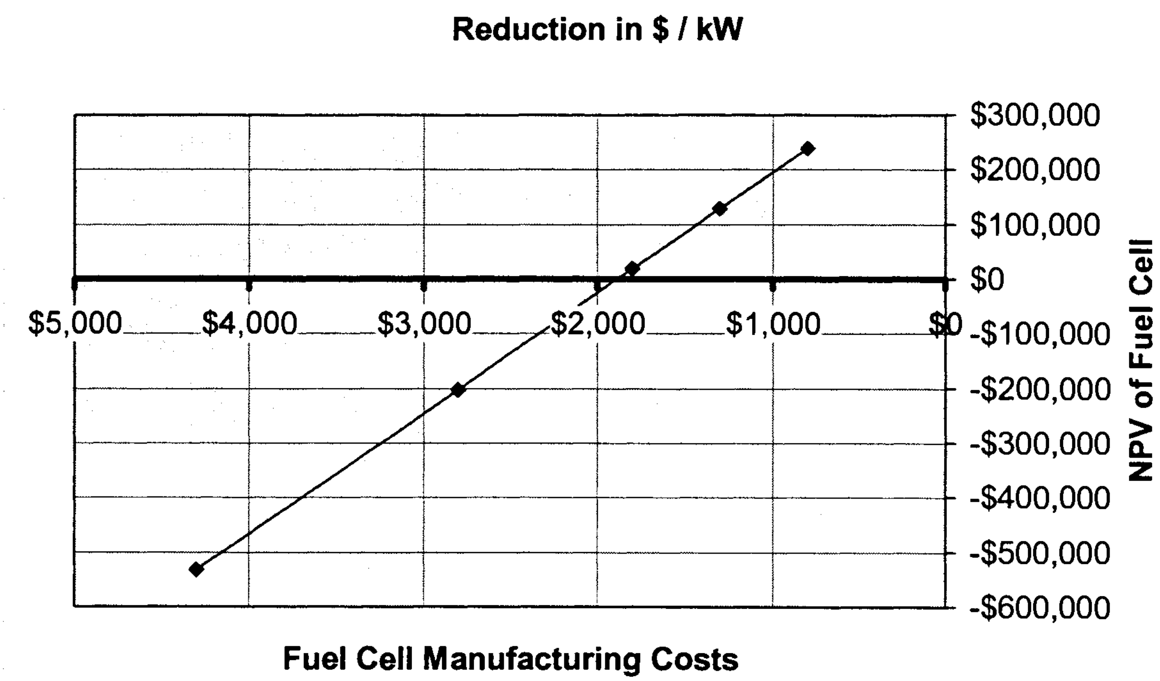


Figure 10 - Changes in Fuel Cell $ / kW Graph

WACC Changes

Lifecycle costs change tremendously depending upon the cost of the money used. The weighted average cost of capital plays a vital role since it will change the net present value of each of the future cash flows. Every future cash flow will be altered greatly with a change in the WACC. Depending how many years out the cash flow is will determine the net change in the NPV for the project.

Table 9 and Figure 11 show changes in the WACC higher and lower than the initial 12.00%. The chart goes on to display the outcome of the rate of return in each case. As can be expected, the higher the cost of money the less the NPV that will be calculated.

Table 9 – Results of Altering WACC

	-2.00%	*-1.00%*	*0.00%*	*1.00%*	*2.00%*
WACC	10.00%	11.00%	12.00%	13.00%	14.00%
NPV	$102,624	$84,903	$68,458	$53,178	$38,960
IRR	17.16%	17.16%	17.16%	17.16%	17.16%
MIRR	12.32%	12.99%	13.66%	14.34%	15.01%

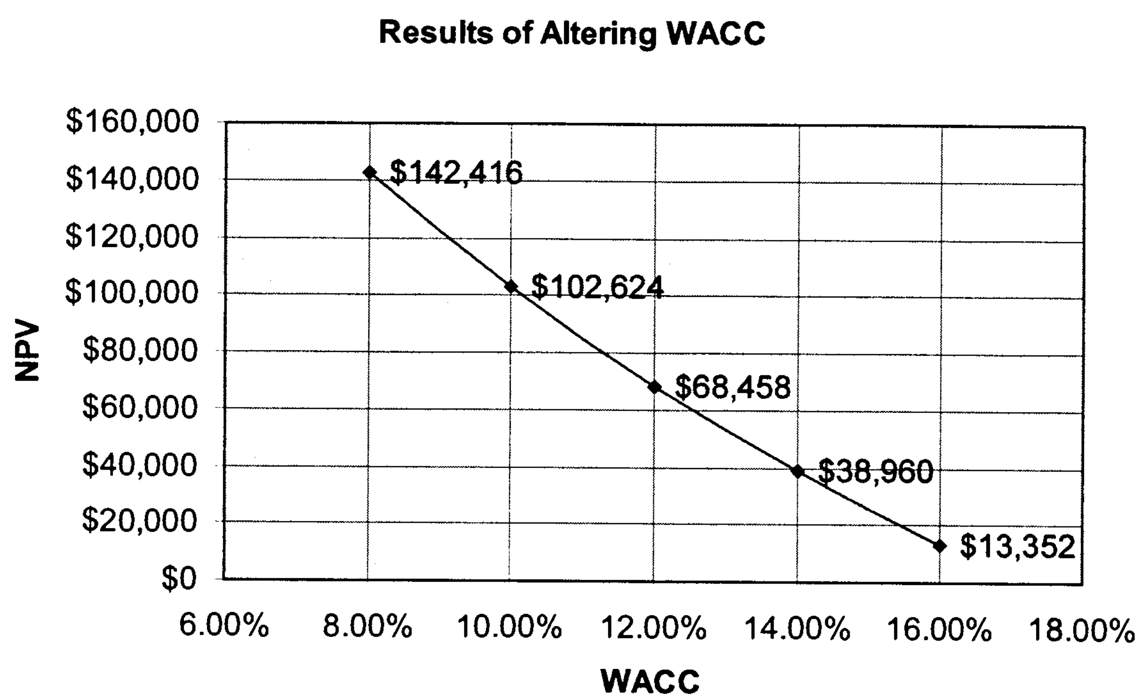


Figure 11 - Changes in WACC Graph

Unique to the changes in WACC is the internal rate of return is constant for the differing percentages. This occurs because the IRR is determined by the project and the WACC has no influence to alter the results. The MIRR used the time value of money to determine its value so it is altered by changes in the WACC.

The modified rate of return is different than one may expect when the WACC increases. The table shows that as the cost of money changes, the MIRR is altered by 2/3 of the change in WACC. The occurrence happens as a result of reinvesting at the higher WACC, which in turn causes the terminal value to increase. When the terminal value increases, a greater MIRR is then needed to make NPV equal to zero. Because of this the MIRR increases as the WACC increases.

Contractor's Markup Change

Contractor's markup will have a direct effect on the net present value of the fuel cell system since the cost is associated with the zero year construction costs. Time value of money does not come into play with the markup and a change in the markup will directly effect the NPV as shown in Table 10 and Figure 12. As the contractor fee increases, the NPV will decrease by the same amount.

Table 10 – Results of Altering Contractor Fee

	-2.00%	***-1.00%***	***0.00%***	***1.00%***	***2.00%***
Markup	8.00%	9.00%	10.00%	11.00%	12.00%
Contractor Fee	$73,467	$82,650	$91,834	$101,017	$110,200
NPV	$86,825	$77,642	$68,458	$59,275	$50,092
IRR	18.92%	18.02%	17.16%	16.35%	15.59%
MIRR	14.16%	13.91%	13.66%	13.42%	13.19%

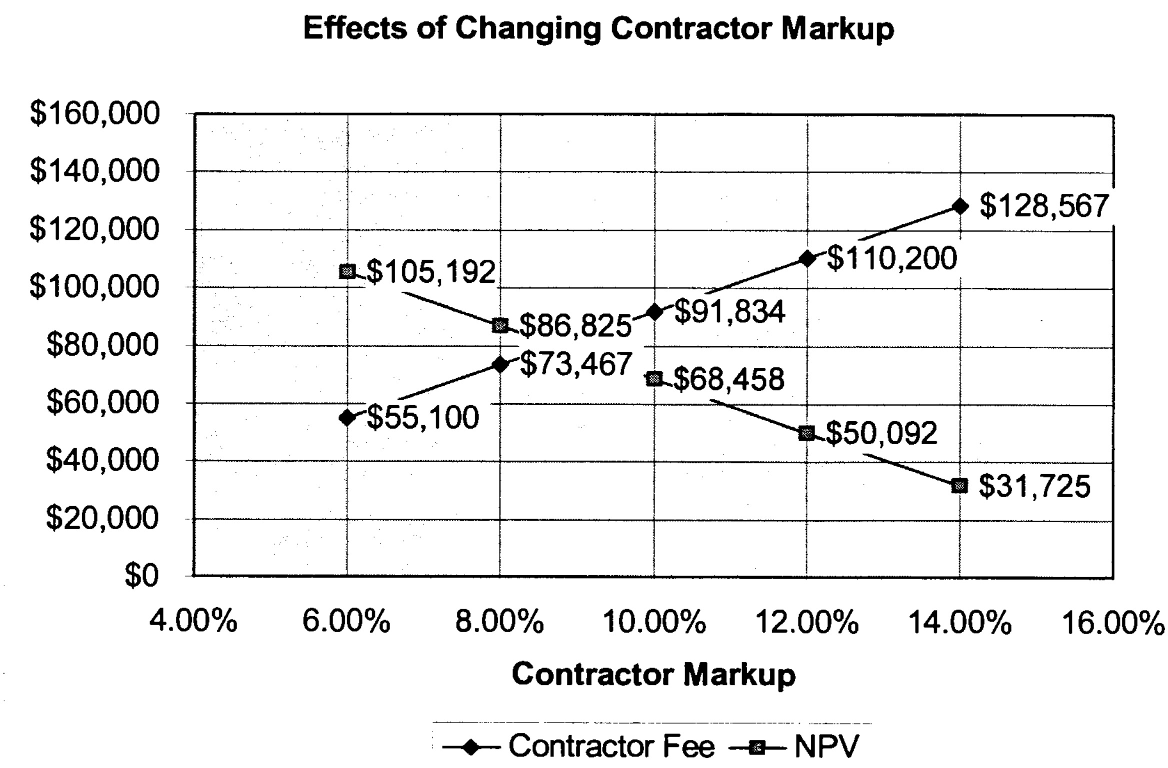


Figure 12 - Changes in Markup Graph

The negative effect markup has on the rate of returns is easily shown above. Return rates continue to fall as the contractor fee increases. The changes in rates are relatively small and a higher contractor fee should not result in the owner turning down a project. A general key is that a project is good if it returns more than the company's cost of capital. This is true when the project is exclusive, meaning the outcome is independent of other options. If there are other choices in lieu of the fuel cell, the small change in return rates could be the deciding factor in choosing one form of distributed generation over the fuel cell.

Gas Price Increases / Decrease

Fuel cells are considered an efficient source of energy, not a renewable resource, since the units consume different forms of natural resources at typically higher efficiency.

To be a renewable resource, the fuel cell would have to run on a resource that will never be completely used up such as wind, solar, or waterpower. Specifically, the fuel cell does run on a renewable source but at this time hydrogen is still taken from a nonrenewable resource such as natural gas. Reliability is a key issue with distributed power generation so the uncertain nature of most renewable resources does not lend itself well toward being a constant source of energy.

Natural gas tends to be the main source of fuel for the fuel cell depending on the type and size of the unit. The 200kW units commercially produced by UTC Fuel cells run on natural gas and are the focus of the analysis. Gas prices have tendency to fluctuate throughout the year and the price even doubled during the winter of 2000 in the Midwest. A fuel cell running on natural gas is likely to have a lower NPV when the cost of gas increases, which makes sense given the fact that systems run on natural gas. Below are the results of increasing the cost of gas by 25%, cutting the cost in half, and other in-between prices.

Table 11 – Results of Altering Gas Prices

	50.00%	***75.00%***	***Input Cost***	***112.50%***	***125.00%***
Gas Cost (MMBtu)	$2.00	$3.00	$4.00	$4.50	$5.00
Annual Savings	$119,046	$107,097	$95,148	$89,174	$83,199
NPV	$227,385	$147,921	$68,458	$28,727	-$11,005
IRR	29.96%	23.40%	17.16%	14.15%	NA
MIRR	17.22%	15.49%	13.66%	12.71%	NA

As can be seen, when the cost of natural gas lowers the fuel cell becomes much more cost effective and when the price of natural gas increases by as little as 25% the effectiveness is greatly reduced. While these changes may seem to decrease the likelihood of installing a fuel cell it must first be realized that some years the prices will be higher, other years they will be lower. Effects from the changes in the cost of natural gas are felt more on the short-term basis rather than the long term. Remember that the time value of money equation makes cash flows later in the lifecycle have less of an impact on the net present value of the project. Figure 13 gives graphical representation of how changes in gas price will change the net present value of the fuel cell(s). The initial cost was $4.00 MMBtu and a cost increase to just under $5.00 MMBtu will cause the system to be countered productive. Remember this for the long-term changes.

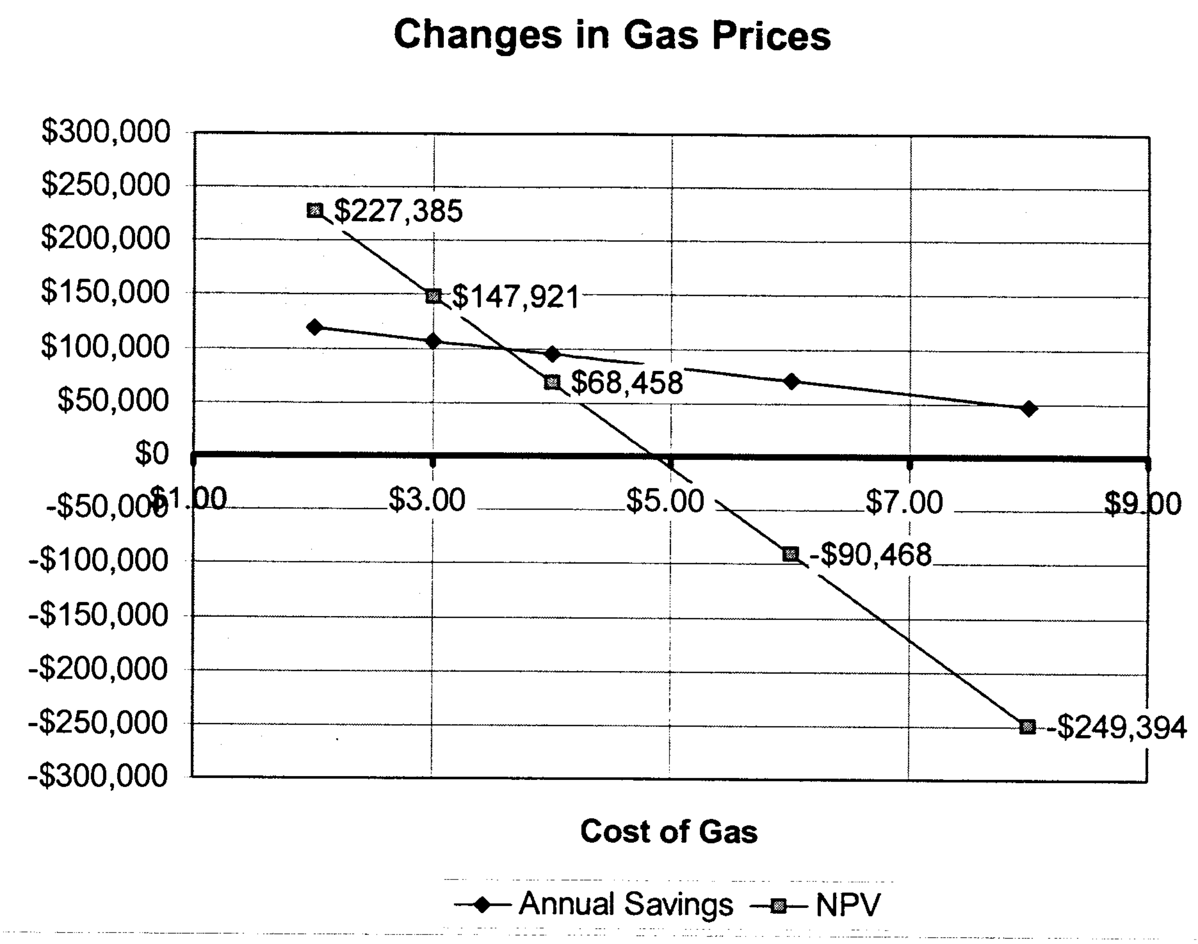


Figure 13 - Changes in Gas Graph

Electricity Price Increases / Decreases

Electricity prices also have a great influence on the cost efficiency of the fuel cell system. The fuel cell's goal is to replace the cost of electricity from the power grid with a more cost effective alternative. It can naturally be assumed that the more expensive the electricity is in a given region, the more the fuel cell helps save the owner and visa versa. Table 12 shows the effects a change in the electricity price has on the fuel cell. Remember that the initial cost inputted will be an average of yearly costs during the lifecycle of the fuel cell system in a particular region.

Table 12 - Results of Altering Electricity Prices

	90.00%	***95.00%***	***Input Cost***	***125.00%***	***150.00%***
Elec. Cost (kWh)	$0.090	$0.095	$0.100	$0.125	$0.150
Annual Savings	$79,380	$87,264	$95,148	$134,568	$173,988
NPV	-$36,402	$16,028	$68,458	$330,610	$592,762
IRR	NA	13.19%	17.16%	39.12%	66.73%
MIRR	NA	12.40%	13.66%	19.39%	24.70%

As can be seen, when the cost of electricity lowers as little as 5-10% the fuel cell becomes less cost effective and as the price of electricity increases, the cost effectiveness is greatly increased. Figure 14 continues to show how lowering the cost of electricity will change the effectiveness. In the past few years, electricity prices continue to increase because of the bottlenecks in transportation and distribution that caused rolling blackouts such as the ones experienced in California. The Midwest can again be used as an example in 1998 when electricity costs increased because of lack of T & D. [(16)] Similar to the effects of the changes in the cost of natural gas are felt more on the short-term basis rather than the long term, electricity effects are much the same when analyzing lifecycle costs.

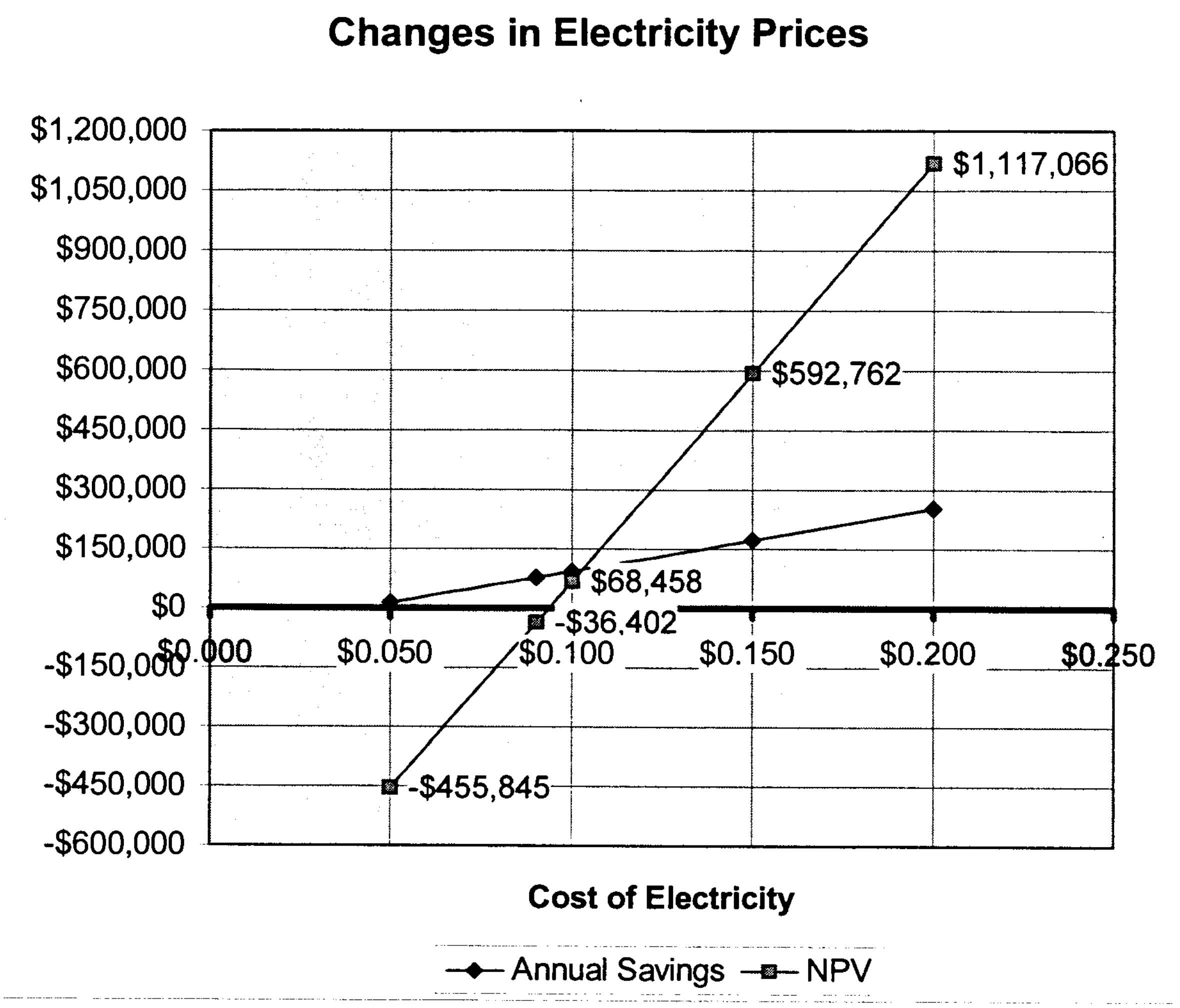


Figure 14 - Changes in Electricity Graph

Changing Various Inputs

The analyses conducted up to this point have been straightforward and probably unrealistic to assume. Changing only one variable is a simple way to see how the changing variables will alter the end results. But what happens when the weighted average cost of capital is reduced and the price of gas increases at the same time? What if the cost per kW of the fuel cell finally goes down but the price of electricity decreases at the same time?

The summary page includes an analysis tool that allows the changing of multiple variables at the same time. Although numbers need to be entered manually, the calculation allows for more flexibility without needing to go back into the economics spreadsheet to change the annual savings details. Table 13 shows where the information is entered and the results that are computed. As an example, the cost per kW was lowered to $3,500, the WACC was increased to 14.00%, and the cost of electricity was lowered to $0.090/kWh. The calculations resulted in the NPV increasing from the original $68,458 to $116,944, IRR doubling, and the MIRR increased about 4-½%.

Table 13 – Multiple Variable Changes

WACC	***14.00%***
Markup	***10.00%***
$ / kW	***$3,500***
Gas Cost (MMBtu)	***$ 4.00***
Elec. Cost (kWh)	***$ 0.090***

Results

NPV	***$116,944***
IRR	***33.82%***
MIRR	***18.19%***

CHAPTER 5: INCENTIVE PROGRAMS

At this point, incentive programs from the Federal and State Governments appear to be the only reason fuel cells are even an option to meet energy and reliability needs. The cost of manufacturing the units makes them way too expensive for most owners to consider the technology without external funding. Until the manufacturing costs are lowered, incentive programs will be used to continue to push research and development as well as the installation of fuel cells.

The most consistent incentive program that this time is a grant of $1,000/kW from the Federal Government for the installation of the fuel cell. The incentive falls under the renewable resource allocation and helps meet the requirements and goals set forth by the Clean Energy Act of 1992 that follows. [(4)]

Energy Policy Act of 1992 (EPAct) Congress passed EPAct, or Public Law 102-486, on October 24, 1992 with the goals of enhancing our nation's energy security and improving environmental quality. The Act includes provisions addressing all aspects of energy supply and demand, including energy efficiency, alternative fuels and renewable energy, as well as more traditional forms of energy such as coal, oil, and nuclear power. With EPAct in place, DOE's primary goals are to decrease the nation's dependence on foreign oil and increase energy security through the use of domestically produced alternative fuels.

State governments are quite responsible for the recent fuel cell advances. They are being active in allocating money for distributed power generation and clean energy sources such as fuel cells. California, Connecticut, New York, and New Jersey are the primary states leading the way by funding fuel cells and other distributed generation. Incentives are known to go above and beyond the cost of the systems and are very alluring to owners willing to risk using an unproven technology. Laws and regulations are also more likely enacted at the state level rather than the federal level for the governing of fuel cells.

One main benefit States can provide fuel cell leaders are tax breaks and tax deductions on fuel cells. Generally an owner can deduct the cost of the fuel cell and quite often the annual savings generated by its use. Rules and regulations are changing daily as Congress and State Legislatures enact new laws to govern distributed power and the new deregulated energy market.

Financial assistance in the forms of loaning money and net metering are other ways the government is advancing fuel cells. There are many forms of financial help out there that differ from state to state. Most often money is available through applied grants, thus not guaranteeing money to an owner. Below are some states with legislation directed towards fuel cells and clean energy.

CALIFORNIA

The state Energy Conservation and Development Commission provides loans and grants to make fuel cells and other innovative technologies more efficient and cost effective. It also conducts research and development and engages in commercialization activities (Cal. Pub. Res. Code § 25467 et seq.).

MARYLAND

The state passed legislation this session (HB 20) that exempts fuel cells with a capacity of 2 kilowatts or more (the amount of electricity used by 20 100-watt light bulbs) from the sales tax.

NEW MEXICO

Under the state's electric industry restructuring law (N.M. Rev. Stat. § 62-3A-1 et seq.), projects to promote fuel cells powered by renewable energy sources are eligible for financial assistance from a ratepayer-funded program.

OHIO

Fuel cells are eligible for net metering under Ohio Rev. Code § 4928.01. Net metering allows a person who owns on-site generation to sell power that he does not need to the local utility. In effect, his electric meter runs backward when he is selling power.

Established by the Ohio General Assembly under the 1999 electric restructuring act (Senate Bill 3), the Fund was created to provide an incentive for purchasing and implementing energy-efficient and renewable energy projects. It reduces the interest rate--by approximately half--on standard bank loans for those qualifying Ohio residents and businesses that borrow money to implement energy efficiency or renewable energy projects.

OREGON

In 1999, the legislature adopted SB 1195, which entitles owners of fuel cells to an income tax credit of up to $1,500. Fuel cells are also eligible for net metering under Ore. Rev. Stat. § 757.300.

Examples of other States with various types of incentive programs are listed below. Most of the States have grants to apply for, loans with low interest rates, and net metering regulations as incentives similar to the ones on the previous page. Note that not all States with incentive programs are listed. The compiled list is used to show that legislation is being done or considered just about everywhere.

- Massachusetts
- Pennsylvania
- Arizona
- Washington
- Hawaii
- Maine
- Rhode Island
- Minnesota
- Montana

Incentive Examples

Listed in Table 14 on the next page are examples of incentives that are available and some that were previously awarded in New York. As can be seen, the state of New York is providing a lot of funding for fuel cell usage up to 50% of the overall cost of the system. It appears that the states most interested in the clean energy that fuel cells provide are the environmental sensitive states in the country. Whether it be cleaning up the air in New York or keeping Yellowstone Park clean, fuel cells are capable of being used anywhere.

The location to view incentives and programs in a particular state are listed below. The sites prove to be a great source of information but it is best to contact your local state energy agency. Figures 10 and 11 on the following pages are examples of the proposals and requirements seen on the following websites.

- http://www.eren.doe.gov/buildings/state_energy/map.html
- http://www.dsireusa.org/dsire/index.htm

Table 14 – Examples of Awarded Incentives

Federal Incentives	Type / Description	Amount Awarded	Project Cost
U.S. Dept of Energy	Rebate per fuel cell	$1,000 / kW	
California			
California Energy Commission	$4,500/kW or 50% of system cost (whichever is less)	$4,500 / kW	
New York			
Sheraton Hotel	250 kW fuel cell system	$920,000	$1,840,000
New York College - SUNY Environmental Science - Syracuse	Natural gas-fueled 250kW fuel cell (NYSERDA)	$1,000,000	$2,700,000
	NY Power Authority Loan	$1,700,000	
Community Environmental Center	Fuel Cell	$600,000	$1,228,800
Verizon Comm.	Fuel Cell	$1,000,000	$5,394,514
Plug Power	Development of PEM fuel cell	$500,000	$1,028,940
XYLON Ceramic	Development of solid oxide fuel cell	$493,343	$1,147,951

(http://www.nyserda.org/press/pressother2002.html#CHP)

Portland, Oregon - Waste Methane-Powered Fuel Cell

Last DSIRE Review: 02/16/2001

Incentive Type: Demonstration Project
Eligible Technologies: Fuel Cells,
Applicable Sectors: General Public, Local Government,
Co-funders: federal and state grants, state tax credit, Portland General Electric, Western Bank
Date Enacted: 1999

Summary:
In July 1999, the City of Portland's Bureau of Environmental Services officially unveiled a waste methane-powered fuel cell at the Columbia Boulevard Wastewater Treatment Plant. The 200-kW fuel cell is one of only a handful of fuel cells operating on a renewable fuel. It is producing more than a million kilowatt-hours a year. This is enough energy to power nearly 100 homes and will save the City about $50,000 a year. Funding to make this project possible was obtained through federal and state grants, a state tax credit, and a rebate of $247,000 from Portland General Electric. Additional financing was provided by Western Bank, a subsidiary of Washington Mutual Saving Bank.

Figure 15 - Example Fuel Cell Proposal

NEW YORK

Green Building Tax Credit Program

Last DSIRE Review: 01/07/2001

Incentive Type: Corporate Tax Credit
Eligible Technologies: Photovoltaics, Fuel Cells,
Applicable Sectors: Commercial, Residential, Construction,
Amount: fuel cells $1/kW, PV $3/kW - DC capacity
Max. Limit: fuel cells 30% capitalized costs; PV 100% building integrated, 25% non-integrated
Terms: distributed over 5 years; transferable; indefinite carry forward
Date Enacted: 2000
Expiration Date: 2004
Website: http://www.dec.state.ny.us/website/dar/ood/grnbldgtxcr.html
Authority: Laws of 2000, Ch. 63, Part II

Figure 16 - New York Tax Credit

CHAPTER 6: CONCLUSION

The financial analysis done here has led to some conclusions regarding the advancement of fuel cell technology. As it stands now, fuel cells are not economically feasible on their own. The main reason they are installed rests on incentives from the government and some local utilities. One main goal prior to starting the research was to find at what price per kW the fuel cell will be able to survive without the benefit of incentives. The analysis determines that the manufacturing cost needs to be reduced to under $2,000 per kW for fuel cells to be commercially competitive with other sources of energy. Once the technology successfully completes field trials, cost should go down with mass-production, industry acceptance, and increased usage. If environmental concerns are more important than the overall economic benefit then production could commence earlier.

The sensitivity review does show a possible problem with installing the fuel cell: high sensitivity to changes in gas and electric prices. In the example throughout the paper, a 20% increase in the price of gas or a 6 ½ % decrease in electric rates would make the net present value of the fuel cell equal to zero. This sensitivity makes the fuel cell a risky technology considering the recent volatility in the prices of gas and electricity in the United States. Some markets are less susceptible because they have a large discrepancy between the costs of gas and electricity in the region. Alaska is a great example because electricity prices are very high (11.3 cents kWh - residential) and gas prices are extremely low ($3.65 MBtu - residential) compared to the rest of the country. In most cases a small decrease in electrical prices will be detrimental to the fuel cell's economic benefit but only in a long-term situation. Short-term changes in electric price will not be as much of a problem. Another upside is as manufacturing costs are reduced the technology's sensitivity to energy costs should lessen as well.

From studying the sensitivity review, electrical contractors should take a long look at fuel cells because of their great potential to earn money. At this time no one industry is in control of installing and maintaining fuel cells outside of the manufacturers. The analysis showed that the amount of contractor markup has little effect on the overall rate of return for the project and allows for increased earnings over the life of the fuel cell. Specializing in the technology means that the industry will be looked upon to solve problems that arise. Dealing with electricity and energy gives the industry an advantage that others may not have the technical skills needed to correctly maintain and trouble shoot the units.

The research done here is a good starting point for determining if the fuel cell is a feasible source of energy. Certain items of the analysis need to be looked at more such as determining the exact cost of preparing the site for the fuel cell to arrive. The economic spreadsheet also needs to be reviewed because the Department of Defense and United Technologies developed it so the sheet deals with the 200 kW mobile units and not the site built fuel cells currently in development. Because of this, the spreadsheet is geared towards UTC Fuel Cells in lieu of other manufacturers. The initial cost as well as the maintenance and annual savings needs to be recalculated if another manufacture is to be used. Contacting an agent of the manufacturer will be the best starting place.

The next step to be done is finding out more about how electrical contractors can prepare for fuel cells when they penetrate the market. Maintaining the units is fairly simple that it involves changing filters and checking connections with the electric grid or outside power sources. The UTC Fuel Cell spokesman said the maintenance could be done by almost anyone with a little training.

The last item that could be investigated is how incentives are actually awarded to owner for installing fuel cells. Many states have programs that award installers of renewable resources grants or low interest loans to help offset the high initial cost. More about these programs can be researched to show what it takes to be awarded for your involvement.

Fuel cells will continue to be used more and more but will not make a huge impact until fuel cell vehicles are fully developed. The current infrastructure is capable of integrating hydrogen but until the vehicle, the major consumer of fossil fuels, changes there is no real reason to change the infrastructure to match. Once vehicles are converted there will be a shift in energy production to the clean burning, environmentally friendly, fully renewable source of energy; hydrogen.

APPENDIX A – SPREADSHEETS AND INSTRUCTIONS

Appendix A.1: Spreadsheet Instructions

The spreadsheet used to conduct the life cycle analysis has been included in the following pages and possibly on an included disk. Instructions are listed on how to use the spreadsheet to conduct your own analysis. Go down the list starting with economic inputs, construction costs, life cycle costs, and then summary/sensitivity analysis. It will be the operator's responsibility to input or update numbers that are in the gray highlighted boxes.

Economics Inputs

1. Input variables according to your building electric load, building thermal load, and local energy rates.
2. Fuel cell size, availability, and efficiencies must also be entered. Consult a fuel cell manufacture or distributor for the most accurate information on the units.
3. Based on the inputs, the spreadsheet will calculate and annual energy produced, energy displaces, annual savings, annual costs, and the net result.
4. Review the results to find out if using a fuel cell will save money on your building energy system. If not, go back to decide upon another fuel cell unit or changing any inputs within the analysis.

Construction Costs

The construction costs page is used to give a general look at what it will take to prepare the site for the fuel cell to arrive. Located at the top of the page are the fuel cell size, manufacturing cost per kW, and total cost. The cost will be added into the construction costs and will have markup added on later. When reviewing construction it generally costs between $50,000 and $200,000 to ready the site for the fuel cell according to Mike Binder of the U.S. Department of Defense. Mike has installed over 30 such units in a demonstration project and was a source of information throughout the research. Note that the numbers used are ballpark numbers to come within the desired range and a more precise examination should be done. Other needed inputs may be crane mobilization, demolition of existing site, or cold weather protection.

1. Shipping – Input the amount to ship 40,000 lb. on a lowboy trailer from Connecticut.
2. Fence – Determine the desired finished fence along with the total length and costs per foot.
3. Concrete Footings – Entered numbers give a walking path around the fuel cell. About 1-2 feet larger on each side than the fuel cell dimensions in Appendix B.
4. Cost per CY – Price to include all labor, equipment, forming, etc.
5. Connection Runs – Determine the fuel cell location onsite and determine the length of connecting runs. Place the unit as close to thermal applications as possible since thermal connections cost more to install than electrical connections. The average length of the runs on the DoD projects has been inputted.
6. Cost per ft (runs) – The costs of connection runs needs to be inputted. It should include all costs associated with material, labor, demolition, etc. Price could be broken down for a more detailed approach.
7. Construction and Shipping Costs – Total is typically between $50,000-$200,000 depending on site conditions.
8. Contractor Markup – The percentage the electrical contractor expects to charge for work being installed. The number is to be entered on the summary sheet.
9. Total Costs – The amount to be used for financial analysis as a first year expense.

Life Cycle Cost

The financial analysis is the critical part of determining the current worth of a fuel cell system. It is important that the following section is setup correctly to allow the spreadsheet to correctly calculate the net present value and rates of return. The only values that need to be entered are the expenses and savings associated with the fuel cell.

1. First thing to notice is the weighted average cost of capital. The value is to be entered on the Summary/Sensitivity Analysis Page.
2. Next entry is the initial cost of installing the fuel cell. The value is inputted from the total construction cost analysis conducted in the previous section.

3. Stack replacement is the next item of concern for expenses. The replacement is currently scheduled to take place in year 5 at a cost of $300,000. Please contact a distributor for the most current information about the cost of a stack replacement.
4. Maintenance is also imported from another page within the spreadsheet. The annual maintenance cost is taken from the economics sheet and is calculated as an output.
5. Room has been left for other expenses that have not been previously been accounted for. Enter the other values in a gray colored line in the corresponding year it occurs and the spreadsheet will automatically update.
6. Annual savings is the first number imported under the savings category. The annual savings is taken from the economics sheet as a calculated output. It is calculated as the net annual savings minus the maintenance costs.
7. Government incentives have been included here. The $1,000 / kW provided by the federal government is automatically figured in and room has been left for other incentive programs.
8. A salvage value in year 10 in the final input for savings. It is not known the exact amount the system will be worth but with technology advancing daily, the usefulness after 10 years is a minimum.
9. The final part of the analysis is finding the net value for each year, discounting the money back to it's present worth, determining the discounted payback period, and finding the corresponding rates of return.

Summary / Sensitivity Analysis

1. Input the needed variables of Fuel Cell Manufacturing Costs, Cost of Money, and Contractor Markup in the gray boxes. (Give initial assumptions if you are not sure.)
2. Construction Costs has previously been completed.
3. Review the initial results listed below the inputs.
4. Look at the "What If" scenarios that are shown below the initial inputs.
5. Adjust the gray boxes at the top of the columns to find different results than what is initially inputted.
6. View the graph below the table for another description of the variable. It is recommended to adjust the changes to the maximum and minimum values to have a full look at the reaction of the graph.

Appendix A.2 – Economics Spreadsheet

INSTRUCTIONS - Sample inputs have been entered below. Inputs should be changed for your individual case.

INPUTS

Input	Value	Unit	*Description*	VARIABLE:
Building Electric Load				
Building Annual Peak Demand:	950	kW	Highest site demand in a year as shown on energy bills.	**Bld_kW**
Annual kWh Consumption:	2,980,000	kWh/Yr.	Total electrical energy consumption as shown on energy bills.	**kWh_Yr**
Building Minimum Demand:	250	kW	Minimum building demand. Should be greater than fuel cell capacity.	**Min_kW**
Building Thermal Load				
Building Annual Gas Load:	6,000	MMBtu/Yr.	Total gas (or steam/oil/other) consumption per energy bills.	**Bld_Gas**
Annual Displaceable Gas Load %:	50%		Percent of gas displaceable by fuel cell (I.e., not gas cooking, etc.).	**Disp_Gas_Per**
Annual Displaceable Gas Load:	3,000	MMBtu/Yr.	Building annual gas load * % displaceable load.	**Disp_Gas**
Thermal Interface Temperature:	130	°F	Temperature required by site thermal application.	**Thm_Temp**
Boiler Efficiency:	75%		Estimated seasonal boiler efficiency.	**Boil_Eff**
Fuel Cell				
Size:	200	kW	Fuel cell capacity in kW.	**FC_kW**
Availability:	90%		Estimated % of time fuel cell will be operating in a year.	**FC_Avail**
Months of Demand Reduction:	12	mos./year	Months that fuel cell reduces site demand in a year.	**Mos_Yr**
Average Operating Load:	200	kW	Average estimated fuel cell operating output during the year.	**Oper_AvgkW**
Electrical Efficiency:	36%	HHV*	Electrical efficiency of fuel cell in Higher Heating Value.	**Elec_Eff**
Thermal Efficiency:	40%	HHV*	Percent of gas consumed by fuel cell available as useable thermal.	**Thrm_Eff**
Sell Back to Utility?:	2	Y=1/N=2	Whether excess fuel cell electricity can be sold back to utility grid.	**Sell_Back**
Fuel Cell Installed Cost:	$900,000		Cost of fuel cell including installation costs.	**FC_Cost**
Energy Rates**				
Electric Demand:	$7.00	/kW/Month	Annual average demand charge from utility.	**DLR_kW**
Electricity:	$0.10	/kWh	Annual average energy charge from utility.	**DLR_kWh**
Input Fuel:	$4.00	MMBtu	Average gas cost in million BTU.	**DLR_MMBtu**
Maintenance Costs:	$0.020	/kWh	Estimated maintenance cost per kWh.	**Maint_kWh**

OUTPUTS

			Formula:	VARIABLE:
Annual Fuel Cell Energy				
Electric Output:	1,576,800	kWh	Oper_AvgkW * FC_Avail * 8760 hrs/yr.	**FC_kWh**
Thermal Output:	5,980	MMBtu	Fuel_In * Thrm_Eff	**Thrm_Out**
Input Fuel:	14,949	MMBtu	Disp_kWh * 3413 / Elec_Eff / 10^6	**Fuel_In**
Displaced Site Energy				
Annual Demand Reduction:	2,400	kW/Yr.	FC_AvgkW * Mos_Yr	**Disp_kW**
Displaced Electricity:	1,576,800	kWh/Yr.	Fuel cell electric output used on site.	**Disp_kWh**
Electricity Sold Back to Utility:	-	kWh/Yr.	Fuel cell electric output less electric output used on site.	**Sold_kWh**
Displaced Site Thermal:	2,250	MMBtu/Yr.	FC Thermal Output or Annual Displaceable Gas * Boiler Efficiency	**Disp_Thrm**
Annual Savings				
Electricity Savings:	$174,480		Disp_kW * DLR_kW + Disp_kWh * DLR_kWh	**Elec_Sav**
Thermal Savings:	$12,000		Thrm_Out / Boil_Eff * DLR_Thrm	**Thrm_Sav**
Subtotal:	$186,480		Elec_Sav + Thrm_Sav	**Sub_Sav**
Annual Costs				
Input Fuel:	$59,796		Fuel_In * DLR_MMBtu	**Fuel_Cost**
Maintenance:	$31,536		Maint_kWh * Disp_kWh	**Maint_Cost**
Subtotal:	$91,332		Fuel_Cost + Maint_Cost	**Sub_Cost**
Annual Net Savings	**$95,148**		Sub_Sav - Sub_Cost	**Net_Sav**

Simple Pay Back Period: **9.5 Years** Fuel Cell Installed Cost / Annual Net Savings

Notes:

Average Building Load (kW)	340
Fuel Cell Size / Average Building Load	59%
Fuel Cell Size / Minimum Building Load	80%
Fuel Cell Output / Annual Building kWh Load	53%
Site Utilization of Fuel Cell Thermal Output	38%

Appendix A.3 – Construction Costs Spreadsheet

Fuel Cell Construction Costs

INSTRUCTIONS - Sample inputs have been entered below. Inputs should be changed for the individual sites.
The grey boxes with blue numbers are the variables within this worksheet.

Fuel Cell Specifications

Size:		200	Fuel cell capacity in kW.
Average Cost per kW - Manufacturing:	$	4,300	
Fuel Cell Manufacturer Costs:	$	860,000	Cost of fuel cell including installation costs.

Construction / Installation Costs

Fuel Cell Manufactured Cost				$	860,000	
Shipping Costs (40,000 lb.)				$	25,000	40,000 lb on a low-boy trailer
Finished Fence for Fuel Cell		Total Length (ft)	Cost / ft	Total		
(Typically 34' x 38')		150	$50	$	7,500	
Concrete Pads	Length (ft)	Width (ft)	Depth (in)			
Fuel Cell (Assumed 22' x 14')	22	14	8			
Cooling Module (Assumed 16' x 6')	16	6	8			
	Volume (CY)	Rounded Up	Cost per CY	Total Concrete Cost		Cost to include excavation, equipment, labor, concrete and base material
	9.98	10	$300	$	3,000	
Connection Runs		Length (ft)	Cost / ft	Total		
Electrical		86.86	$60.00	$	5,212	86.86 ft. AVG - DoD sites
Thermal		104.14	$115.00	$	11,976	104.14 ft. AVG - DoD sites
Natural Gas		66.96	$50.00	$	3,348	66.96 ft. AVG - DoD sites
Cooling Module		20	$115.00	$	2,300	20 ft. AVG - DoD sites
Construction Costs / Shipping				$	58,336	Generally between $50,000 - 200,000 (site specific conditions)
Total Shipping and Installation				$	918,336	
Contractor Markup			10%	$	91,834	
Total Construction / Installation Costs				$	1,010,169	

Appendix A.4 – Life Cycle Cost Spreadsheet

Life Cycle Cost Analysis - Fuelcell

INSTRUCTIONS - Sample inputs have been entered below. Inputs should be changed for your individual case. Grey boxes are the variables on this worksheet

Weighted Average Cost of Capital (WACC)	12%

(Entered on Summary-Sensitivity page)

(Match the interest rate with the time period, i.e. yr to yr or month-month)

Time (yr, semi-annual, monthly)	0	1	2	3	4	5	6	7	8	9	10
Fuel Cell Expenses	(Enter as positve numbers)										
Initial Cost											
Cash Flow	$1,010,169	----	----	----	----	----	----	----	----	----	----
Stack Replacements											
Cash Flow	----	----	----	----	----	$300,000	----	----	----	----	----
Maintenance											
Cash Flow	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536	$31,536
Other Expenses											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Other Expenses											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Other Expenses											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Other Expenses											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Total Cost Value	$1,041,705	$31,536	$31,536	$31,536	$31,536	$331,536	$31,536	$31,536	$31,536	$31,536	$31,536

Life Cycle Cost Analysis - Fuelcell

INSTRUCTIONS - Sample inputs have been entered below. Inputs should be changed for your individual case. Grey boxes are the variables on this worksheet

Time (yr, semi-annual, monthly)	0	1	2	3	4	5	6	7	8	9	10
Fuel Cell Savings	(Enter as positive numbers)										
Annual Savings											
Cash Flow	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684
Government Incentive Program											
$1,000 / kW	$200,000	----	----	----	----	----	----	----	----	----	----
Federal Rebate											
Cash Flow	$400,000	----	----	----	----	----	----	----	----	----	----
Other Savings											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Other Savings											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Other Savings											
Cash Flow	----	----	----	----	----	----	----	----	----	----	----
Salvage Value											
Cash Flow	----	----	----	----	----	----	----	----	----	----	$50,000
Total Savings Value	$726,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$126,684	$176,684

Life Cycle Cost Analysis - Fuelcell

INSTRUCTIONS - Sample inputs have been entered below. Inputs should be changed for your individual case. Grey boxes are the variables on this worksheet

Time (yr, semi-annual, monthly)	0	1	2	3	4	5	6	7	8	9	10
Overall Cash Flows											
Total (Future Costs Estimates)	($315,021)	$95,148	$95;148	$95,148	$95,148	($204,852)	$95,148	$95,148	$95,148	$95,148	$145,148
Discounted Rates of Future Values net present value	($315,021)	$84,954	$75,852	$67,725	$60,468	($116,238)	$48,205	$43,040	$38,429	$34,311	$46,734
Discounted Payback Period		(Payback year occurs when the number becomes positive)									
	($315,021)	($230,067)	($154,216)	($86,491)	($26,023)	($142,261)	($94,056)	($51,016)	($12,587)	$21,725	$68,458
NPV	$68,458										
IRR	17.16%	*Only applicable if NPV is positive.*									
MIRR	13.66%	*Only applicable if NPV is positive.*									

Appendix A.5 – Summary and Sensitivity Sheets

Summary / Sensitivity Analysis

Inputs..........

Construction Costs

Averages from the DoD demonstration project have been entered into the spreadsheet analysis.
Specific site conditions should be adjusted for on the Construction Cost worksheet.

Fuelcell Manufacturing Costs

Average Cost per kW - Manufacturing:	$4,300	Excluding construction costs

Contractor Cost of Money

Weighted Average Cost of Capital	12%	(WACC) - Cost of money

Contractor Markups

Construction	10%

Results..........

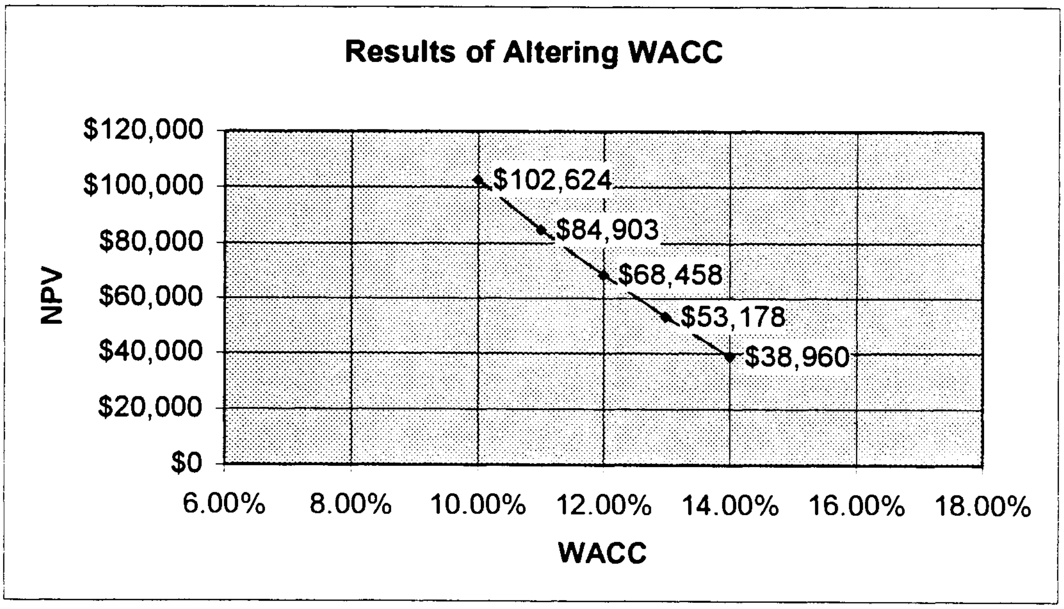
NPV	**$68,458**	
IRR	**17.16%**	*Only applicable if NPV is positive.*
MIRR	**13.66%**	*Only applicable if NPV is positive.*

WHAT IF..........

(Input the difference you want to see in the grey boxes)

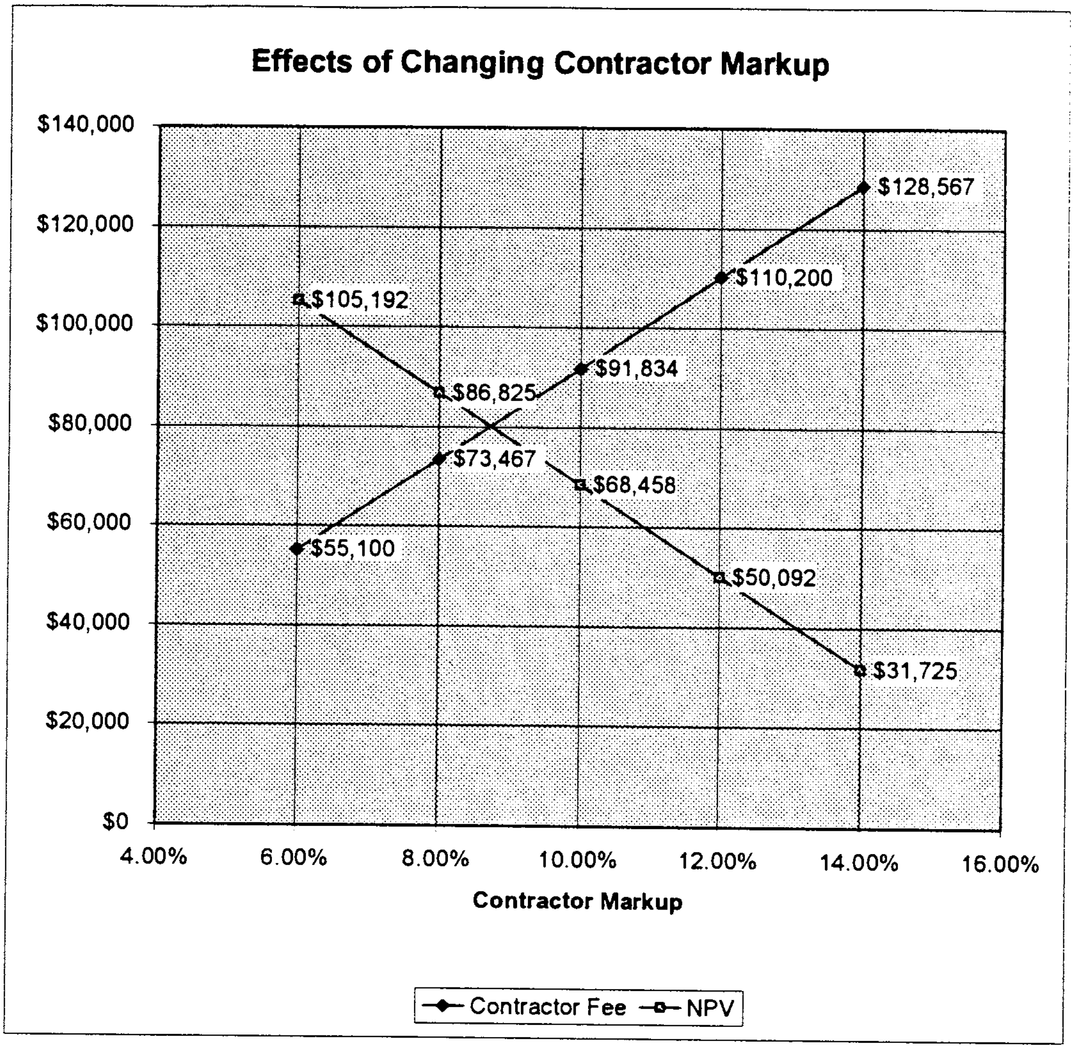
WACC Differs from the Expected %.

	-2.00%	***-1.00%***	***0.00%***	***1.00%***	***2.00%***
WACC	10.00%	11.00%	12.00%	13.00%	14.00%
NPV	$102,624	$84,903	$68,458	$53,178	$38,960
IRR	17.16%	17.16%	17.16%	17.16%	17.16%
MIRR	12.32%	12.99%	13.66%	14.34%	15.01%



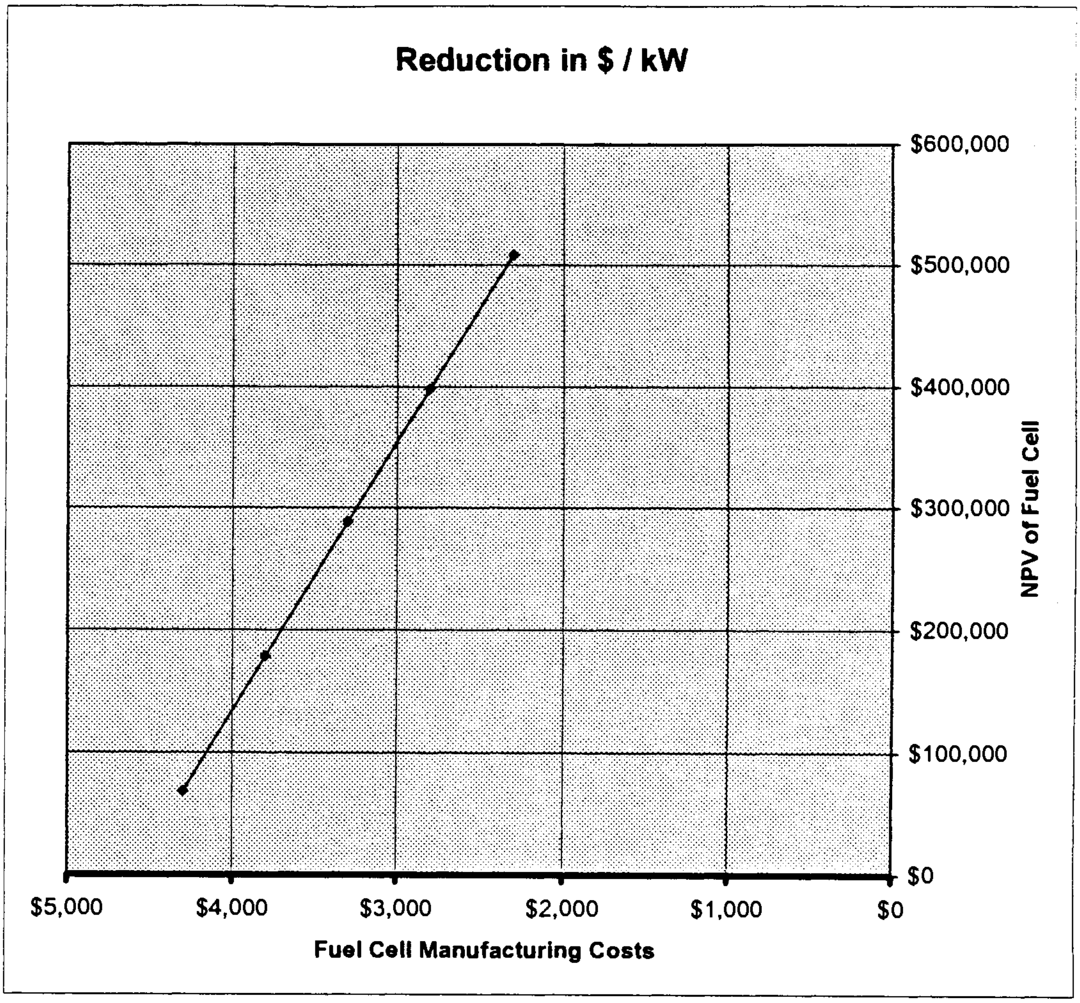
Contractor Construction Markup Changes.

	-4.00%	*-2.00%*	*0.00%*	*2.00%*	*4.00%*
Markup	6.00%	8.00%	10.00%	12.00%	14.00%
Contractor Fee	$55.100	$73.467	$91.834	$110.200	$128.567
NPV	$105.192	$86.825	$68.458	$50.092	$31.725
IRR	20.91%	18.92%	17.16%	15.59%	14.16%
MIRR	14.68%	14.16%	13.66%	13.19%	12.74%



Fuelcell Cost per kW (manufacturing)

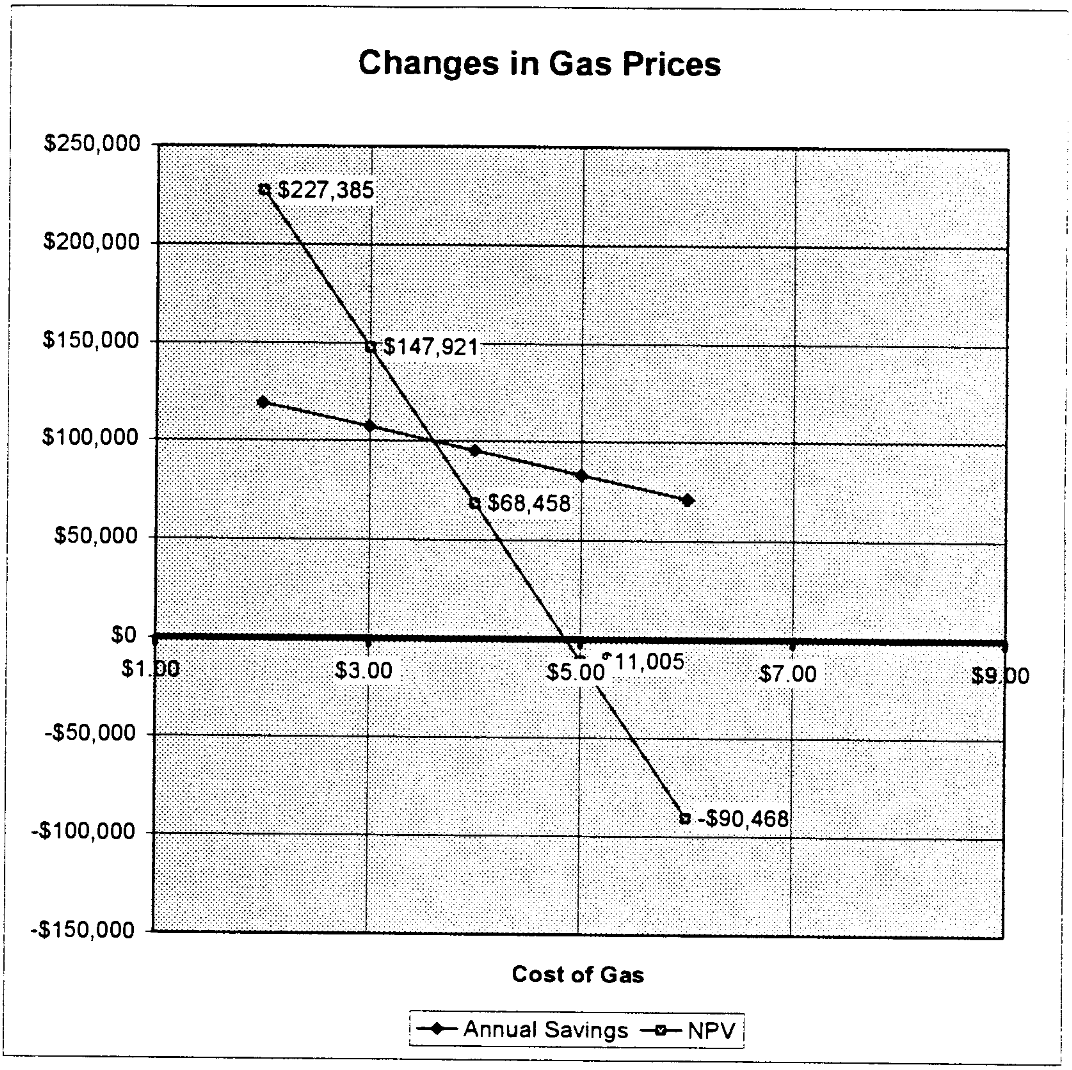
	-$2,000	*-$1,500*	*-$1,000*	*-$500*	*$0 Difference*
$ / kw	$2.300	$2.800	$3.300	$3.800	**$4.300**
NPV	$508.458	$398.458	$288.458	$178.458	$68.458
IRR	#NUM!	#DIV/0!	88.25%	32.44%	17.16%
MIRR	32.51%	29.97%	22.07%	17.06%	13.66%



Changes in Cost of Gas

	50.00%	*75.00%*	*Input Cost*	*125.00%*	*150.00%*
Gas Cost (MMBtu)	$2.00	$3.00	$4.00	$5.00	$6.00
Annual Savings	$119,046	$107,097	$95,148	$83,199	$71,250
NPV	$227,385	$147,921	$68,458	-$11,005	-$90,468
IRR	29.96%	23.40%	17.16%	NA	NA
MIRR	17.22%	15.49%	13.66%	NA	NA

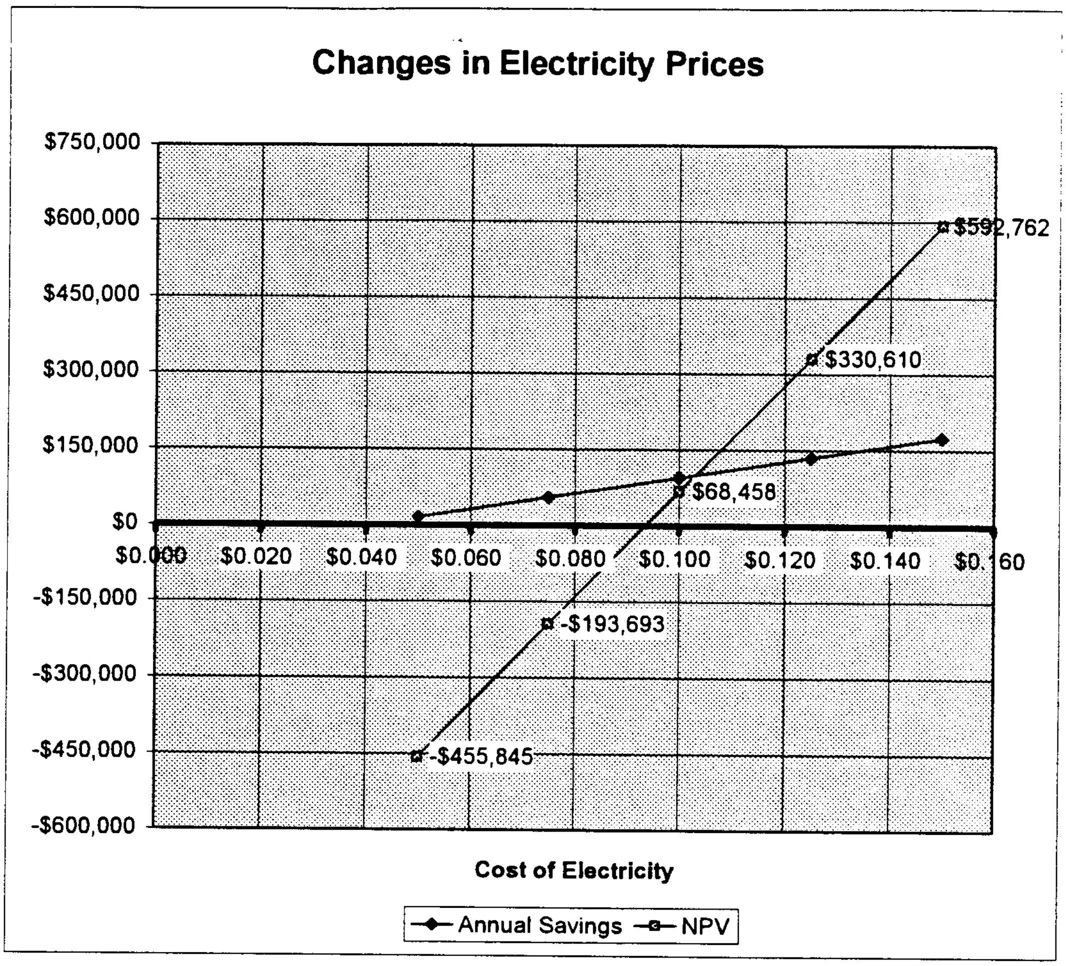
(maintainence costs removed from annual savings)



Changes in Cost of Electricity

	50.00%	*75.00%*	*Input Cost*	*125.00%*	*150.00%*
Elec. Cost (kWh)	$0.050	$0.075	$0.100	$0.125	$0.150
Annual Savings	$16,308	$55,728	$95,148	$134,568	$173,988
NPV	-$455,845	-$193,693	$68,458	$330,610	$592,762
IRR	NA	NA	17.16%	39.12%	66.73%
MIRR	NA	NA	13.66%	19.39%	24.70%

(maintainence costs removed from annual savings)



Changes is All Variables

WACC	*12.00%*
Markup	*10.00%*
$ / kW	*$4,300*
Gas Cost (MMBtu)	*$ 4.00*
Elec. Cost (kWh)	*$ 0.100*

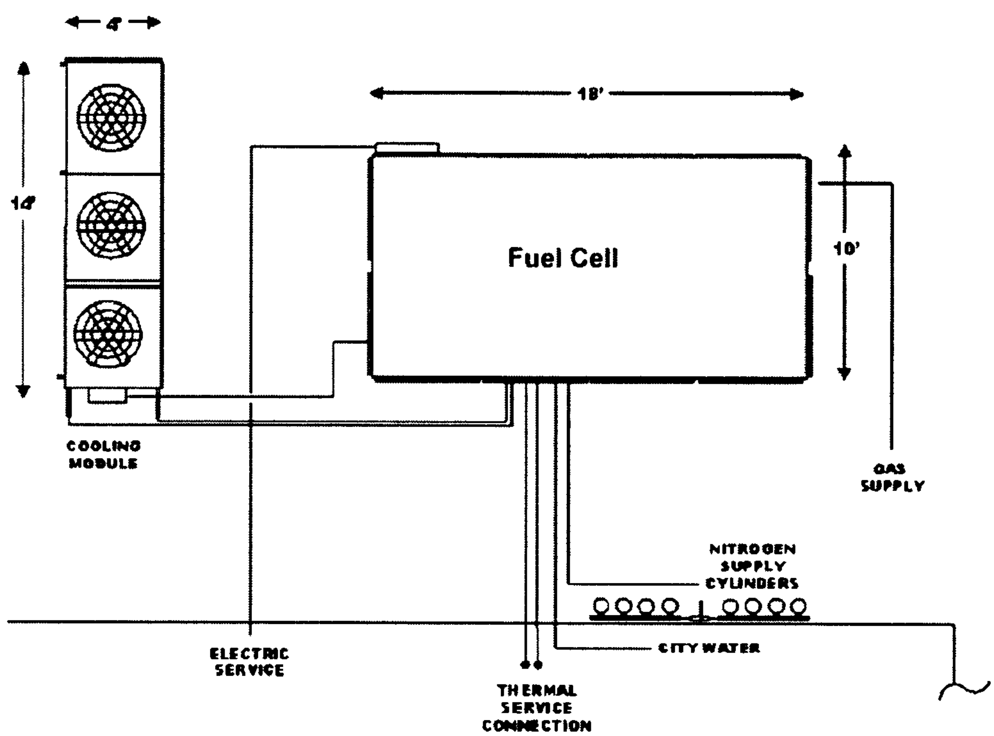
NPV	*$68,458*
IRR	*17.16%*
MIRR	*13.66%*

APPENDIX B – DOD / UTC FUEL CELL INFORMATION

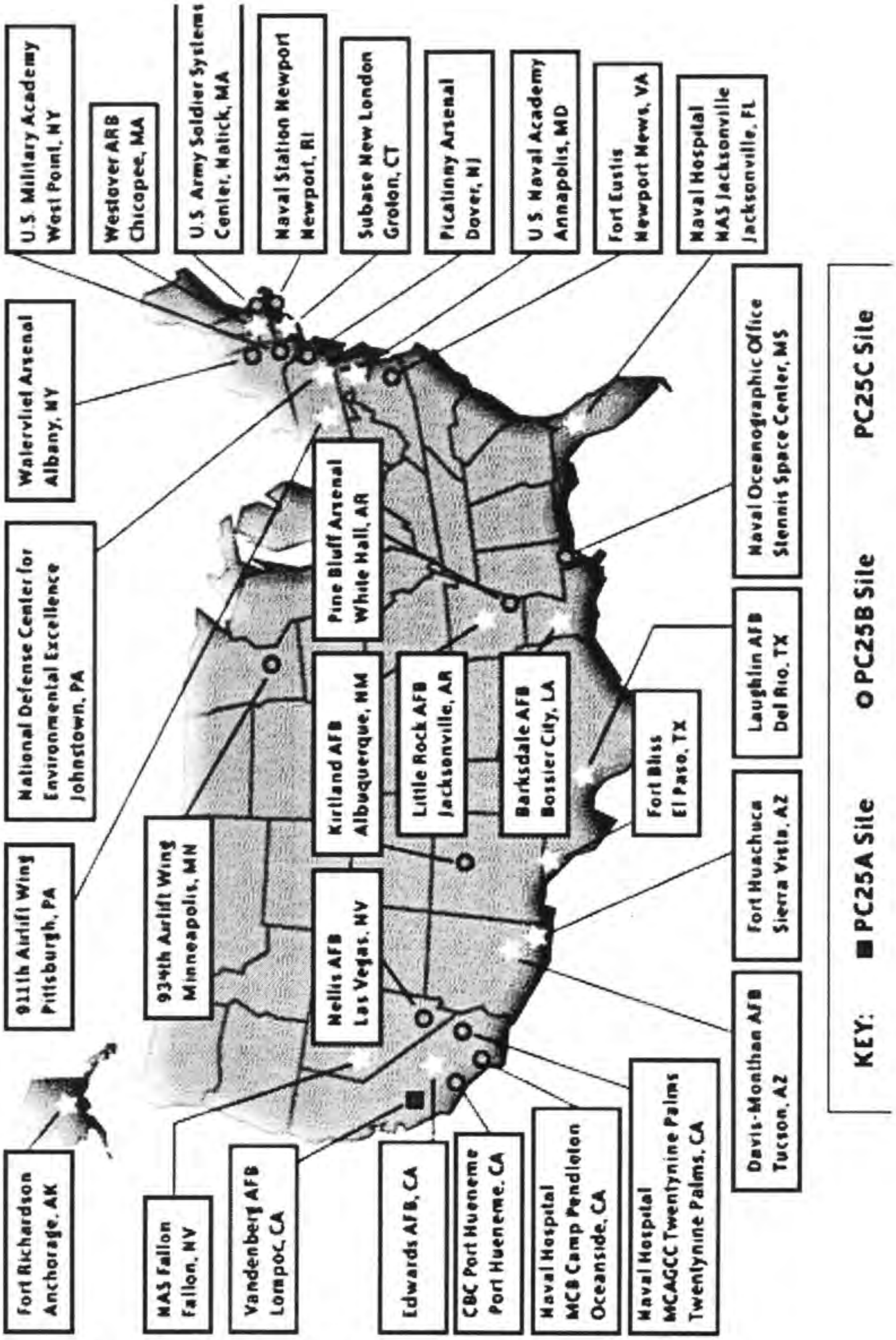
Basic fuel cell information from UTC

PC25C Performance Data

Feature	Characteristics
Rated Electrical Capacity	200 kW/235kVA
Voltage and Frequency	480/277 V, 60 Hz, 3 phase 400/230 V, 50 Hz, 3 phase
Fuel Consumption	Natural gas: 2050 cft/h @ 4-14" water pressure Anaerobic digester gas: 3200 cft/hr at 60% CH_4
Efficiency (LHV Basis)	87% Total: 40% Electrical, 50% Thermal
Emissions	< 2 ppmv CO, < 1 ppmv NOx and negligible SOx (on 15% O_2, dry basis)
Thermal Energy Available	
Standard:	900,000 Btu/hr @ 140F
High heat options:	450,000 Btu/hr @ 140F and 450,000 Btu/hr @ 250F
Sound Profile	Conversational level (60dBA @ 30 ft.), acceptable for indoor installation.
Modular Power	Flexibility to meet redundancy requirements as well as future growth in power requirements.
Flexible Siting Options	Indoor or Outdoor installation, Small footprint
Power Module: **Dimensions and Weight**	10' x 10' x 18' 40,000 lbs.
Cooling Module: **Dimensions and Weight**	4' x 14' x 4' 1700 lbs.



Info from the DoD about location of fuel cells



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