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Costs and benefits of using fuel cells for stationary power generation at Marine Corps Logistics Base Barstow Maintenance Center

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COSTS AND BENEFITS OF USING FUEL CELLS FOR STATIONARY POWER GENERATION AT MARINE CORPS LOGISTICS BASE BARSTOW MAINTENANCE CENTER

by

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December 2002

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We compare the costs and benefits of using two types of fuel cell power generation systems versus Southern California Edison to provide the base electricity load for the Marine Corps Logistics Base Barstow Maintenance Center. The results indicate that the break-even point is not likely to occur before year eight and under certain conditions may not occur at all during the 20-year program life cycle. The results do indicate a pollution reduction from fuel cells, but the reduction would not have any measurable impact on the nation's air quality.

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ABSTRACT

We compare the costs and benefits of using two types of fuel cell power generation systems versus Southern California Edison to provide the base electricity load for the Marine Corps Logistics Base Barstow Maintenance Center. The results indicate that the break-even point is not likely to occur before year eight and under certain conditions may not occur at all during the 20-year program life cycle. The results do indicate a pollution reduction from fuel cells, but the reduction would not have any measurable impact on the nation's air quality.

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ACRONYMS

AEO	Annual Energy Outlook
CAISO	California Independent System Operator
CALEPA	California Environmental Protection Agency
CEC	California Energy Commission
CO_2	Carbon Dioxide
COE	Cost of Electricity
CPUC	California Public Utilities Commission
DOD	Department of Defense
DOE	Department of Energy
EIA	Energy Information Administration
IOU	Investor-Owned Utility
kWh	Kilowatthour
LADWP	Los Angeles Department of Water and Power
LCOE	Levelized Cost of Electricity
MCFC	Molten Carbonate Fuel Cell
MCLB	Marine Corps Logistics Base
MWh	Megawatthour
NG	Natural Gas
NOx	Nitrogen Oxides
NO_2	Nitrogen Dioxide
NPV	Net Present Value
O^3	Ozone
O&M	Operations and Maintenance
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
PG&E	Pacific Gas & Electric
PM_{10}	Particulate Matter Less than 10 Microns
ppm	Parts Per Million

PV	Photovoltaic
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SOFC	Solid Oxide Fuel Cell
SOx	Sulfur Oxides
SO_2	Sulfur Dioxide
UTC	United Technologies Corporation

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I. INTRODUCTION

A. GENERAL INFORMATION

This research evaluates the functionality and cost of using commercially available fuel cells to provide electrical power to the Marine Corps' Barstow Maintenance Center. The objective is to determine whether implementing this technology as a replacement for the established power grid is a good idea. Research includes: conducting a detailed analysis of current fuel cell technology, conducting a review of the current California energy and environmental regulations affecting electricity generation and reliability, examining Maintenance Center energy costs, and conducting a cost-benefit analysis of implementing fuel cell technology.

B. RESEARCH QUESTIONS

1. Primary Research Question

- Is it a good idea to install fuel cells as the energy generator at the Marine Corps' Barstow Maintenance Center?

2. Secondary Research Questions

- What are fuel cells? What are the advantages and disadvantages of fuel cells?
- Where are fuel cells currently being used in the commercial world? In DoD?
- What energy or environmental policies are affecting California's power supply?
- What are the current costs of energy at Barstow's Maintenance Center?
- What is the cost of a power outage to Barstow's Maintenance Center operations?
- What are the direct costs and benefits of changing the power supply to fuel cells?
- What are the indirect benefits?

- What back-up systems will be required to support fuel cells?
- What skills will be necessary to implement fuel cells?
- Will maintenance personnel require special skills? If so, how much will training cost?

C. DISCUSSION

With the faltering electricity “deregulation" effort and recent power crisis in California, Marine Corps Logistics Base (MCLB) Barstow is seeking an alternative method to acquire energy for its facilities. With many distributed generation options to choose from, including solar, fuel cells, wind and combustion turbines, each type has its own advantages and disadvantages. However, fuel cells are gaining popularity and acceptance in using the world’s most abundant resource, hydrogen, to generate substantial power for the future.

Fuel cell technology has undergone tremendous growth in the past decade. The technology has evolved from being used only on Apollo and Space Shuttle missions to being used by everyday businesses to provide reliable power. Both commercial business and government agencies have realized the tremendous capabilities of fuel cells, helping to accelerate their growth beyond a technology “concept” to a reality in power generation.

In the very recent past, 2000-2001, the United States has seen large-scale problems associated with its power network, particularly in California. Although conservation and building new power generators have eliminated the use of “rolling black outs” or “brown outs” in 2002, future power shortages may still arise, as noted by the recent “Stage 2” warnings, which are issued when power reserves fall below five percent. Any future shortage could have negative impacts upon the nation’s military facilities.

The current power grid operates with an average reliability of three nines, or 99.9 percent, resulting in a power outage of over eight hours per year, mainly the result of the transmission grid. Fuel cells have the potential to significantly lower that failure rate to a reliability of 4-6 nines, 99.99-99.9999 percent, by co-locating with the demand site. This eliminates transmission and distribution. [Ref. 1] A reliability level of six nines results in approximately thirty seconds of outage a year.

Until recently, the cost of fuel cell technology has made it impractical for all but a few companies. Technology and reliability advances have reversed that trend. Today you will find fuel cells operating a United States Postal Service mail sorting facility in Alaska, a bank in Omaha, a police station in New York City, and a hospital in Sacramento, to name a few. Fuel cells are increasing in popularity as a primary distributed power generator.

Beyond reliability, there appear to be many other benefits from fuel cell usage. Providing “green power,” site flexibility, operating flexibility in hot and cold climates, and the ability to scale power output based on the user’s requirement are some of the other benefits of fuel cell power generation. With the government trying to reduce costs, update facilities, and be environmentally conscious, fuel cells may provide alternatives to the status quo for power generation.

MCLB Barstow’s Maintenance Center is the main production facility for depot level repairs on Marine Corps ground equipment west of the Mississippi River. It encompasses thousands of square feet and used 16,761 Megawatthours (MWH) of electricity in fiscal year 2000. [Ref. 2] However, due to its location, in the middle of the Mojave Desert, it does not have a large heating requirement, which reduces the efficiency potential of a fuel cell by not utilizing the cogenerated heat.

This research deals with the fact that our maintenance depots and other government operations and support facilities operate on the existing power grid. It addresses cost requirements and reliability and maintenance issues, and quantifies the direct benefits of using fuel cells as an alternative.

D. SCOPE OF THESIS

This thesis centers on a case study of the Marine Corps Logistics Base Barstow Maintenance Center’s baseload energy demand and costs of supply. The present electricity costs are then compared to the hypothetical case of using either Phosphoric Acid (PAFC) or Proton Exchange Membrane (PEMFC) fuel cells to generate the Maintenance Center’s baseload power in lieu of the existing power grid.

This research includes:

- An evaluation of Barstow Maintenance Center’s current power requirements and costs
- An in-depth review of fuel cells that are currently available and suitable
- An explanation of the policies affecting Barstow’s power supply
- A feasibility study of implementing fuel cells at the Barstow Maintenance Center

The thesis concludes by recommending not to transition from the current power grid to fuel cells.

E. METHODOLOGY

In order to conduct this case study, numerous literary sources were consulted. This thesis required reviewing fuel cell topics found in current news articles, official government reports, documents published by the United States Department of Energy (DOE), journal reports, and literature produced by fuel cell manufacturers. The literature review provides a clear explanation of current fuel cell capabilities and usage.

Next, electricity rate schedules and energy-related data from Barstow's Maintenance Center were reviewed to establish the baseline energy costs for Maintenance Center operations.

Additionally, given that energy prices routinely fluctuate, United States energy forecasts were used to gather future energy prices. These prices are used for high-, baseline-, and low-case examples for comparison against present and future fuel cell power generation.

Finally, the researcher presents a comprehensive comparison of costs and benefits of using fuel cell power generation at the Barstow Maintenance Center. This data is then compared to the current and future costs of energy, and conclusions are drawn.

F. CHAPTER OUTLINE

1. Introduction

Chapter I provides an introduction to fuel cell power generation and identifies the focus and purpose of this study. The primary and secondary research questions are also stated.

2. California Power Generation

Chapter II gives a brief look at the recent California power crunch from 2000 to 2001, strangely following the 1996 electricity "deregulation" movement, intended to decrease prices through open competition. Additionally, it discusses the push for distributed generation and the incentives for doing so. Finally, Chapter II examines the California environmental policies affecting typical power generation.

3. Fuel Cell Technology

This chapter looks at the types, capabilities, and limitations of fuel cells. Efficiency being a key fuel cell advantage, fuel cell cogeneration of electricity and heat is explained. Chapter III also digs into the current fuel cell market and looks at its future potential.

4. Implementation of Fuel Cells at Barstow Maintenance Center

Chapter IV looks specifically at the power requirements for the Barstow Maintenance Center. Examining electricity load data and current rate schedules, the researcher shows the Maintenance Center energy costs. Finally, constraints such as space, hydrogen source, and maintenance requirements are examined.

5. Feasibility of Changing Barstow Maintenance Center to Fuel Cell Power

This chapter compares the costs associated with fuel cells to the current rates being paid by Marine Corps Logistics Base Barstow. The comparison is conducted using two measures: net present value and the levelized cost of electricity. It also looks at the future of the electricity and natural gas market. Using low, baseline, and high energy prices, comparisons of fuel cells to the power grid are made. Finally, Chapter V contrasts pollution generated by SCE with that generated by on-site fuel cells.

6. Conclusions and Recommendations

Chapter VI concludes that based on the high capital costs and unknown reliability of fuel cells, the Barstow Maintenance Center should not transition to fuel cell based power system. Recommendations for further study are also provided.

G. BENEFITS OF STUDY

This study provides the necessary information required to help decide whether it is a good idea to implement a fuel cell based power system for Barstow’s Maintenance Center. It serves as an example for other DOD organizations seeking to implement fuel cell technology as an augment or alternative to their existing power grid.

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II. CALIFORNIA POWER GENERATION

A. INTRODUCTION

Legislation, such as the Energy Policy Act of 1992 (EPACT), shifted the paradigm of the electric industry and started a nationwide restructuring effort. The EPACT provided wholesale electricity generators nondiscriminatory access to the transmission grid at "reasonable" rates. This effort increased competition and lowered rates within the wholesale generation market created by non-utility generators. [Ref. 3]

On September 23, 1996, the governor of California, Pete Wilson, signed Assembly Bill 1890 (AB 1890), which would serve to restructure almost 80 percent of the electricity service provided by California's three investor-owned utilities (IOU): Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). [Ref. 4]

AB 1890 was written in response to the high electricity rates paid in California and the changing composition of the then-regulated electricity industry. California legislators and consumers were frustrated with the electricity rates paid in California compared to the rest of the country. Despite having lower than average electric bills, Californians paid per-unit electricity rates that were 40 percent higher than the national average. [Ref. 5] Consumer electric bills were kept low due to strict conservation and efficiency measures, but higher rates emerged from IOUs spreading their fixed costs over the lower energy consumption. [Ref. 3]

At the time, the California Energy Commission (CEC), a state agency, believed that lower electricity rates were essential to the well being of the state. The CEC stated,

> Energy is essential to California's economy. The state's long-term economic growth relies on, among other factors, an adequate and stable supply of energy in all major forms: transportation fuels, electricity and natural gas. It is time for reform. California needs stable energy prices, as low as can be achieved consistent with concern for the environmental impacts of energy use, as part of the foundation for a sound economy, new industries, jobs and export opportunities for California's businesses. [Ref. 6]

When the reform began in 1996, the three largest IOUs were vertically integrated: generating, transmitting, and distributing electricity to 75 percent of California's retail customers. AB 1890 restructured and increased retail competition using several key elements. First, AB1890 required the California IOUs to allow other generators access to transmission and distribution lines, thereby disintegrating the traditional utility. Further mandates required the IOUs to participate as buyers and sellers, in centralized bid-based spot wholesale markets, where sellers can bid any price, for day-ahead and day-of power sales run by a new organization, the California Power Exchange (CALPX). This requirement eliminated the popular method of entering into longer-term contracts for buying and selling electricity. Third, the newly formed non-profit California Independent System Operator (CAISO) took operational control of the existing high-voltage transmission grid that continued to be owned by the IOUs. Next, with the introduction of customer choice, retail customers were allowed to switch to other electricity suppliers. Fifth, retail customers were assessed a “competitive transition charge” to recover the IOUs’ costs that were forecasted to be above the market price, labeled “stranded costs.” These "stranded costs" came from pre-AB1890 investment by the IOUs in system upgrades and overhaul. Finally, retail tariffs were cut by 10 percent and frozen for four years or until the IOUs had recovered stranded costs, whichever came first. [Ref. 7]

B. FALTERING OF CALIFORNIA’S ENERGY RESTRUCTURING

California’s restructured wholesale market and customer choice program began in March 1998 and worked fairly well for a year and a half. However, in the summer of 2000 retail electricity prices in southern California reached all time highs and generation capacity shortages forced power outages. The resulting California energy crisis was widely publicized and had impacts that are still felt today. The three interrelated problems and other factors that surrounded the crisis are detailed below.

1. High Wholesale Electricity Prices

Wholesale electricity prices, on the CALPX, began to escalate in June 2000, increasing to never before seen levels for the rest of 2000. By December 2000, wholesale prices on the CALPX cleared at $.37699 per kilowatthour (kWh), over 11 times as high than in December 1999. [Ref. 8]

The high wholesale prices resulted in a steep although temporary increase in retail electricity prices in southern California during the summer of 2000. The two largest IOUs', PG&E and SCE, customers were protected from the dramatic increase since the retail price freeze had been imposed during the restructuring plan. With retail prices not covering costs, PG&E and SCE rapidly began to accumulate debt. However, SDG&E's retail price freeze was lifted in July 1999 as part of the restructuring plan, therefore exposing their customers to unregulated retail electricity prices. SDG&E customers were paying 16 cents per kWh in July 2000, up from 11 cents in July 1999, an increase of 45 percent. [Ref. 9]

2. Intermittent Power Shortages

Beginning in 1999, California experienced a significant increase in emergency conditions that in some cases necessitated rotating blackouts. Stage 3 emergency notifications, which can require rotating blackouts, increased from 1 in 2000 to 38 through May 22, 2001. Stage 1 and 2 notifications also increased from a total of 91 in 2000 to 127 through May 22, 2001. Figure 1 details California's Stage 1, 2 and 3 power emergency notifications from 1998 to May 22, 2001. [Ref. 8]

A Stage 1 notification is declared any time an operating reserve shortfall is unavoidable or when in real-time operations, the operating reserve is forecast to be less than the minimum after utilizing available resources. A Stage 2 notification results any time it is clear that an operating reserve shortfall, less than 5 percent, is unavoidable or when the operating reserve in real-time operations, is forecast to be less than 5 percent after dispatching all resources available. Finally, a Stage 3 notification is issued any time it is clear that an operating reserve shortfall, less than 1.5 percent, is unavoidable or when the operating reserve in real-time operations is forecast to be less than 1.5 percent after dispatching all resources available. [Ref. 10]

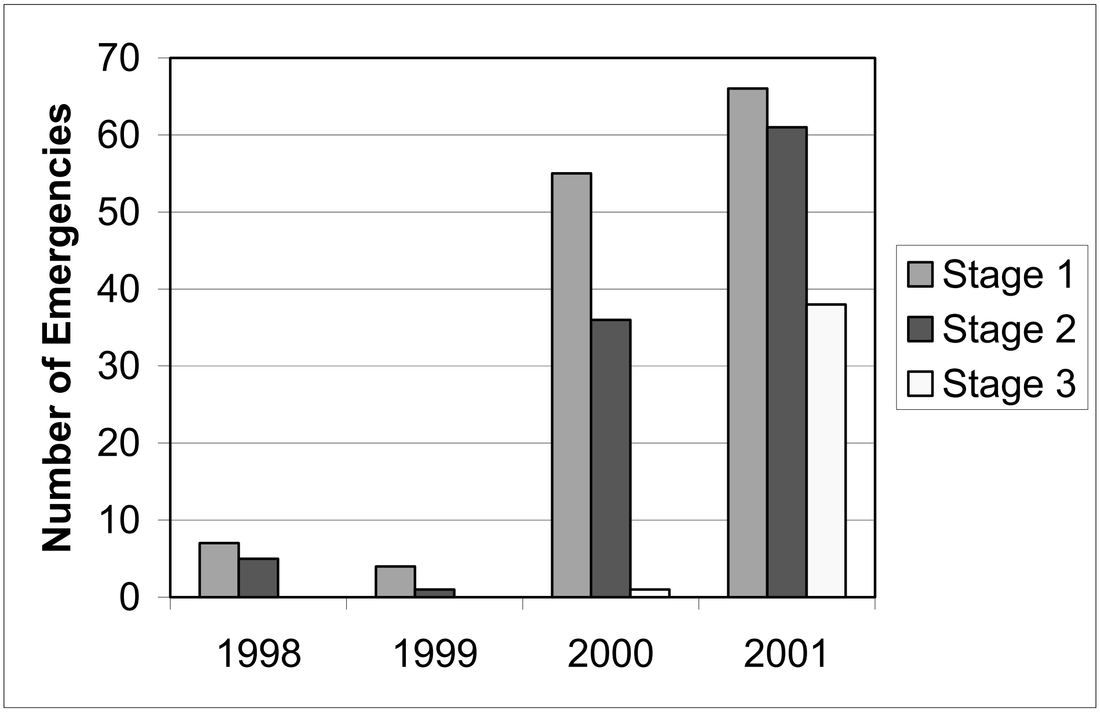

Figure 1. California’s Declared Staged Power Emergencies.
(From: California Independent System Operator)

3. Financial Problems for the Three IOUs

Facing high wholesale power prices and with retail price caps restricting cost recovery, the three major IOUs experienced severe financial problems. Ultimately, PG&E filed for Chapter 11 bankruptcy protection on April 6, 2001, after spending $9 billion for wholesale power without reimbursement. SCE was in a similar situation; in November 2000, SCE estimated its unrecovered power costs at $2.6 billion. In December 2000, SDG&E estimated its unrecovered costs at $447 million. [Ref. 8]

4. Other Contributing Factors

While retail sales of electricity rose by 11 percent from 1990 through 1999, California’s generation capability actually declined by 2 percent during the same period.

Additionally, no new electricity generating capability was constructed. [Ref. 8]

Next, increasing natural gas prices and the high costs of meeting California’s power plant emissions requirements also contributed to the increase in wholesale electricity prices. True, California has very stringent environmental standards. However, it was not just the strict standards, but also how the standards were implemented. It took almost twice as long to get state and local siting and permitting approvals for new generating plants in California as it did in any other state. The California legal and political systems allowed residents near the sites of proposed facilities and environmental groups to block or substantially delay the siting and permitting process for most new generating plants. [Ref. 7] Consequently, supply stagnated while demand steadily increased.

Typically, California relies on 7 to 11 gigawatts of electricity imports to meet demand. A large portion of these imports are generated from hydroelectric power plants, but in 2000 unusually low water levels in the northwest United States resulted in lower imports to northern California. [Ref. 8]

Also during 2000, approximately 10 gigawatts of generation were out of commission during the peak demand times, further contributing to power shortages. [Ref. 8]

The three IOUs paid high wholesale prices for power, but were unable to recover their costs because retail electricity prices were frozen. As noted previously, these price ceilings resulted in the IOUs building up enormous debt. This large debt, inability to contract for future purchases or sales, and overall financial difficulty for the IOUs only exacerbated the problem, as independent power generators were reluctant to sell power to PG&E’s and SCE’s distribution entities due to the uncertainty of payment. [Ref. 8]

Finally, in response to PG&E’s and SCE’s financial inability to purchase power, the California government appointed a state agency to purchase wholesale power and resell it to the distribution companies in early 2001. This eliminated the spot-market aspect of California’s plan by creating a single-buyer model. However, this type of market has a key disadvantage. The appointed buyer is generally not a skilled buyer and may be susceptible to political pressures to sign higher-priced power purchase agreements. In 2002, there remain allegations that California paid too much for the power it purchased. [Ref. 7]

From the start, California’s wholesale, bid-based spot market did not contain the right conditions for success. With heavy regulatory requirements hindering the construction of new power plants, retail tariffs that did not cover costs, the inability of buyers and sellers to enter into contracts to hedge against price volatility, and the state’s participation in the market, coupled with some bad luck, the initial restructuring effort did not succeed.

C. ELECTRICITY GRID RELIABILITY

It is estimated that the current United States electricity grid, composed of the generation and the transmission and distribution system, operates at a 99.9 percent reliability level. This .1 percent downtime results in an average of eight hours of electricity outage per year per customer. Most of this downtime results from nature-related factors affecting the end distribution of electricity. [Ref. 1] While this may not seem very large for a regular household, this results in one lost shift of production for United States industry. In a single production facility of 200 workers averaging $20 per hour, labor costs alone from an 8-hour loss reach $32,000 per year. Including reduced production, lost product and reduced customer service, the lost dollars may be much higher.

California’s three largest IOUs provide annual reports to the California Public Utilities Commission (CPUC) detailing their system downtime for the past year. Since SCE is the electricity provider for MCLB Barstow, its reliability statistics are described below. System statistics are computed as follows: (1) including transmission, substation, and distribution outages, and (2) excluding planned outages.

System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) values include sustained outages, which are defined as outages lasting five minutes or more. SAIDI is the average number of minutes of outages per customer per year. SAIFI is the average number of sustained outages per customer per year. The Momentary Average Interruption Frequency Index (MAIFI) values include momentary outages, which are defined as outages lasting less than five minutes.

Table 1 shows the historical system reliability data for SCE during the ten-year period 1992-2001, with and without major events. Excludable major events are those events that meet either of the two following criteria: (a) the event is caused by earthquake, fire, or storms of sufficient intensity to give rise to a government declared state of emergency, or (b) any other disaster not in (a) that affects more than 15% of the system facilities or 10% of the utility's customers, whichever is less for each event. [Ref. 11]

	All Interruptions Included			**Major Events Excluded**		
YEAR	**SAIDI**	**SAIFI**	**MAIFI**	**SAIDI**	**SAIFI**	**MAIFI**
1992	91.73	0.90	1.64	65.41	0.77	1.43
1993	58.02	0.72	1.29	58.02	0.72	1.29
1994	119.87	0.68	1.42	41.15	0.53	1.30
1995	63.30	0.71	1.25	63.30	0.71	1.25
1996	120.94	1.19	1.63	57.80	0.76	1.61
1997	69.95	0.79	1.64	69.95	0.79	1.64
1998	69.13	0.91	1.79	69.13	0.91	1.79
1999	40.42	0.68	1.59	40.42	0.68	1.59
2000	37.98	0.71	1.64	37.98	0.71	1.64
2001	41.03	0.65	1.55	41.03	0.65	1.55

Table 1. SCE Reliability Data.

1. Year 2000

During the year 2000, the SCE generation, transmission and distribution system was out of service for an average of 37.98 minutes or .633 hours per customer. This resulted in a system wide reliability of 99.999928 percent. As there were no excludable major events in 2000, this value was unaffected by excluded events.

2. Year 2001

For the year 2001, the SCE generation, transmission, and distribution system was out of service for an average of 41.03 minutes or .68 hours per customer. This resulted in a system wide reliability of 99.999922 percent. As in 2000, there were no excludable major events in 2001.

3. 1992-2001

For the ten-year period the SCE system wide outages averaged 71.24 minutes or 1.19 hours, including all major events as defined above. This figure equates to a reliability of 99.999864 percent, almost six nines of reliability. This is far greater than the estimated 99.9 percent. Overall, the SCE electricity grid system appears very reliable or at least above the national average.

4. Other IOUs

PG&E reports remarkably different reliability statistics. Including all events for 2001, the PG&E SAIDI value was 252.8 minutes, or 4.21 hours, for an annual reliability of 99.952 percent. PG&E's ten-year average SAIDI from 1992-2001 was 243.75 for a reliability of 99.954 percent. [Ref. 11]

SDG&E reliability data is much closer to the values provided by SCE. For 2001, SDG&E reports a SAIDI of 68.5 minutes, or 1.14 hours, including all major events. This one-year value equates to an annual reliability of 99.987 percent. SDG&E's ten-year average SAIDI was 82.3 minutes, or 99.984 percent reliable. [Ref. 11]

D. ENVIRONMENTAL POLICIES

California is known for its tough environmental regulations. The California Air Resources Board (CARB), Department of Industrial Relations (DIR) and California Environmental Protection Agency (CALEPA), all maintain tough regulatory standards. In fact, the California ambient air quality standards are more restrictive than the federal standards. CARB limits the amount of Ozone (O^3) to 66 percent of the federal standard while also limiting the Respirable Particulate Matter (PM_{10}) and Sulfur Dioxide (SO_2) to 33 percent of the federal standards. [Ref. 12] All three of these pollutants are large contributors to the poor air quality found in several areas in California. Those environmental policies that specifically affect electricity generation in Barstow are discussed below.

1. Emissions

California has very stringent emissions standards throughout its 35 local Air Districts, each with authority to regulate stationary pollution sources within their district. The Mojave Air Quality Management District (MOJAQMD) is responsible for establishing emission regulations for the Barstow area. MOJAQMD Rule 475 limits emissions of nitrogen oxides (NO_x) and Particulate Matter (PM) from non-mobile, Electric Power Generating Equipment. Nitrogen Oxides originate from any source that burns fuel, such as cars, trucks, and residential heating. [Ref. 13] The current NO_x limits within the MOJAQMD, except for gas turbines, are 80 parts per million (ppm) when operating on gaseous fuels. [Ref. 14]

PM emanates from various sources, including incomplete combustion of any fuel, road dust, and fireplaces. [Ref. 33] PM is also regulated to both of the following limits: 5 kilograms (11 pounds) per hour and 23 milligrams per standard cubic meter (0.01 grams/standard cubic foot). [Ref. 14]

Although not regulated by rule MOJAQMD 475, Federal and CARB Ambient Air Quality Standards regulate SO_2. SO_2 is limited to an average .04 ppm over a 24-hour time period or

.25 ppm averaged over one hour. Keeping with the tough standards, CARB's 24-hour SO_2 standard allows only 29 percent of the SO_2 permitted under the .14 ppm federal standard. [Ref. 12]

2. Noise Levels

The California Code of Regulations, Title 8, Subchapter 7, Group 15, Article 105, Section 5096 regulates the level of noise to which employees are exposed.

Sound Level	**Duration Per Workday**		**Sound Level**	**Duration Per Workday**	
(decibels)	(hrs-mins)	(hours)	(decibels)	(hrs-mins)	(hrs)
90	8-0	8	103	1-19	1.32
91	6-58	6.96	104	1-9	1.15
92	6-4	6.06	105	1-0	1
93	5-17	5.28	106	0-52	0.86
94	4-36	4.6	107	0-46	0.76
95	4-0	4	108	0-40	0.66
96	3-29	3.48	109	0-34	0.56
97	3-2	3.03	110	0-30	0.5
98	2-38	2.63	111	0-26	0.43
99	2-18	2.3	112	0-23	0.38
100	2-0	2	113	0-20	0.33
101	1-44	1.73	114	0-17	0.28
102	1-31	1.52	115	0-15	0.25

Table 2. Permissible Noise Exposure Limits.

Table 2 lists the sound levels and duration limitations for which employee hearing protection is not required.

Exceeding these limits requires employers to use engineering controls to decrease the ambient noise levels, prohibits employees from being in the environment, or requires employers to provide adequate personal protective equipment to reduce sound levels to within the table limitations. [Ref. 15]

As shown in Table 2, any sound level below 90 decibels (dB) for any duration does not require employee hearing protection. 90dB is comparable to a busy urban street, diesel truck or food blender, while office or restaurant conversation is approximately 60 dB. [Ref. 16]

3. Water Quality

The CALEPA'S, State Water Resources Control Board works to protect California’s water resources against pollution and misuse. However, fuel cells have only a positive impact on water quality, because pure water, H_2O, is a by-product of electricity generation. Therefore, water quality regulations are disregarded as not applicable.

E. SUMMARY

Generating, distributing and transmitting power to California’s residents is neither easy nor cheap. Until the spring of 2000, its traditional large-scale power utilities routinely generated and transmitted sufficient electricity in a highly reliable fashion. However, California's restructuring miscue and its strict emissions laws have led to a resurgence in the search for effective distributed energy resources. The following chapter highlights one such technology.

III. FUEL CELL TECHNOLOGY

A. INTRODUCTION

Fuel cells are the cleanest fossil-fueled power generating technology available today, and, when using regular hydrogen, are completely emissions-free. Fuel cell power installations are exempt from air emission permitting requirements in most U.S. states and provide flexibility under many federal, state, and local air pollution standards. Fuel cells operate below air emission standards in every state, including California. For example, each United Technologies Corporation (UTC) 200 kW Phosphoric Acid fuel cell, model PC25, when operating at its rated power, eliminates more than 40,000 pounds of air pollutants, including nitrogen oxides (NO_x), sulfur oxides (SO_x), and two million pounds of carbon dioxide (CO_2) emissions per year when compared against typical US combustion-based generators. [Ref. 17]

Fuel cells have come a long way from their invention in 1839 by Sir William Robert Grove, a British physicist. Originally, Grove built a device that could reverse the electrolysis process. [Ref. 18] This process takes water molecules and splits them into the component hydrogen and oxygen atoms by sending a small electric current through the water. Grove sought to reverse this process, thereby generating electricity. Today all four major types of fuel cells operate on this principle.

Engineers pursued more modern fuel-cell technology in the 1960s when the United States and the former Union of Soviet Socialist Republics were seeking to conquer space. Of several technologies tried for use in power production aboard spacecraft, fuel cells proved much safer than nuclear energy and cheaper than solar power. Incorporated into the Apollo missions, fuel cells still see use in today’s space shuttle missions. [Ref. 19]

Widespread use of fuel cells remains a futuristic concept, but as their cost comes down and hydrogen becomes more accessible, fuel cells are beginning to show up in many locations. In 1997, the First National Bank of Omaha dropped its dependence on the established power grid and replaced them with fuel cells after experiencing a costly computer crash in a data processing center. The crash cost one of its large customers, The Gap, $6 million in sales. [Ref. 18] After receiving over $36 million in FY 1993 and 1994 appropriations, the U.S. Army’s Construction Engineering Research Laboratory installed thirty UTC phosphoric acid fuel cells, models PC25A/B/C, at DOD installations in seventeen states from Alaska to Florida. [Ref. 20]

Hailed as a primary electricity provider in a hydrogen-based economy, fuel cells maintain several advantageous characteristics for electricity producers and consumers. [Ref. 21] Table 3 summarizes the general advantages of fuel cells over a typical combustion powered generator. These items are discussed throughout the chapter.

Attribute	**Advantages**
Fuel cells are electromechanical devices, rather than combustion-powered generators.	Greater efficiency and lower operating costs through fuel savings.
Fuel cells are virtually pollution and odor-free.	More suitable for home use; can be located within the home or business.
Fuel cells operate quietly.	More suitable for residential and densely populated environments.
Fuel cells are reliable and require minimal maintenance.	Better adapted to intermittent use in backup power systems.
Even small units can efficiently recover by-product heat.	Greater fuel economy through cogeneration of power and heat.

Table 3. Fuel Cell Advantages.
(From: H Power Corporation, 2001)

B. FUEL CELL PRINCIPLES

All fuel cells operate using the same electrochemical process, combining hydrogen and oxygen into water, while simultaneously producing electricity. Hydrogen fuel dissociates into free electrons and protons (positive hydrogen ions) in the presence of the platinum catalyst at the anode. The free electrons are conducted in the form of usable electric current through the external circuit. The protons migrate through the membrane electrolyte to the cathode. At the cathode, oxygen from air, electrons from the external circuit and protons combine to form pure water and heat. The externally flowing electrons are captured in an external circuit and converted to an alternating current (AC) supply before being utilized. Individual fuel cells produce about 0.6 Volt and are combined into a fuel cell stack to provide the amount of electrical power required. [Ref. 22]

1. Characteristics

The major differences in the various types of fuel cells lie in their electrolytes, startup times, and operating temperatures. Table 4 shows the characteristics of the four major types of fuel cells.

Characteristic	**Proton Exchange Membrane (PEMFC)**	**Phosphoric Acid (PAFC)**	**Solid Oxide (SOFC)**	**Molten Carbonate (MCFC)**
Electrolyte	Polymer	Phosphoric Acid	Ceramic	Lithium Potassium Carbonate Salt
Operating Temperature	175° F	300-400° F	1800° F	1200° F
Power Density (mW/cm^2)	~700	~200	150~200	~160
Start-up Time (hours)	<0.1	1-4	5-10	10+
Environmental	Nearly zero emissions	Nearly zero emissions	Nearly zero emissions	Nearly zero emissions
Commercially Available	No	Yes	No	No

Table 4. Characteristics by Fuel Cell Type.

The most common type of fuel cell technology today is the Proton Exchange Membrane Fuel Cell (PEMFC). Due to its high power density and short start-up time, the PEMFC can be found in small home generators, larger scale industrial generators, and transportation applications. However, despite its popularity with developers, the PEMFC has not yet entered the commercial marketplace. According to the CEC, manufacturers like H Power Corporation and Ballard Power Systems will commercialize the PEMFC in 2003-2004. [Ref. 23]

There are several other types of fuel cells that vary only in the type of electrolyte used. The phosphoric acid type uses just that, phosphoric acid as the electrolyte. Another type uses molten carbonate salt and yet another uses a ceramic electrolyte. All of these can use similar sources of hydrogen and oxygen to produce electricity within a similar range of efficiency.

The one noticeable difference is the range of operating temperatures. While the PEMFC type runs close to 175 degrees Fahrenheit, the others operate at two to ten times that temperature. [Ref. 24] The other fuel cell types give off tremendous quantities of heat, which can be captured for use; this "cogeneration" is discussed later.

2. Limitations

Currently, there is no limit on the amount of electricity that fuel cells can produce. Although, commercial and prototype fuel cell products are available only from 1 kW to 250 kW, enough power for about 100 homes or a medium sized office building, these systems can be installed in parallel to form large power production facilities. The largest fuel cell facility currently in operation today uses seven UTC PC25 200 kW fuel cells to produce 1.4 MW of electricity for a Verizon call routing facility on Long Island, New York. This facility serves 40,000 Verizon customers on a 24-hour basis. [Ref. 25]

Also related to power output is the physical size of the fuel cell generator. The larger the power the larger the space required for the unit. The smallest fuel cell ever produced could fit into a cellular phone [Ref. 26], but this type of application remains largely experimental until hydrogen re-supply is improved. Larger fuel cells, like the UTC model PC25, are 18 feet long by 10 feet wide by 10 feet high and weigh approximately 40,000 pounds. Multiple kilowatt-sized fuel cells are comparable in size to an outside air conditioner, while 50 kW to 75 kW PEM fuel cells fit under the hood of United States and Japanese cars or SUVs [Ref. 17], and can be seen at manufacturer's car shows or driving down the road during demonstrations by fuel cell manufacturers.

Despite appearing to be the "perfect" power generator, fuel cells have one big limitation: cost. While they remain relatively expensive compared to a like-sized diesel or turbine generator, they are considerably cheaper than photovoltaic generators. Current production levels keep prices at about double that of a typical turbine backup generator. With uninstalled fuel cells costing about $3,000 per kW and combustion type generation costing $1,500 per kW, many potential customers do not focus on the additional benefits of lower emissions and quieter operation. [Ref. 19] However, with fuel cells becoming more popular and the sizable investments by the DOE and DOD, manufacturers hope to decrease that amount to more reasonably accepted levels. Figure 2 shows the current installed costs per kilowatt of electricity generated by type. With the PAFC gaining popularity, its costs are likely to drop more quickly than the other fuel cell types, ultimately achieving its goal of $1500 per kW or less. Table 5 gives the projected costs of fuel cell technology in the long term, after 2004.

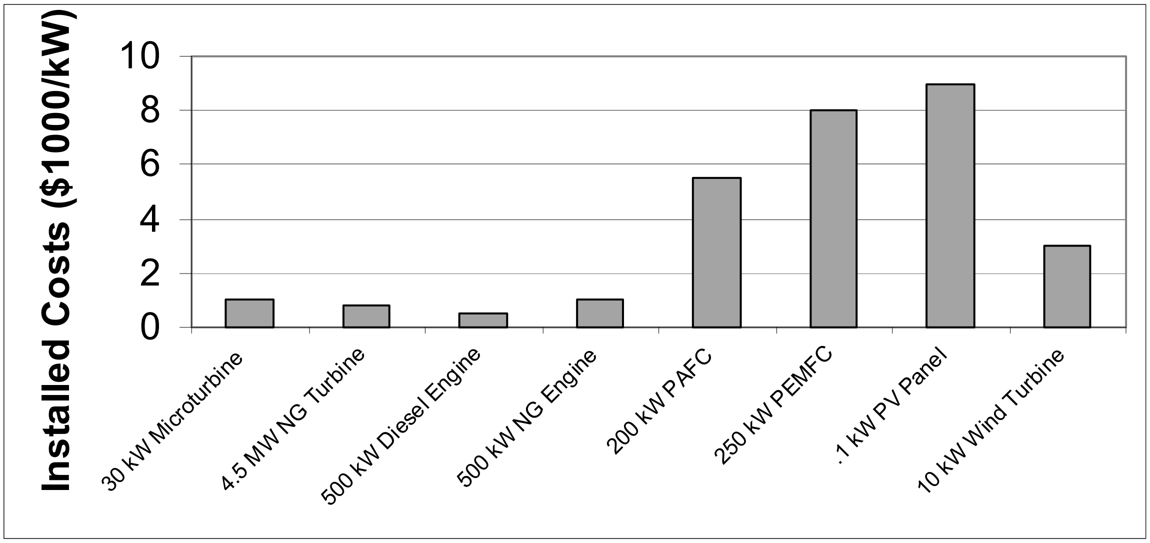

Figure 2. Current Installed Costs by Type of Generator.
(From: CEC Distributed Energy Resources Guide)

Technology	**Projected Cost (Long-term, Uninstalled)**
PEMFC	Initially $5000/kW Long term $1000/kW
PAFC	Initially $4000/kW Long term $1500/kW
SOFC	$1000-1500/kW
MCFC	$1200-1500/kW

Table 5. Projected Fuel Cell Costs.
(From: CEC Distributed Energy Resources Guide)

Rather than focusing on initial capital costs alone, fuel cell manufacturers are asking consumers to look at the payback period. If a significant power and heating cost reduction is achieved, the savings could feasibly pay for the fuel cell within 3-5 years. With limited use of the thermal waste heat for cogeneration, it appears the payback period could be significantly longer and may keep consumers from investing in this technology.

Despite their relatively high costs, installation of fuel cells or other forms of distributed generation does eliminate the need for transmission and distribution systems, since distributed generation systems are sited in very close proximity to their respective electric loads. This can be true for all forms of distributed generation microturbines, photovoltaics, or wind turbines. The national average cost of upgrading the transmission and distribution infrastructure is $1260/kW. [Ref. 27] Adding generator installation and infrastructure upgrade costs for multi-megawatt turbine type generators, fuel cells may prove to be cost competitive in the $2000/kW range.

Table 6 details the maintenance schedule and costs of several forms of electricity generation. Although they are estimated, fuel cell maintenance costs are within the range of costs of other types of generation. With only regular combustion type turbines being cheaper to maintain, fuel cells appear to be very competitive. Not until more fuel cells are installed and operated over long time periods, will these estimates be accurately verified or updated accordingly.

A more abstract limitation to overcome is the idea of doing something new. Although this technology is rather old, its use remains limited. But, as previously noted, some power reliant businesses have changed over to fuel cell power generation. As fuel cells become more common, slower reacting agencies, like the United States Government, may see potential benefits and get on board. For organizations like the government, that tactic may be beneficial because the government can capitalize on business best practices, allowing the government to gain the lessons learned from success without the pain of several failures.

Generator Type	**Time Until Maintenance Required (operating hours)**	**Average Maintenance Costs (cents/kWh)**
Microturbine	5000-8000	.5-1.6 (estimated)
Combustion Turbine	4000-8000	.4-.5
Internal Combustion Engine	750-1000: change oil and filter 8000: rebuild engine head 16000: rebuild engine block	.7-1.5 (natural gas) .5-1.0 (diesel)
Fuel Cell	Yearly: fuel supply system check Yearly: reformer system check 40000: replace cell stack	.5-1.0 (estimated)
Photovoltaic	Biyearly maintenance check	1% of initial investment per year
Wind Turbine	Biyearly maintenance check	1.5-2% of initial investment per year

Table 6. Maintenance Schedule and Costs.
(From: CEC Distributed Energy Resources Guide)

C. CAPABILITIES

The four major types of fuel cells do have capabilities that may limit installation options, without careful planning. With limited power output in single generators, restrictions in ambient temperature, fuel requirements by type and flow, and different efficiencies, fuel cell capabilities vary. Table 7 highlights the capabilities by fuel cell type.

Capability	**Proton Exchange Membrane (PEM)**	**Phosphoric Acid (PAFC)**	**Solid Oxide (SOFC)**	**Molten Carbonate (MCFC)**
Power Range	3-250 kW	100-200 kW	1 kW- 10 MW	250 kW-10MW
Operating Climate	-20°-110°F	-20°-110°F	-20°-110°F	-20°-110°F
Fuel Type(s)	Natural gas, hydrogen, propane, diesel	Natural gas, landfill gas, digester gas, propane	Natural gas, hydrogen, landfill gas, fuel oil	Natural gas, hydrogen
Efficiency (HHV)	32-40%	36-45%	43-55%	43-55%
Cogeneration	80°C water	Hot water	Hot water, LP or HP steam	Hot water, LP or HP steam
Reliability	>90%	>90%	>90%	>90%

Table 7. Fuel Cell Capabilities.

The fuel cell electrochemical process is remarkably efficient, rivaling the best of the large megawatt producing power plants. The previously mentioned UTC PC25 generates electricity at approximately 40 percent efficiency, while a similar more-popular gas turbine generator operates at about 30 percent. Fuel cell efficiency can be increased to over 85 percent when the owner captures the waste heat, which the PC25 produces at 900,000 BTUs per hour. [Ref. 17] Since fuel cells do not emit noxious gases, the heat can be easily harnessed for a number of uses. First National Bank of Omaha uses the waste heat to warm its buildings and the warm water to melt the ice and snow in its parking lot, all resulting in an annual savings of $200,000 in heating costs. In contrast to warming the building, the heat can also be used to drive a type of air conditioner called an “absorption chiller.” [Ref. 18]

The nation’s current power grid operates with an average reliability of three nines, 99.9 percent, resulting in a power outage of over eight hours per year. The power grid’s main reliability problem is within its transmission and distribution network, not necessarily in the generation system. Typical transmission power lines are susceptible to many hazards such as wind, rain, fire, earthquakes, vandalism, and accidents. Since fuel cells do not need a transmission or distribution network, they have the potential to lower that failure rate to a reliability of 4-6 nines, 99.99 to 99.9999 percent. For reference, a reliability level of six nines is approximately thirty seconds of electricity outage a year. According to an article in *Public Utilities Fortnightly*, there may even be a future market for individual customers demanding to increase reliability to nine nines or 99.9999999 percent, provided customers are willing to pay for it. [Ref. 1] Continued development of digital production and control systems may require this level of reliability, when electricity is "never off," to prevent production line stoppages.

Beyond efficiency and reliability there are other benefits from fuel cell usage. Providing “green power,” site flexibility, climate flexibility, and the ability to scale based on the user’s power requirement are some of the other benefits of fuel cell power generation. With the government trying to reduce military base operating costs, update facilities, improve security, and be environmentally aware, fuel cells may provide alternatives to the status quo of power generation.

Other capabilities include providing computer grade power without spike or interruption. This reduces the need for additional uninterruptible power supplies and can prevent damaging power spikes. Given the government’s increasing level of dependency on computer and software systems, this could be an additional benefit.

By using fuel cells that are fueled by the existing natural gas supply you can also eliminate outside storage tanks and secondary containment vessels. Those items are typically found near a combustion type generator and are required to store fuel and contain any fuel spills to prevent environmental harm. Those tanks and vessels also require regular inspection and certification, requiring additional manpower and financial assets.

As noted in the above tables, fuel cells can operate in various locations and climates. The UTC PC25 has demonstrated consistent operation in a range of temperatures from -20°F to 110°F. [Ref. 17] This ambient operating temperature range also includes installing the fuel cell inside a facility. By eliminating the noxious emissions, indoors installation is possible and quite practical. With such close proximity, the co-generated heat can be more easily captured and routed throughout the facility, while concurrently connecting the fuel cell's water by-product to the building's potable supply.

While not totally noise-free due to the required cooling fans and water pumps, fuel cells are remarkably quiet, unlike typical diesel generators. With no internal moving parts, the UTC PC25 operates at 60 dB at 30 feet, a noise level similar to an outside air conditioner or a human conversation in a room [Ref. 17]. This noise level is similar with all types of fuel cells.

D. CURRENT USES

Fuel cells are growing in popularity across the nation and around the world. They are now used in hospitals, banks, office buildings, wastewater treatment facilities, and remote power stations.

1. Commercial

UTC, formerly International Fuel Cells, of South Windsor, CT, has taken the early lead in the fuel cell power generation market. UTC supplies First National Bank of Omaha, and, over the last six years, has sold 220 of its PC25 models. The PC25 generates sufficient power for a medium sized office building or about 100 homes and has been installed to augment, replace, or supplement electricity at various businesses, schools, and government agencies in fifteen different countries. Other customers include the Central Park police station, which uses its PC25 to augment the deficient New York City power grid without creating an emissions problem to Central Park. The main U.S. Postal Service facility in Anchorage, AK, uses multiple PC25s to replace the electricity grid to prevent jams in its sorting equipment that result from brown or black outs. [Ref. 18]

2. Government

Beginning in 1994 and continuing through 1997, the DOD installed and conducted demonstrations using UTC's PC25 fuel cell at thirty different locations aboard military facilities. The fuel cells were used in various applications and different climates. From east to west and north to south, first, second, and third variations of the PC25 fuel cell were installed at gymnasiums, galleys, barracks, offices, laundries, hospitals, and central electrical plants. The DOD hoped to demonstrate fuel cell capabilities in real world situations, stimulate growth and economies of scale in the fuel cell industry, and determine the role of fuel cells in DOD's long-term energy strategy.

As of 31 January 2002, the DOD's 30 fuel cell generators had 794,621 hours of operation, generating over 134,000 MWh of electricity. Although these fuel cells are touted as greater than 90 percent reliable, the data gathered by the DOD Fuel Cell Demonstration Program did not support this claim. Average fuel cell availability was approximately 63 percent. [Ref. 28] This is a far cry from the 99.99-99.9999 percent reliability discussed early in this chapter, but within those calculations are periods of unavailability that are not directly related to the fuel cell's operation. Individual performance ranged from 30 percent to 82 percent but included downtime for scheduled maintenance, shutdown of the natural gas supplies to maintain the natural gas pipeline system, shutting down the electrical output power to safely maintain the utility grid, etc. If these downtime periods were accounted for, the resulting "adjusted availability" would be higher than the unadjusted values quoted above. [Ref. 28] The amount of non-fuel cell related "downtime" is unknown; therefore any "adjusted availability" is difficult to approximate. Due to this important unknown, the calculations and break-even point analysis in Chapter V account for various levels of fuel cell reliability.

Monitoring in the DOD fleet is on going. Of the thirty original sites, fifteen are still operational. Others were shut down when they became obsolete (one model was dropped for a newer improved model) or the cell stacks showed excessive degradation beyond feasible repair. As the newer models have come online or evolved from retrofitted older models, performance and average reliability have improved from 50 percent to the current 63 percent. [Ref. 24]

The Los Angeles Department of Water and Power (LADWP) Headquarters installed a 250 kW MCFC, and the Santa Barbara County Jail installed a UTC 200 kW PAFC. Installed for the LADWP in the summer of 2001, the Fuel Cell Energy model DFC300 operates at 47 percent efficiency, based on the lower heating value (LHV) of natural gas, to supply electricity at the headquarters in downtown Los Angeles. The Santa Barbara Jail’s 200 kW PAFC is an earlier version PC25 unit that currently operates only at 25 percent of capacity, 50 kW, to supply electricity and heat to the jail. [Ref. 23]

E. FUEL CELL INCENTIVES

Incentives from public or private subsidies can significantly affect the user's decision whether to purchase a distributed energy resource, such as fuel cells. The California and federal incentives, discussed below, seek to lower the purchaser's capital costs and accelerate the payback period to more competitive levels. This study does not ascribe any negative or positive values to any of the fuel cell subsidies. It does not weigh the costs and benefits of each subsidy, nor does it revisit the original considerations; correcting perceived market problems or achieving social objectives, which are the domain of policymakers. This section identifies and quantifies certain energy subsidies, but it does not evaluate their merit.

Not all state and federal incentives are discussed here due to the specificity of some of the programs, such as grants for customers only in Los Angeles or Sacramento. Only the financial incentives that could be applied to the Barstow Logistics Base are described.

1. California

The California state government offers several incentives for fuel cell buyers. The CEC gives cash rebates for fuel cells under the Emerging Renewables Buydown Program. However, since it is intended only for renewable fuel, digester gas from wastewater treatment facilities, or landfill gas, this program would be unlikely to apply to natural-gas-fueled fuel cells. [Ref. 29] Additionally, the CEC runs the Solar Energy and Distributed Generation Grant Program, which is open to all California residents who purchase distributed generation systems.

The California Public Utilities Commission (CPUC) is also offering incentives through 2004 to utility customers who install generation systems on their own property to supply all or a portion of their energy needs. This program, titled the Self Generation Incentive Program, was initiated on July 3, 2001 after the 2001 California energy crisis. It provides money for distributed generation systems that are interconnected for parallel operation with the utility grid. [Ref. 23] Like the Emerging Renewables

Buydown Program, larger incentives are provided for those fuel cell systems operating on renewable fuel. Renewable fueled fuel cells are eligible for a $4.50 per watt rebate up to 50 percent of project cost, while fuel cells using non-renewable fuels are entitled only to $2.50 per watt up to 40 percent of project cost. [Ref. 30] For a fuel cell like the UTC PC25 a $4.50 per watt rebate is subject to the 50 percent limitation of $550,000. The $2.50 per watt rebate is also subject to the 40 percent cap of $440,000. For the 250 kW PEMFC, the $4.50 per watt renewable fuel rebate is constrained to 50 percent cap while the non-renewable fuel rebate of $625,000 is less than 40 percent of project cost.

2. Federal

The DOE is the Federal Government's lead agency for fuel cell research and development. In addition to its own research, the DOE offers incentives to those parties who want to purchase fuel cells. The DOE currently offers a $1000 per kW grant to fuel cell purchasers to help offset the initial cost. [Ref. 23] For a large unit like the UTC PC25, this equates to $200,000, or about 20 percent of the installed costs.

F. SUMMARY

At first glance, the fuel cell appears to be the answer to reducing emissions and conserving fossil fuels. But with only limited demonstration in the private and government arena and large subsidies, it is hard to make a definitive decision, although these factors suggest that fuel cells are uneconomic compared to purchasing traditional electricity.

Fuel cells clearly have far reaching benefits. By almost eliminating emissions, widespread use of fuel cells in a hydrogen-based economy could noticeably reduce greenhouse gases and pollutants. But within the scope of this thesis, examining the use of fuel cells at one facility, the world environmental benefits would be extremely small. However, on a per kilowatt comparison against a California natural gas-fueled fuel cell, the reduction in emissions is significant.

Although reliability is stated to be close to 100 percent, the DOD's experience with its 30 fuel cell generators from 1994 to present indicates much lower reliability. To attract widespread customers, improvements in reliability must be made or further data must be gathered and analyzed. The major fuel cell manufacturers showcase reliability, but only continued real life demonstration will prove their statements and encourage product improvements.

Flexibility remains a key to the success of the fuel cell. With scalable power and multiple installation options, users can determine the "best fit" for their requirements. Keeping this in mind will assist in future site selection and facility application.

Finally, fuel cells are costly. It will take a committed government and industry to conduct further research and development to maximize the full potential while keeping costs affordable.

IV. IMPLEMENTATION OF FUEL CELLS AT BARSTOW MAINTENANCE CENTER

A. INTRODUCTION

To correctly see if fuel cells can become a viable source of electricity for the Maintenance Center, the power requirements of the facility must be reviewed to develop an appropriate fuel cell system to meet its base load electrical requirements. Additionally, several factors must be discussed, including the applicable rate schedule, space, layout, and site permitting.

B. MAINTENANCE CENTER POWER REQUIREMENTS

The Maintenance Center is an industrial facility that repairs Marine Corps ground equipment. This heavy industrial work requires large amounts of electricity to support operations. Over the 15-year period from Fiscal Year (FY) 1986 to FY 2000, the Maintenance Center's electricity consumption increased over 50 percent as the facility has increased capacity and capability.

1. Electricity Usage

In fiscal year 2000, the Maintenance Center consumed 16,761 MWh of electricity. For the five years from FY 1996 to FY 2000 the annual average was 15,496 MWh [Ref. 2], for an average daily consumption of 42.45 MWh.

2. Costs

As an industrial user, MCLB Maintenance Center pays for electricity under SCE rate schedule Time of Use, General Service, Large (TOU-8) using a single meter. Charges under TOU-8 consist of a customer charge, demand charges and energy charges. The monthly customer charge covers a portion of basic services, such as meter reading and customer billing.

The demand charge is comprised of "Time-Related Demand" and "Facilities-Related Demand" charges. The Time-Related Demand charge is applied only during SCE's summer season to help offset the higher costs of transmission and distribution services. It is a per-kW charge applied to the greatest amount of each summer month's demand.

The Facilities-Related Demand charge is also a per-kW charge, but is in effect each month of the year. It is applied to the greatest amount of demand created in the current month or 50 percent of the highest demand created in the previous 11 months, whichever is greater. This type of billing is a ratchet charge. Ratchet charges penalize any unusually high peak demands by replacing actual demand with the highest demand over the last 12 months. Like a ratchet in a toolbox, it operates in one direction. When demand rises above the consumer's peak, the demand charges are "ratcheted" up, but when demand decreases, demand charges remain constant.

Table 8 displays the details of SCE's TOU-8 schedule, which are applicable to Barstow.

The energy charge is based on three "time-of-use" periods: on-peak, mid-peak, and off-peak. On-peak hours are noon to 6 p.m. but only during SCE's summer, the first Sunday in June through the first Sunday in October. Mid-peak hours are 8 a.m. to noon and 6 p.m. to 11 p.m. in the summer and 8 a.m. to 9 p.m. during the winter. The remaining hours are considered off-peak. [Ref. 31]

Charges	Time of Year	Amount
Customer Charge ($/month/meter)	All	299.00
Facilities Related Demand Charge ($/kW)	All	6.60
Time Related Demand Charge ($/kW)	Summer Season	
	On-Peak	17.95
	Mid-Peak	2.70
	Off-Peak	0.00
	Winter Season	
	On-Peak	N/A
	Mid-Peak	0.00
	Off-Peak	0.00
Energy Charge ($/kWh)	Summer Season	
	On-Peak	.19544
	Mid-Peak	.10897
	Off-Peak	.08808
	Winter Season	
	On-Peak	N/A
	Mid-Peak	.12121
	Off-Peak	.08924

Table 8. Electricity Costs Under Rate Schedule TOU-8.

C. IMPLEMENTATION ISSUES

1. Power Requirements

Fuel cells offer the greatest efficiency and heat generation advantages when operating at full power. With the Maintenance Center’s limited need for heat, the fuel cells chosen for this thesis, the PAFC and PEMFC, do not produce large amounts of heat like the SOFC or MCFC. Therefore, the fuel cells should be operated at nearly full power to maximize electrical output and efficiency. This requirement leads to examining a system of fuel cells operating at full power to provide the Maintenance Center’s base electricity load.

Using published demand profiles for buildings and industrial facilities, the minimum demand or base load of the average hourly demand is approximately 67 percent. [Ref. 32] Using the five-year average consumption of 15,496 MWh, the Maintenance Center's average hourly demand is calculated at 1.77 megawatts. Multiplying the hourly demand by 67 percent results in a minimum demand of 1.18 megawatts. This base electricity load can be achieved using six 200 kW PAFC or five 250 kW PEMFC. Either of these setups relies on the assumption that the local utility would provide any additional power over 1.2 or 1.25 megawatts respectively.

2. Space

A 1.2-megawatt PAFC facility would consist of six PC25s. The bank of six fuel cells, including required ancillary equipment, requires a level ground space of 60 feet by 90 feet. The 5400 square feet meets the fuel cells' dimensions and manufacturer's required free space. For the PC25, UTC recommends eight feet of space on all sides of the power module and two feet surrounding the cooling module. [Ref. 33] Figure 3, not drawn to scale, is a proposed layout of a six fuel cell bank. Due to their similar size and site requirements, a five PEMFC layout would also fit within the proposed 5400 square feet.

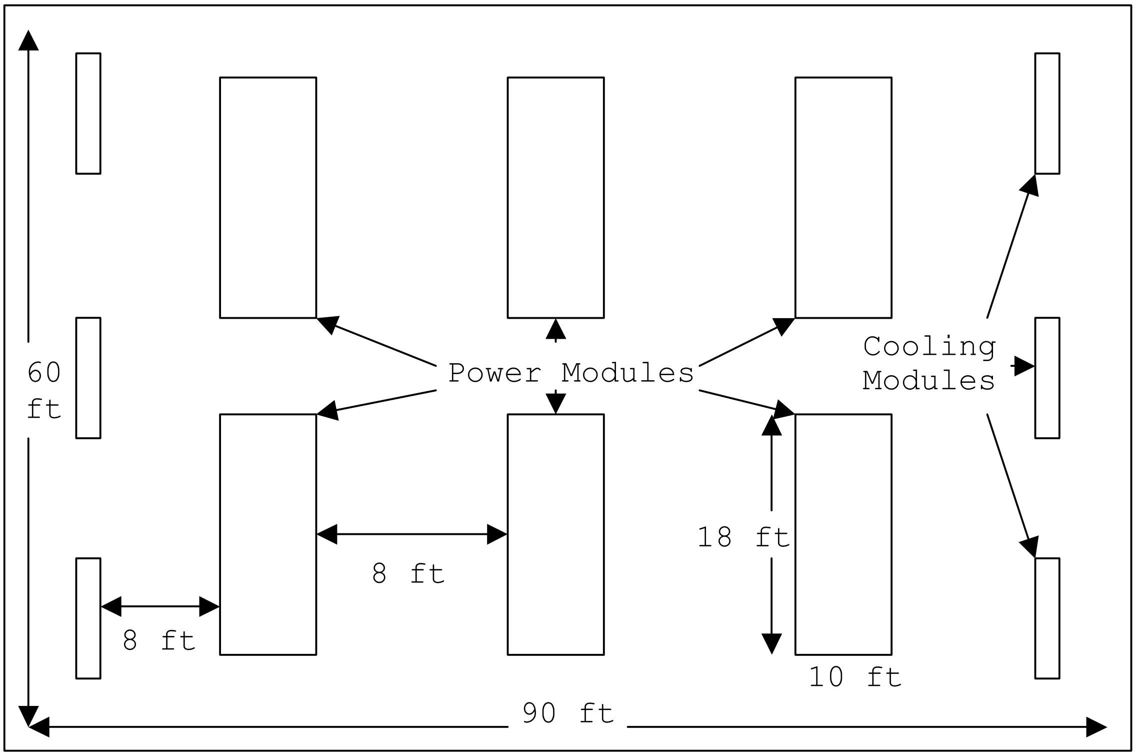

Figure 3. PAFC Fuel Cell Layout.

3. Hydrogen Source

Fuel cells can operate on many forms of hydrogen. For this study, it is assumed that natural gas is the source of hydrogen. Natural gas is the most common source of hydrogen-rich gas used in fuel cell installations and is readily available at the Maintenance Center. Positioning the fuel cells near the natural gas source is preferred as this eliminates additional expense. Each PC25 unit consumes 1900 cubic feet per hour; a bank of six requires 11400 cubic feet per hour. [Ref. 33] To keep all six fuel cells operating, sufficient pipeline capacity must exist at the Maintenance Center.

4. Permits

In California, fuel cells are exempt from water, air, and noise permit requirements. However, fuel cells do require proper installation, grid integration and certification to be accepted by the utility and to receive rebates or other incentives. For the purposes of this thesis, it is assumed that installation would be conducted by the manufacturer and be in accordance with any applicable local, state, and federal regulations.

D. SUMMARY

Using Maintenance Center electricity consumption data and data from other commercial and industrial facilities, this chapter describes a base electricity load fuel cell system that is used in the Chapter V to calculate costs and benefits. The SCE TOU-8 rate schedule is also explained to help the reader understand the energy costs calculated in the next chapter. Finally, this chapter briefly discusses the need for proper site space and fuel cell installation.

V. FEASIBILITY OF CHANGING BARSTOW MAINTENANCE CENTER TO FUEL CELL POWER

A. TECHNICAL FEASIBILITY

Installing and operating fuel cells at the Maintenance Center requires several supporting actions. Voltage panels will need to be installed or upgraded to handle the fuel cell power. A piece of ground close to the Maintenance Center will have to be excavated, leveled, and certified to support the weight of the fuel cells. This space will also need a security fence or other barrier to discourage unauthorized access. If the natural gas pipeline capacity is not sufficient to accommodate the future demand including the fuel cell fuel consumption, it may require an upgrade or service. All of these factors may cost additional money during installation or at some point in the fuel cell's life cycle. It is not the purpose of this thesis to examine all of these factors or calculate them in detail. However, since they may affect the decision maker, these hidden costs are applied during the sensitivity analysis as a small percentage increase on the initial fuel cell capital cost.

Training may be required for the fuel cell operators. However, during the installation of the DOD's 30 fuel cell generators, operator training was included in the installation costs. As in the DOD's experience, this study includes training costs in the fuel cell's installation costs.

B. OPERATIONAL FEASIBILITY

A large obstacle to overcome is the idea of relying on a new source of power. This involves risk and the

Maintenance Center’s propensity to accept risk. If the Maintenance Center is risk averse and chooses the status quo, fuel cell power may not be acceptable, despite what the financial savings and emissions reductions may be. If they accept the risk, they may receive electricity cost savings later in the program.

C. ECONOMIC FEASIBILITY

Fuel cell power generation costs were calculated using the fuel cell installation costs, estimated operations and maintenance (O&M) costs, and fuel cell efficiencies from Chapter 3. Additionally, the Office of Management and Budget (OMB) real current Discount Rate of 3.5 percent for a 20-year federal program [Ref. 34] and the Energy Information Agency’s (EIA) energy cost forecasts from its Annual Energy Outlook 2002 (AEO 2002) were used to discount monetary values and estimate growth in energy prices. A spreadsheet, shown in Appendix A, was developed to calculate the results. Two separate spreadsheets were used to compare results between electricity generation by SCE and a 1200 kW PAFC or a 1250kW PEMFC from EIA’s baseline, low, and high economic growth forecasts. Values were deflated from 2002 nominal dollars to constant 2000 dollars. [Ref. 35]

The AEO 2002 forecasts the real price, in 2000 dollars, of electricity to fall annually while natural gas prices will rise through the year 2020 for three different levels of economic growth. The base, low, and high economic growth scenarios are based on 3 percent, 2.4 percent, and 3.4 percent growth in Real Gross Domestic Product, respectively. [Ref. 36] Table 9 shows EIA’s forecasts for annual growth percentages in electricity and natural gas prices.

Energy Type	**Base Growth**	**Low Economic Growth**	**High Economic Growth**
Natural Gas (Price delivered to generator)	2.22%	1.65%	2.80%
Electricity (retail prices)	-.3%	-.53%	-.07%

Table 9. Electricity and Natural Gas Annual Growth Forecasts.

Using the figures from Chapter III for fuel cell installation and capital cost, O&M, and the available incentives, the net present value (NPV) and levelized energy cost (LCOE) were calculated. The levelized energy cost is an industry standard that compares average generating costs per kilowatthour over the plant lifetime, including capital costs, O&M, and fuel costs using a specific time period, output, and discount rate. Both values, NPV and LCOE, were used to compare the break-even points (BEP).

A summary of the standard assumptions used in the fiscal and emissions calculations is listed in Table 10. After the initial calculations, some of the assumptions and cost factors were modified to conduct sensitivity analysis on the initial results.

Assumption	Source
20 Year Federal Program Annual Discount Rate of 3.5%	OMB Circular A-94
Fuel Cell Capital Cost of $5500 per kW PAFC; $8000 per kW PEMFC	Chapter III from CEC
Fuel Cell O&M Cost of $.01 per kWh	Chapter III from CEC
Fuel Cell Incentives- California $2.50 per watt and Federal $1000 per kW	Chapter III from CEC & CPUC
PAFC 40% Fuel Cell Efficiency PEMFC 36% Efficiency	Chapter III from CEC
Fuel Cell Power Degradation of .7% per year	DOD Construction Engineering Research Laboratory
Energy Price Growth Forecasts	DOE AEO 2002
Delivered Natural Gas Price $2.64/MBtu	DOE AEO 2002
Operator training costs are included in the fuel cell capital cost	DOD Construction Engineering Research Laboratory
95% Fuel Cell Reliability	Fuel Cell Industry Claims
SCE Reliability of 99.999864%	10 year SCE Reliability History
California natural gas-fueled electricity generation emissions rate is the average of total pounds over total kWh generated	DOE State Electricity Profiles- California
2000 Constant Dollars	

Table 10. Summary of Assumptions.

Any degradation in fuel cell power output creates a power deficit that must be filled by another generator. To keep the analysis consistent at 10,511,986 kWh output per year, any fuel cell power deficit was offset by a purchase of SCE electricity. This additional cost was calculated at the annual average SCE per-kilowatthour rate since the power degradation would not take place specifically at off-peak, on-peak, or at mid-peak prices. This power deficit cost was then added to the fuel cell operating cost.

Oppositely, any fuel cell production of electricity reduces the peak monthly demand on which the time-related and facilities related demand charges are based. This cost avoidance is evident in the reduced demand charges for the fuel cell power generation. For SCE's electricity costs, the time-related and facilities related demand charges are based solely on the required output of 1200 kW, 24 hours per day with 99.999864 percent reliability.

1. 1200 kW PAFC Cost Analysis

Using PAFC fuel cells augmented by SCE power over the next 20 years, under the standard assumptions, the NPV cost of electricity ranges from $10.3 million to $10.8 million in the low and high growth cases, respectively. This equates to a LCOE for 20 years from $.0587 per kWh in the low economic growth case to $.0619 per kWh for the high economic growth case.

2. SCE Electricity Cost Analysis

The NPV of using SCE to produce the same amount of electricity over the next 20 years at their current level of reliability ranges from $19.3 million in the low growth case to $18.7 million in the high growth case. SCE's LCOE ranged from $.0905 per kWh to $.0920 per kWh, in the low and high economic growth cases, respectively.

3. Break-Even Point

The break-even point based upon the NPV calculation was 3.1 years for all three cases. The break-even point based upon the LCOE was approximately 3.5 years. The above results for the baseline, low, and high economic growth case are summarized in Table 11 and graphically shown in Figures 4, 5, and 6, respectively.

Growth Case	Generator	20-Year LCOE ($/kWh)	LCOE BEP (Years)	NPV BEP (Years)
Baseline Growth	PAFC	.0605	3.6	3.1
	SCE	.0905		
Low Economic Growth	PAFC	.0587	3.5	3.1
	SCE	.0891		
High Economic Growth	PAFC	.0619	3.6	3.1
	SCE	.0920		

Table 11. PAFC and SCE Electricity Cost Results Using Standard Assumptions.

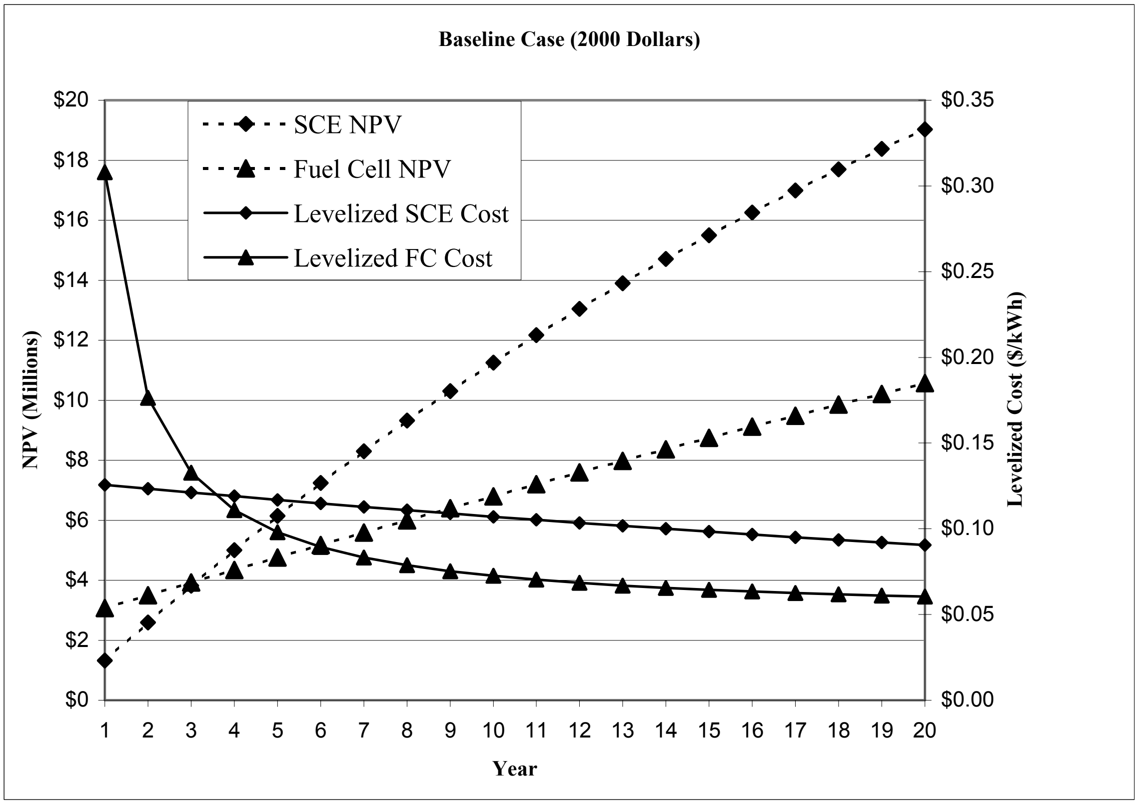

Figure 4. PAFC Baseline Growth Case.

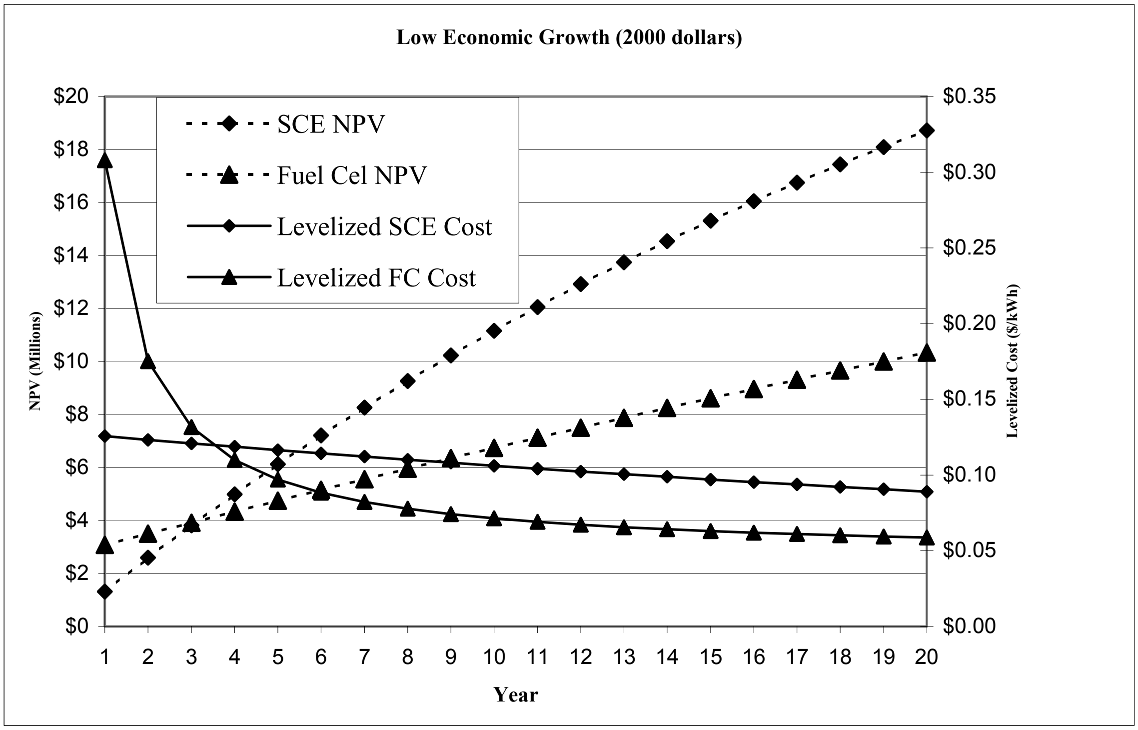

Figure 5. PAFC Low Economic Growth Case.

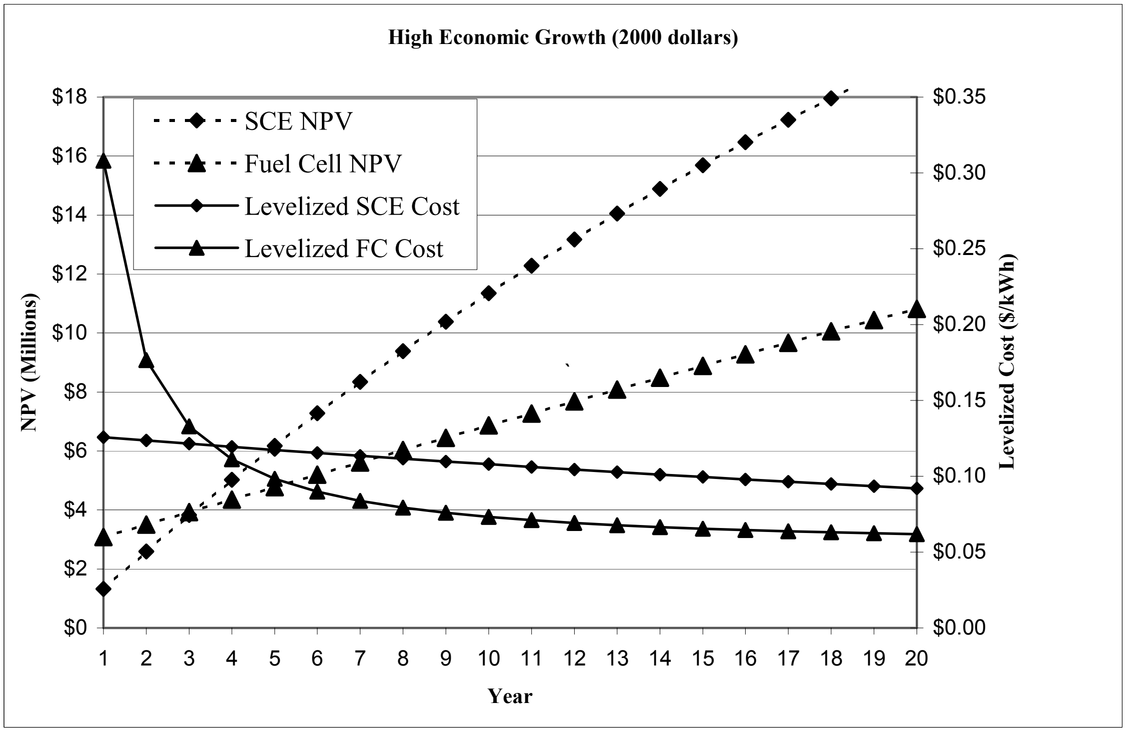

Figure 6. PAFC High Economic Growth Case.

4. 1200 kW PAFC Sensitivity Analysis

Under the standard assumptions there may exist some unrealistic figures, particularly with holding O&M costs steady over the 20-year period. Additionally, fuel cell reliability is questionable, as found by the DOD experience with its 30 fuel cell generators. Therefore, these factors, along with decreasing the available incentives, were used to conduct sensitivity analysis on the original results. The break-even points for the different conditions under the baseline economic growth case are listed below in Table 12. The results come from changing only those factors listed; they are not progressively added and all other factors remain constant from the standard calculations. The low and high economic growth cases do not affect the BEP by more than .1 years from the baseline case, and so they are not presented.

The BEP is notably sensitive to the fuel cell's reliability and the available fuel cell incentives. In combination, these two factors are the primary reason that there is no break-even point shown in the "worst case" condition.

Because the fuel cell incentives are a pure transfer from the Federal Treasury to the DOD, the fuel cell incentives should be identified and analyzed but not included in the calculation of benefits. As stated in the OMB Circular A-94, there are no economic gains from a pure *transfer payment* because the benefits to those who receive such a transfer are matched by the costs borne by those who pay for it. Therefore, transfers should be excluded from the calculation of net present value. Transfers that arise as a result of the program or project being analyzed should be identified. [Ref. 51] Based on these federal guidelines, the "No Incentives" condition provides the most accurate NPV BEP of 8.7 years or LCOE BEP of 11.5 years.

PAFC Condition	LCOE BEP (Years)	NPV BEP (Years)
O&M Increasing annually at 10%	3.7	3.2
O&M is 50% higher and Increasing annually at 10%	3.9	3.3
Fuel Cell Reliability is 90%	4.5	3.5
Fuel Cell Reliability is 85%	5.8	3.8
Fuel Cell Reliability is 80%	10.0	4.1
No Federal Incentive	5.5	4.7
No California Incentive	8.4	6.8
No Incentives	11.5	8.7
Site Design and Upgrade adds 2% to the Fuel Cell Capital Cost ($110k)	3.7	3.2
Worst Case- O&M is 50% higher and rising, reliability is less than 85%, and no incentives are available	None	None

Table 12. PAFC Sensitivity Analysis Results.

5. SCE Sensitivity Analysis

It is assumed that the AEO 2002 forecasted growth percentages included any growth in SCE’s O&M costs and that SCE would continue to provide the specified power output of 1200 kW at their current level of reliability. Therefore, no sensitivity analysis is done on the SCE results.

6. 1250 kW PEMFC Cost Analysis

Using a bank of five 250 kW PEMFC produces significantly different results. The BEP shifts later in time based on the higher capital cost of $8000 per kW and the decreased fuel cell efficiency of 36 percent. This four percent lower efficiency creates a 14 percent larger fuel cost than the PAFC. Since fuel costs are expected to rise while retail electricity prices are expected to fall, the increased fuel costs amplify the break-even point’s shift. With the standard assumptions, the break-even point is almost nine years, based on the LCOE, and seven years, based upon the NPV. The break-even point results are displayed in Table 13.

Growth Case	**Generator**	**20-Year LCOE ($/kWh)**	**LCOE BEP (Years)**	**NPV BEP (Years)**
Baseline Growth	PEMFC	.0775	8.8	7.0
	SCE	.0905		
Low Economic Growth	PEMFC	.0755	8.8	7.0
	SCE	.0890		
High Economic Growth	PEMFC	.0790	8.7	7.0
	SCE	.0920		

Table 13. PEMFC and SCE Electricity Cost Results Using Standard Assumptions.

7. 1250 kW PEMFC Sensitivity Analysis

Sensitivity analysis was conducted on the PEMFC using the same conditions from the PAFC. The results from the various conditions are listed in Table 14. The PEMFC sensitivity results are consistent with the higher capital cost and decreased efficiency. As the different conditions were applied, the break-even point shift was amplified beyond the results from the PEMFC standard assumptions. When comparing the LCOE of SCE and the PEMFC, of the ten conditions, six did not yield a break-even within the twenty-year program.

Applying the rules of OMB Circular A-94, incentives should be ignored for BEP analysis. The BEP results in the PEMFC "No Incentives" condition are 15.5 years for NPV and no BEP within 20 years for the LCOE.

PEMFC Condition	**LCOE BEP (Years)**	**NPV BEP (Years)**
O&M Increasing annually at 10%	9.7	7.4
O&M is 50% higher and Increasing annually at 10%	None	8.3
Fuel Cell Reliability is 90%	13.0	7.8
Fuel Cell Reliability is 85%	None	8.6
Fuel Cell Reliability is 80%	None	9.8
No Federal Incentive	12.6	9.0
No California Incentive	None	12.6
No Incentives	None	15.5
Site Design and Upgrade adds 2% to the Fuel Cell Capital Cost ($110k)	9.3	7.3
Worst Case- O&M is 50% higher and rising, reliability is less than 85%, and no incentives are available	None	None

Table 14. PEMFC Sensitivity Analysis Results.

8. Differences in the Break-Even Points

A question may arise from the difference in the NPV and LCOE break-even points. The BEP of NPV and LCOE are at the same point in time if the following factors are taken out of the calculations: if both the fuel cell and SCE operate at 100% reliability, there is zero growth in fuel cell O&M costs, and there is no power degradation from the fuel cell. However, removing these factors is not realistic and produces inaccurate BEP results. The difference can be explained as follows.

As explained earlier, fuel cell power output degrades over time requiring a power purchase from SCE so that the costs for both alternatives reflect purchasing the same kWh of electricity. This "deficit power" purchase is calculated using the average costs of SCE electricity for that respective year. The average cost is used, because it is impossible to tell when the "deficit power" will be purchased (on-peak, off-peak, or mid-peak and summer or winter). That average skews the fuel cell LCOE towards SCE's LCOE and moves the BEP later in time than the NPV BEP.

With SCE reliability below 100 percent, at 99.999864 percent, the fuel cell can produce electricity only equal to or less than the kWh produced by SCE. Although the capital costs are calculated on a 1200 or 1250 kW basis, the fuel cell produces less than its maximum output throughout its lifetime. This lower power output is the basis for O&M and fuel costs, and the incentives and demand charge savings. These factors are on a $/kW basis, so a lower kW output changes their effect. These interactions also move the LCOE BEP further in time than the NPV.

D. EMISSIONS REDUCTION

The EIA’s California state electricity profile provides electricity and electricity production generated pollution statistics for the year 1999. The emission production rates were calculated using the specific data for natural gas electricity generators. In 1999, California’s natural gas generators produced 107,000 short tons of NOx and 64,692,000 short tons of CO_2, while generating 90,515,671 MWh of electricity. [Ref. 37] According to the California profile, SO_2 was eliminated in 1997 as a pollutant from electricity generation. Thus, $S0_2$ emissions are considered to be zero or undetectable.

Assuming that California’s electricity emissions generation rate has not changed since 1999, this data is then compared to emissions generated by the combination of fuel cells and California natural gas fueled generators.

The DOD has measured emissions output on its natural gas fuel cells as follows: DOD fuel cells emit NOx at less than 1 ppm, CO at less than 5 ppm, and SOx in undetectable limits well below 1ppm. [Ref. 30] These rates are consistent with other published fuel cell emission rates. The fuel cell emission rates in terms of lb/MWh are .03 for NOx, 1078 for CO_2, and undetectable for PM_{10} and SO_2. [Ref. 38] For comparison, the emission rates are shown in Table 15.

Emission Rates		
Emission	**Source**	**Rate (lbs/MWh)**
NOx	Natural Gas Fuel Cell	.03
	CA Natural Gas Fueled Generator	2.36
CO_2	Natural Gas Fuel Cell	1087
	CA Natural Gas Fueled Generator	1429
SO_2	Natural Gas Fuel Cell	0
	CA Natural Gas Fueled Generator	0
PM_{10}	Natural Gas Fuel Cell	0
	Large Natural Gas Turbine Generator	.07

Table 15. Emission Rates By Type and Generator.

The EIA did not list PM_{10} emissions for California's natural gas generators. Therefore, the PM_{10} value for a Large Gas Turbine of .07 lb/MWh is taken from the Regulatory Assistance Project. [Ref. 38] It is assumed that this value is consistent with California's natural gas turbine generators.

These emission rates are used in calculating the total amount of emissions over the same 20-year period used to calculate the energy cost. The amount of electricity produced by SCE over the 20-year period was used as the baseline. SCE producing 1200 kW at its 10-year average reliability would produce 210,239,714 kWh of electricity over twenty years. Multiplying that total by the emissions rate of California's natural gas generators yields the total emissions over 20 years. To maintain the comparison, the fuel cell emission rates are multiplied only by the portion of electricity they are producing. The remaining electricity is produced by SCE, and so its emission rates are applied to the remainder. Using the standard assumptions from Table 10, the fuel cells would produce 89 percent, 186,987,698 kWh, of the required electricity over the 20 years. Therefore, the fuel cell emission rates are applied to that 89 percent, while the SCE emission rates are applied to the remaining 11 percent. The results for NOx, CO_2, and PM_{10} are displayed in Figures 7, 8, and 9 respectively.

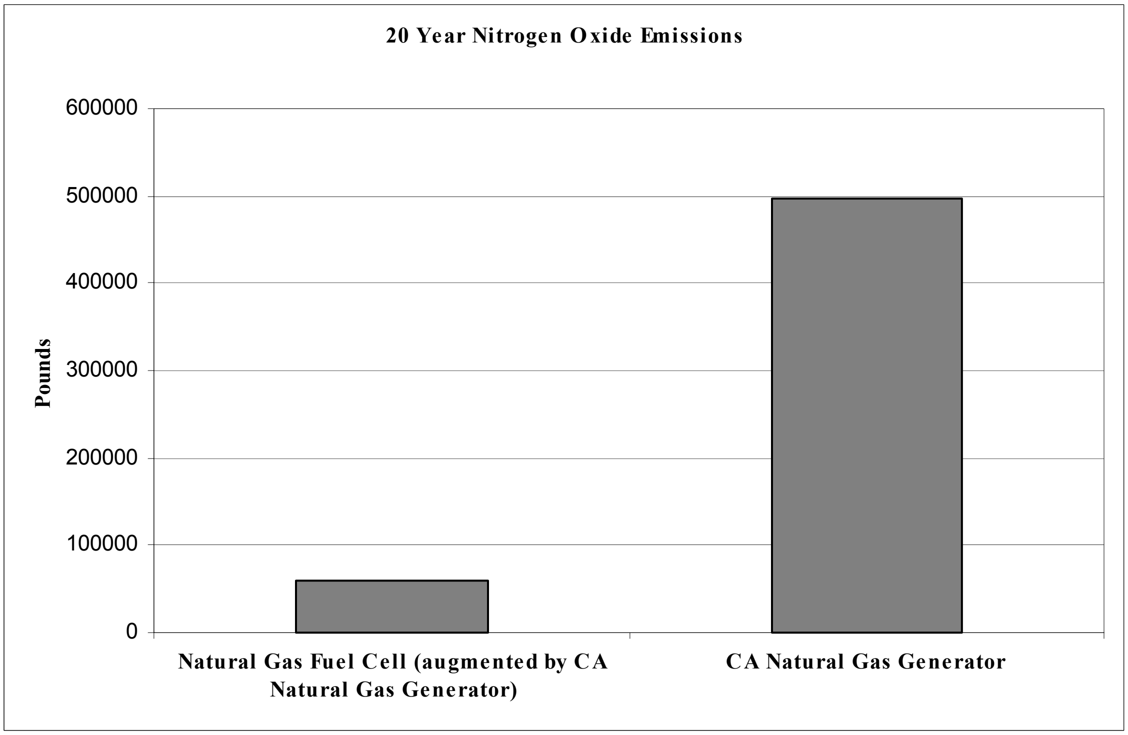

Figure 7. Comparison of Nitrogen Oxide Emissions.

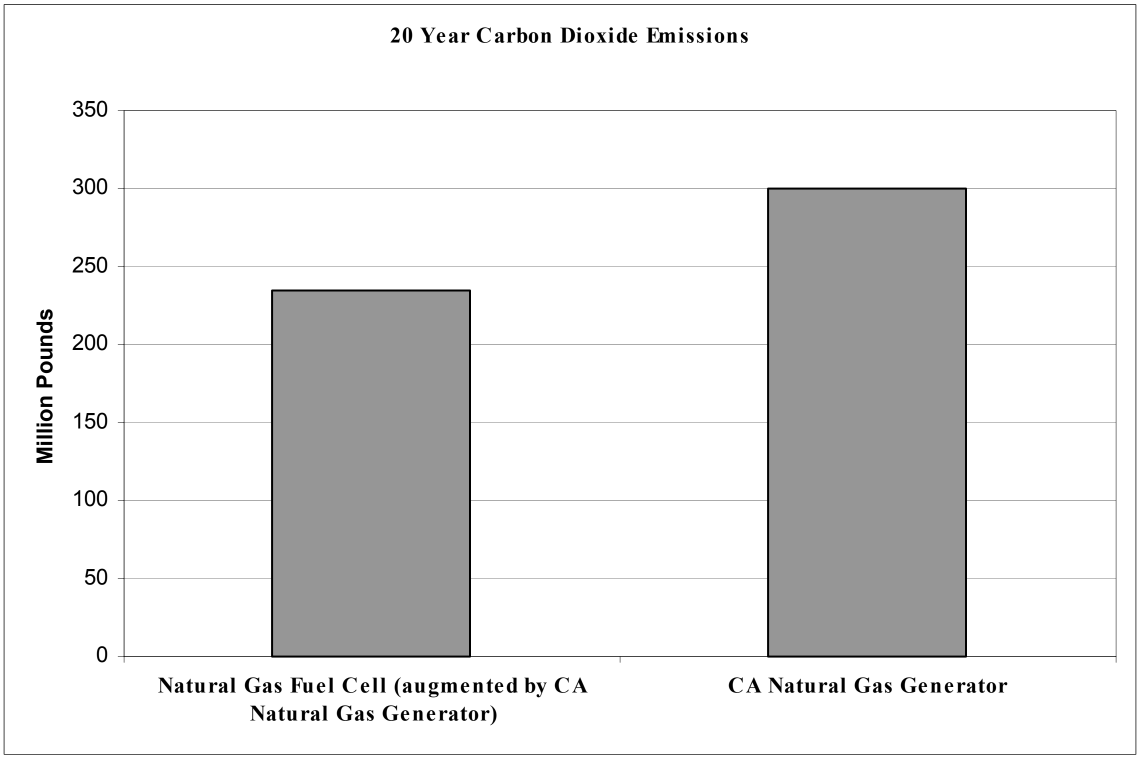

Figure 8. Comparison of Carbon Dioxide Emissions.

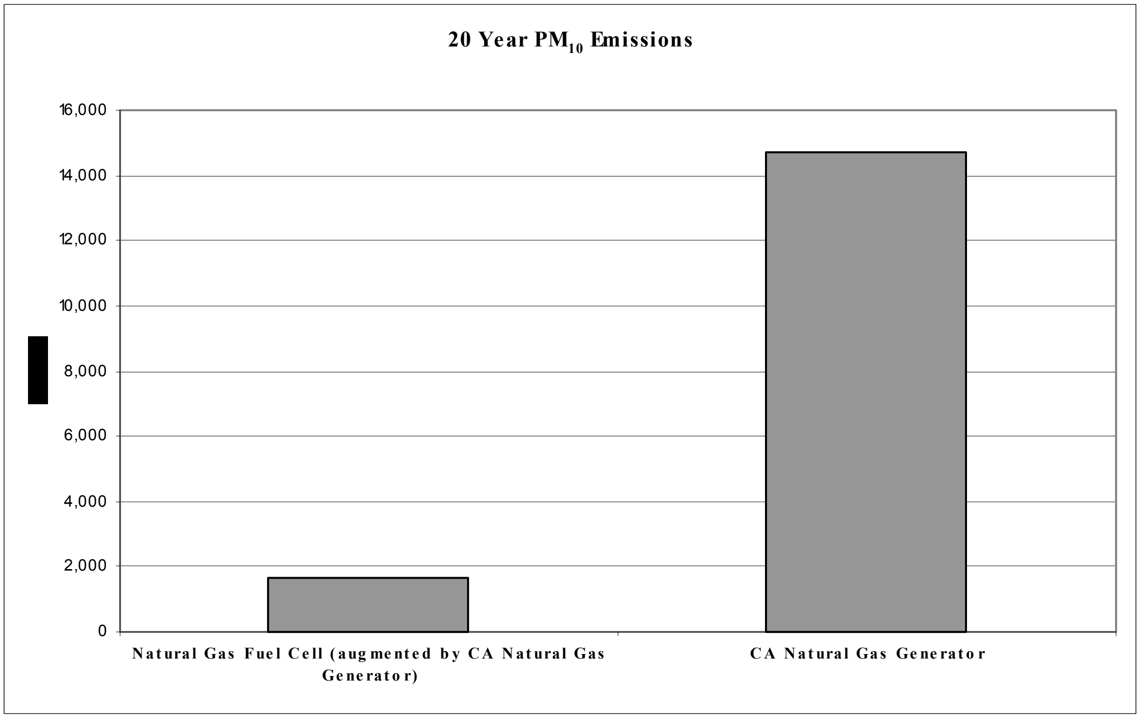

Figure 9. Comparison of Particulate Matter Smaller than 10 Microns.

On a direct comparison, the fuel cell alternative reduces NOx, the leading component of smog, by 88 percent. A similar 89 percent emissions reduction is achieved in the PM_{10} category. Less significant is the reduction in carbon dioxide, the leading greenhouse gas, of 22 percent. Despite the large percentage reductions in emissions, it must be noted that the comparison is based solely on like fueled generators and it is for an extremely small percentage of the world's total electricity production.

E. SUMMARY

This chapter first examined the life cycle and levelized electricity costs for producing electricity under two conditions; using primarily fuel cells augmented by SCE and with SCE operating independently. Using the standard fuel cell assumptions provided from Chapter III, the fuel cell alternative looks inviting. However, in the sensitivity analyses, introducing realistic conditions and the federal guidelines on transfer payments within OMB Circular A-94, the fuel cell alternative is more costly, based upon the LCOE, until at least year 11 for the PAFC and throughout the 20-year period for the PEMFC.

Secondly, it showed that significant emissions reductions would result from using a fuel cell based power generation system rather than the established utility. However, since this one study represents such a small percentage of the nation’s emissions output, it is unlikely that any measurable effect on national air quality would be achieved. Any measurable air quality improvements would remain regionally within the SCE area of operation and the MOJAQMD. However, an argument could be made that installing fuel cells within the Barstow base would actually increase local pollution since SCE or other IOUs do not produce their electricity in the Barstow area.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. No, it is not a good idea to install fuel cells as the energy generator at the Marine Corps' Barstow Maintenance Center. Fuel cells have large up-front capital investments that require subsidies to bring the costs down to competitive levels.

The results indicate that fuel cells depend on state and federal subsidies to make them financially attractive. Under realistic operating conditions and without the subsidies, which is the way OMB Circular A-94 requires government investments to be analyzed, the fuel cell system is not likely to break even with SCE within the expected 20-year life cycle. Additionally, stationary fuel cell power systems have seen limited introduction into the civilian and government sectors, which keeps capital costs high.

2. Fuel cell users and producers report significantly different levels of reliability.

If fuel cells are unreliable, their purpose of improving or at least maintaining electricity reliability while lowering energy costs is undermined. SCE's long-term reliability of five nines is hard to beat with an average fuel cell reliability of one nine. To maintain the current level of reliability, fuel cell systems would have to be overly redundant with "back-up" fuel cells. These additional fuel cells would significantly increase costs and move the BEP even later in time. The established power grid could also provide "back-up" but that would further defeat the original purposes of the fuel cell system:

reducing reliance on SCE, decreasing costs, and improving reliability.

3. With the large up front capital cost, installing a fuel cell power system would compete with other high value MCLB Barstow initiatives and DOD programs.

With disparate levels of reported reliability and limited data on long-term O&M costs, the decision to install a fuel cell based power system would involve significant risk.

4. The emission reduction between the fuel cell and SCE alternative is significant.

Two emissions, NOx and PM_{10}, were reduced by 88 percent while CO_2 was reduced by 22 percent. With increased fuel cell efficiency and reliability the emission reduction should be even larger.

5. This project would represent only a small portion of California's or the United States' pollution; any air quality improvement would be extremely small and confined to a limited region of California.

Fuel cells are environmentally "friendlier" than their fossil fuel burning turbine counterparts. However, installing fuel cells aboard MCLB Barstow would actually increase local pollutants compared to the SCE option. Since SCE does not actually produce electricity in the Barstow area, it is not considered a direct contributor to pollution at the base, ignoring any SCE pollution carried to the base by wind and weather effects.

B. RECOMMENDATIONS

1. The Maintenance Center should wait until fuel cell capital costs come down to more competitive levels and reliability is proven at greater than 95 percent.

After these two conditions are met, the Maintenance Center should re-examine its energy needs and the costs and benefits of a fuel-cell-based power system. As discussed in Chapter III, fuel cells may prove more competitive at $2000 per kW rather than current $5500+ per kW. Using the standard assumptions from Chapter V, the break-even points are less than three years at $2000 per kW with zero incentives.

2. MCLB Barstow should continue to pursue efforts to protect the environment.

MCLB Barstow is a leader in DOD's fight for the environment as noted by its past awards. Technologies to reduce pollutants, such as fuel cells, should be explored and implemented only upon directive or when it is financially responsible to do so.

C. AREAS FOR FURTHER STUDY

Further studies should include validating fuel cell O&M costs and reliability. For this study, those two factors were based on estimates, industry claims, and the limited DOD data. DOD's fuel cell experience has indicated lower than expected reliability. Lower reliability significantly delays the BEP. These factors must be accurate for a more solid cost and benefit analysis.

Research should also examine using other fuel cell types, particularly the MCFC and SOFC. Discussed briefly in Chapter III, these two fuel cell types produce large amounts of waste heat that can drive an air conditioner, called an “absorption chiller.” While the Maintenance Center does not need large amounts of heat or domestic hot water, it does require air conditioning. That air-conditioning requirement could be met by a system of fuel cells that produce electricity and heat to drive an absorption-chiller-based air conditioner. Using the cogenerated heat increases fuel cell efficiency and would affect the BEP analysis.

Further studies should also examine the costs and benefits of using other forms of distributed generation. Fuel cells remain costly on a dollars per kilowatt basis compared to other types of natural gas turbines. A different form of distributed generation may prove less costly up front, while still producing lower cost electricity and fewer emissions at a suitable level of reliability.

Finally, a study should calculate the costs and benefits of using distributed generation on a wider scale. A larger fuel cell operation would produce a larger emissions reduction and may have a more positive effect on regional or national air quality.

APPENDIX. ENERGY COSTS

ELECTRICITY COST FORECAST

Baseline Growth		Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SCE Electricity (2000 $)		$/kWh																				
		On-Peak	$0.18785	$0.18728	$0.18672	$0.18616	$0.18560	$0.18505	$0.18449	$0.18394	$0.18339	$0.18284	$0.18229	$0.18174	$0.18120	$0.18065	$0.18011	$0.17957	$0.17903	$0.17849	$0.17796	$0.17742
	Summer	Mid-Peak	$0.10474	$0.10442	$0.10411	$0.10380	$0.10349	$0.10318	$0.10287	$0.10256	$0.10225	$0.10194	$0.10164	$0.10133	$0.10103	$0.10072	$0.10042	$0.10012	$0.09982	$0.09952	$0.09922	$0.09893
		Off-Peak	$0.08466	$0.08440	$0.08415	$0.08390	$0.08365	$0.08340	$0.08315	$0.08290	$0.08265	$0.08240	$0.08215	$0.08191	$0.08166	$0.08142	$0.08117	$0.08093	$0.08069	$0.08044	$0.08020	$0.07996
		On-Peak	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Winter	Mid-Peak	$0.11650	$0.11615	$0.11580	$0.11546	$0.11511	$0.11476	$0.11442	$0.11408	$0.11373	$0.11339	$0.11305	$0.11271	$0.11238	$0.11204	$0.11170	$0.11137	$0.11103	$0.11070	$0.11037	$0.11004
		Off-Peak	$0.08577	$0.08552	$0.08526	$0.08500	$0.08475	$0.08449	$0.08424	$0.08399	$0.08374	$0.08349	$0.08323	$0.08298	$0.08274	$0.08249	$0.08224	$0.08199	$0.08175	$0.08150	$0.08126	$0.08101
Natural Gas (2000 $)		**$/M Btu**	$2.54	$2.59	$2.65	$2.71	$2.77	$2.83	$2.89	$2.96	$3.02	$3.09	$3.16	$3.23	$3.30	$3.38	$3.45	$3.53	$3.61	$3.69	$3.77	$3.85
Low Economic Growth		Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SCE Electricity (2000 $)		$/kWh																				
		On-Peak	$0.18785	$0.18685	$0.18586	$0.18488	$0.18390	$0.18292	$0.18195	$0.18099	$0.18003	$0.17908	$0.17813	$0.17718	$0.17624	$0.17531	$0.17438	$0.17346	$0.17254	$0.17162	$0.17071	$0.16981
	Summer	Mid-Peak	$0.10474	$0.10418	$0.10363	$0.10308	$0.10253	$0.10199	$0.10145	$0.10091	$0.10038	$0.09985	$0.09932	$0.09879	$0.09827	$0.09775	$0.09723	$0.09671	$0.09620	$0.09569	$0.09518	$0.09468
		Off-Peak	$0.08466	$0.08421	$0.08376	$0.08332	$0.08288	$0.08244	$0.08200	$0.08157	$0.08113	$0.08070	$0.08028	$0.07985	$0.07943	$0.07901	$0.07859	$0.07817	$0.07776	$0.07735	$0.07694	$0.07653
		On-Peak	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Winter	Mid-Peak	$0.11650	$0.11588	$0.11527	$0.11466	$0.11405	$0.11345	$0.11285	$0.11225	$0.11165	$0.11106	$0.11047	$0.10989	$0.10930	$0.10872	$0.10815	$0.10758	$0.10701	$0.10644	$0.10587	$0.10531
		Off-Peak	$0.08577	$0.08532	$0.08487	$0.08442	$0.08397	$0.08352	$0.08308	$0.08264	$0.08220	$0.08177	$0.08133	$0.08090	$0.08047	$0.08005	$0.07962	$0.07920	$0.07878	$0.07836	$0.07795	$0.07754
Natural Gas (2000 $)		**$/M Btu**	$2.54	$2.58	$2.62	$2.67	$2.71	$2.75	$2.80	$2.85	$2.89	$2.94	$2.99	$3.04	$3.09	$3.14	$3.19	$3.24	$3.30	$3.35	$3.41	$3.46
High Economic Growth		Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SCE Electricity (2000 $)		$/kWh																				
		On-Peak	$0.18785	$0.18772	$0.18759	$0.18745	$0.18732	$0.18719	$0.18706	$0.18693	$0.18680	$0.18667	$0.18654	$0.18641	$0.18628	$0.18615	$0.18602	$0.18589	$0.18576	$0.18563	$0.18550	$0.18537
	Summer	Mid-Peak	$0.10474	$0.10466	$0.10459	$0.10452	$0.10444	$0.10437	$0.10430	$0.10422	$0.10415	$0.10408	$0.10401	$0.10393	$0.10386	$0.10379	$0.10372	$0.10364	$0.10357	$0.10350	$0.10343	$0.10335
		Off-Peak	$0.08466	$0.08460	$0.08454	$0.08448	$0.08442	$0.08436	$0.08430	$0.08424	$0.08419	$0.08413	$0.08407	$0.08401	$0.08395	$0.08389	$0.08383	$0.08377	$0.08372	$0.08366	$0.08360	$0.08354
		On-Peak	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Winter	Mid-Peak	$0.11650	$0.11642	$0.11634	$0.11626	$0.11618	$0.11609	$0.11601	$0.11593	$0.11585	$0.11577	$0.11569	$0.11561	$0.11553	$0.11545	$0.11536	$0.11528	$0.11520	$0.11512	$0.11504	$0.11496
		Off-Peak	$0.08577	$0.08571	$0.08565	$0.08559	$0.08553	$0.08547	$0.08541	$0.08535	$0.08529	$0.08523	$0.08517	$0.08512	$0.08506	$0.08500	$0.08494	$0.08488	$0.08482	$0.08476	$0.08470	$0.08464
Natural Gas (2000 $)		**$/M Btu**	$2.54	$2.61	$2.68	$2.76	$2.83	$2.91	$2.99	$3.08	$3.16	$3.25	$3.34	$3.44	$3.53	$3.63	$3.74	$3.84	$3.95	$4.06	$4.17	$4.29

SOUTHERN CALIFORNIA EDISON ELECTRICITY COSTS																					
Baseline Growth																					
SCE Electricity	**(2000 Dollars)**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Summer Energy Charge	On-Peak	$165,005.49	$164,510.47	$164,016.94	$163,524.89	$163,034.31	$162,545.21	$162,057.57	$161,571.40	$161,086.69	$160,603.43	$160,121.62	$159,641.25	$159,162.33	$158,684.84	$158,208.79	$157,734.16	$157,260.96	$156,789.17	$156,318.81	$155,849.85
	Mid-Peak	$138,001.29	$137,587.28	$137,174.52	$136,763.00	$136,352.71	$135,943.65	$135,535.82	$135,129.21	$134,723.83	$134,319.65	$133,916.69	$133,514.94	$133,114.40	$132,715.06	$132,316.91	$131,919.96	$131,524.20	$131,129.63	$130,736.24	$130,344.03
	Off-Peak	$111,545.87	$111,211.23	$110,877.60	$110,544.97	$110,213.33	$109,882.69	$109,553.04	$109,224.38	$108,896.71	$108,570.02	$108,244.31	$107,919.58	$107,595.82	$107,273.03	$106,951.21	$106,630.36	$106,310.47	$105,991.54	$105,673.56	$105,356.54
Winter Energy Charge	On-Peak	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Mid-Peak	$441,633.41	$440,308.51	$438,987.59	$437,670.63	$436,357.61	$435,048.54	$433,743.40	$432,442.16	$431,144.84	$429,851.40	$428,561.85	$427,276.16	$425,994.34	$424,716.35	$423,442.20	$422,171.88	$420,905.36	$419,642.65	$418,383.72	$417,128.57
	Off-Peak	$275,126.46	$274,301.09	$273,478.18	$272,657.75	$271,839.77	$271,024.26	$270,211.18	$269,400.55	$268,592.35	$267,786.57	$266,983.21	$266,182.26	$265,383.71	$264,587.56	$263,793.80	$263,002.42	$262,213.41	$261,426.77	$260,642.49	$259,860.56
Facilities-Related	Demand Charges	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00
Time-Related	Demand Charges	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50
	Customer Charge	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00
	COE	**$1,321,518.02**	**$1,318,124.08**	**$1,314,740.33**	**$1,311,366.72**	**$1,308,003.24**	**$1,304,649.85**	**$1,301,306.51**	**$1,297,973.21**	**$1,294,649.91**	**$1,291,336.57**	**$1,288,033.18**	**$1,284,739.70**	**$1,281,456.09**	**$1,278,182.34**	**$1,274,918.41**	**$1,271,664.27**	**$1,268,419.90**	**$1,265,185.25**	**$1,261,960.31**	**$1,258,745.05**
	PV (2000)	**$1,321,518.02**	**$1,273,549.84**	**$1,227,324.16**	**$1,182,777.65**	**$1,139,849.26**	**$1,098,480.16**	**$1,058,613.69**	**$1,020,195.21**	**$983,172.10**	**$947,493.64**	**$913,110.95**	**$879,976.95**	**$848,046.24**	**$817,275.10**	**$787,621.38**	**$759,044.47**	**$731,505.25**	**$704,966.01**	**$679,390.39**	**$654,743.40**
	Cumulative PV	**$1,321,518.02**	**$2,595,067.86**	**$3,822,392.02**	**$5,005,169.67**	**$6,145,018.93**	**$7,243,499.09**	**$8,302,112.78**	**$9,322,307.99**	**$10,305,480.09**	**$11,252,973.73**	**$12,166,084.68**	**$13,046,061.63**	**$13,894,107.87**	**$14,711,382.97**	**$15,499,004.35**	**$16,258,048.82**	**$16,989,554.08**	**$17,694,520.08**	**$18,373,910.47**	**$19,028,653.88**
Undiscounted Annual	**COE ($/kWh)**	**$0.13**	**$0.13**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**
Discounted Annual	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**	**$0.08**	**$0.08**	**$0.08**	**$0.07**	**$0.07**	**$0.07**	**$0.07**	**$0.06**	**$0.06**
Levelized	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**
Low Economic Growth																					
SCE Electricity	**(2000 Dollars)**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Summer Energy Charge	On-Peak	$165,005.49	$164,130.96	$163,261.06	$162,395.78	$161,535.08	$160,678.95	$159,827.35	$158,980.26	$158,137.67	$157,299.54	$156,465.85	$155,636.58	$154,811.71	$153,991.20	$153,175.05	$152,363.22	$151,555.70	$150,752.45	$149,953.46	$149,158.71
	Mid-Peak	$138,001.29	$137,269.88	$136,542.35	$135,818.68	$135,098.84	$134,382.81	$133,670.58	$132,962.13	$132,257.43	$131,556.47	$130,859.22	$130,165.66	$129,475.79	$128,789.56	$128,106.98	$127,428.01	$126,752.64	$126,080.85	$125,412.63	$124,747.94
	Off-Peak	$111,545.87	$110,954.68	$110,366.62	$109,781.67	$109,199.83	$108,621.07	$108,045.38	$107,472.74	$106,903.13	$106,336.55	$105,772.96	$105,212.37	$104,654.74	$104,100.07	$103,548.34	$102,999.53	$102,453.64	$101,910.63	$101,370.51	$100,833.24
Winter Energy Charge	On-Peak	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Mid-Peak	$441,633.41	$439,292.76	$436,964.51	$434,648.59	$432,344.96	$430,053.53	$427,774.24	$425,507.04	$423,251.85	$421,008.62	$418,777.27	$416,557.75	$414,350.00	$412,153.94	$409,969.53	$407,796.69	$405,635.37	$403,485.50	$401,347.02	$399,219.89
	Off-Peak	$275,126.46	$273,668.29	$272,217.85	$270,775.10	$269,339.99	$267,912.49	$266,492.55	$265,080.14	$263,675.22	$262,277.74	$260,887.67	$259,504.96	$258,129.58	$256,761.50	$255,400.66	$254,047.04	$252,700.59	$251,361.28	$250,029.06	$248,703.91
Facilities-Related	Demand Charges	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00
Time-Related	Demand Charges	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50
	Customer Charge	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00
	COE	**$1,321,518.02**	**$1,315,522.06**	**$1,309,557.89**	**$1,303,625.32**	**$1,297,724.19**	**$1,291,854.34**	**$1,286,015.61**	**$1,280,207.81**	**$1,274,430.80**	**$1,268,684.41**	**$1,262,968.47**	**$1,257,282.82**	**$1,251,627.31**	**$1,246,001.78**	**$1,240,406.06**	**$1,234,840.00**	**$1,229,303.43**	**$1,223,796.21**	**$1,218,318.18**	**$1,212,869.19**
	PV (2000)	**$1,321,518.02**	**$1,271,035.81**	**$1,222,486.30**	**$1,175,795.35**	**$1,130,891.66**	**$1,087,706.69**	**$1,046,174.52**	**$1,006,231.77**	**$967,817.48**	**$930,873.04**	**$895,342.11**	**$861,170.48**	**$828,306.05**	**$796,698.71**	**$766,300.28**	**$737,064.41**	**$708,946.56**	**$681,903.88**	**$655,895.17**	**$630,880.81**
	Cumulative PV	**$1,321,518.02**	**$2,592,553.83**	**$3,815,040.13**	**$4,990,835.48**	**$6,121,727.14**	**$7,209,433.83**	**$8,255,608.36**	**$9,261,840.13**	**$10,229,657.60**	**$11,160,530.65**	**$12,055,872.75**	**$12,917,043.23**	**$13,745,349.29**	**$14,542,048.00**	**$15,308,348.27**	**$16,045,412.68**	**$16,754,359.24**	**$17,436,263.11**	**$18,092,158.28**	**$18,723,039.09**
Undiscounted Annual	**COE ($/kWh)**	**$0.13**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**
Discounted Annual	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**	**$0.08**	**$0.08**	**$0.08**	**$0.07**	**$0.07**	**$0.07**	**$0.06**	**$0.06**	**$0.06**
Levelized	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**	**$0.09**
High Economic Growth																					
SCE Electricity	**(2000 Dollars)**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Summer Energy Charge	On-Peak	$165,005.49	$164,889.98	$164,774.56	$164,659.22	$164,543.96	$164,428.77	$164,313.67	$164,198.65	$164,083.72	$163,968.86	$163,854.08	$163,739.38	$163,624.76	$163,510.23	$163,395.77	$163,281.39	$163,167.09	$163,052.88	$162,938.74	$162,824.68
	Mid-Peak	$138,001.29	$137,904.69	$137,808.15	$137,711.69	$137,615.29	$137,518.96	$137,422.70	$137,326.50	$137,230.37	$137,134.31	$137,038.32	$136,942.39	$136,846.53	$136,750.74	$136,655.01	$136,559.35	$136,463.76	$136,368.24	$136,272.78	$136,177.39
	Off-Peak	$111,545.87	$111,467.79	$111,389.76	$111,311.79	$111,233.87	$111,156.01	$111,078.20	$111,000.44	$110,922.74	$110,845.10	$110,767.50	$110,689.97	$110,612.48	$110,535.05	$110,457.68	$110,380.36	$110,303.09	$110,225.88	$110,148.72	$110,071.62
Winter Energy Charge	On-Peak	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Mid-Peak	$441,633.41	$441,324.27	$441,015.34	$440,706.63	$440,398.14	$440,089.86	$439,781.80	$439,473.95	$439,166.32	$438,858.90	$438,551.70	$438,244.71	$437,937.94	$437,631.39	$437,325.04	$437,018.92	$436,713.00	$436,407.30	$436,101.82	$435,796.55
	Off-Peak	$275,126.46	$274,933.88	$274,741.42	$274,549.10	$274,356.92	$274,164.87	$273,972.95	$273,781.17	$273,589.53	$273,398.01	$273,206.63	$273,015.39	$272,824.28	$272,633.30	$272,442.46	$272,251.75	$272,061.17	$271,870.73	$271,680.42	$271,490.24
Facilities-Related	Demand Charges	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00	$91,348.00
Time-Related	Demand Charges	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50	$95,269.50
	Customer Charge	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00	$3,588.00
	COE	**$1,321,518.02**	**$1,320,726.10**	**$1,319,934.74**	**$1,319,143.93**	**$1,318,353.67**	**$1,317,563.97**	**$1,316,774.82**	**$1,315,986.22**	**$1,315,198.17**	**$1,314,410.68**	**$1,313,623.73**	**$1,312,837.34**	**$1,312,051.50**	**$1,311,266.20**	**$1,310,481.46**	**$1,309,697.27**	**$1,308,913.62**	**$1,308,130.53**	**$1,307,347.98**	**$1,306,565.98**
	PV (2000)	**$1,321,518.02**	**$1,276,063.87**	**$1,232,173.20**	**$1,189,792.24**	**$1,148,869.06**	**$1,109,353.51**	**$1,071,197.16**	**$1,034,353.27**	**$998,776.69**	**$964,423.82**	**$931,252.58**	**$899,222.31**	**$868,293.77**	**$838,429.06**	**$809,591.58**	**$781,746.01**	**$754,858.23**	**$728,895.27**	**$703,825.35**	**$679,617.73**
	Cumulative PV	**$1,321,518.02**	**$2,597,581.89**	**$3,829,755.09**	**$5,019,547.33**	**$6,168,416.39**	**$7,277,769.89**	**$8,348,967.06**	**$9,383,320.33**	**$10,382,097.02**	**$11,346,520.84**	**$12,277,773.42**	**$13,176,995.72**	**$14,045,289.49**	**$14,883,718.55**	**$15,693,310.13**	**$16,475,056.14**	**$17,229,914.37**	**$17,958,809.64**	**$18,662,634.99**	**$19,342,252.72**
Undiscounted Annual	**COE ($/kWh)**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**
Discounted Annual	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**	**$0.08**	**$0.08**	**$0.08**	**$0.07**	**$0.07**	**$0.07**	**$0.07**	**$0.06**
Levelized	**COE ($/kWh)**	**$0.13**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.12**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.11**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.10**	**$0.09**	**$0.09**	**$0.09**

Fuel Cell Electricity Costs																				
Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Operating Hours	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322	8322
Power Output	1200	1192	1183	1175	1167	1159	1150	1142	1134	1126	1119	1111	1103	1095	1088	1080	1072	1065	1057	1050
Generation (kWh)	9986400	9916495	9847080	9778150	9709703	9641735	9574243	9507223	9440673	9374588	9308966	9243803	9179097	9114843	9051039	8987682	8924768	8862295	8800259	8738657
Power Deficit (kWh)	525586	595491	664906	733836	802283	870251	937743	1004762	1071313	1137398	1203020	1268183	1332889	1397143	1460947	1524304	1587218	1649691	1711727	1773329
Baseline Case	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Installation	$6,343,620	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Incentive	$1,153,385	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
CA Incentive	$2,537,448	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
O&M	$95,985	$95,313	$94,646	$93,983	$93,325	$92,672	$92,023	$91,379	$90,739	$90,104	$89,474	$88,847	$88,225	$87,608	$86,994	$86,386	$85,781	$85,180	$84,584	$83,992
Fuel	$239,104	$242,701	$246,352	$250,059	$253,821	$257,639	$261,515	$265,450	$269,443	$273,497	$277,612	$281,788	$286,028	$290,331	$294,699	$299,132	$303,633	$308,201	$312,838	$317,544
Deficit Power Purchased	$75,405	$85,242	$94,964	$104,573	$114,071	$123,457	$132,733	$141,901	$150,961	$159,915	$168,763	$177,507	$186,147	$194,686	$203,123	$211,460	$219,698	$227,838	$235,880	$243,827
Demand Charges	$9,331	$10,572	$11,804	$13,028	$14,243	$15,449	$16,648	$17,837	$19,019	$20,192	$21,357	$22,514	$23,663	$24,803	$25,936	$27,061	$28,178	$29,287	$30,388	$31,482
Customer Charge	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588
COE	**$3,076,198**	**$437,415**	**$451,354**	**$465,231**	**$479,047**	**$492,806**	**$506,508**	**$520,155**	**$533,751**	**$547,296**	**$560,793**	**$574,244**	**$587,651**	**$601,016**	**$614,340**	**$627,627**	**$640,877**	**$654,094**	**$667,278**	**$680,432**
PV (2000)	**$3,076,198**	**$422,623**	**$421,344**	**$419,612**	**$417,462**	**$414,929**	**$412,044**	**$408,837**	**$405,337**	**$401,568**	**$397,557**	**$393,326**	**$388,898**	**$384,292**	**$379,528**	**$374,624**	**$369,598**	**$364,463**	**$359,237**	**$353,931**
Cumulative PV	**$3,076,198**	**$3,498,822**	**$3,920,166**	**$4,339,778**	**$4,757,240**	**$5,172,169**	**$5,584,213**	**$5,993,050**	**$6,398,387**	**$6,799,955**	**$7,197,512**	**$7,590,838**	**$7,979,736**	**$8,364,028**	**$8,743,556**	**$9,118,181**	**$9,487,778**	**$9,852,242**	**$10,211,478**	**$10,565,409**
Disc. Ann. COE ($/kWh)	**$0.3080**	**$0.0426**	**$0.0428**	**$0.0429**	**$0.0430**	**$0.0430**	**$0.0430**	**$0.0430**	**$0.0429**	**$0.0428**	**$0.0427**	**$0.0426**	**$0.0424**	**$0.0422**	**$0.0419**	**$0.0417**	**$0.0414**	**$0.0411**	**$0.0408**	**$0.0405**
Levelized COE ($/kWh)	**$0.3080**	**$0.1764**	**$0.1327**	**$0.1110**	**$0.0980**	**$0.0894**	**$0.0833**	**$0.0788**	**$0.0753**	**$0.0725**	**$0.0703**	**$0.0684**	**$0.0669**	**$0.0655**	**$0.0644**	**$0.0634**	**$0.0625**	**$0.0618**	**$0.0611**	**$0.0605**
Low Economic Growth	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Installation	$6,343,620	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Incentive	$1,153,385	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
CA Incentive	$2,537,448	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
O&M	$95,985	$95,313	$94,646	$93,983	$93,325	$92,672	$92,023	$91,379	$90,739	$90,104	$89,474	$88,847	$88,225	$87,608	$86,994	$86,386	$85,781	$85,180	$84,584	$83,992
Fuel	$239,104	$241,348	$243,613	$245,899	$248,207	$250,536	$252,887	$255,260	$257,656	$260,074	$262,514	$264,978	$267,465	$269,975	$272,508	$275,066	$277,647	$280,252	$282,882	$285,537
Deficit Power Purchased	$75,405	$85,094	$94,636	$104,033	$113,286	$122,398	$131,369	$140,203	$148,900	$157,464	$165,894	$174,194	$182,365	$190,409	$198,327	$206,120	$213,792	$221,342	$228,774	$236,088
Demand Charges	$9,331	$10,572	$11,804	$13,028	$14,243	$15,449	$16,648	$17,837	$19,019	$20,192	$21,357	$22,514	$23,663	$24,803	$25,936	$27,061	$28,178	$29,287	$30,388	$31,482
Customer Charge	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588
COE	**$3,076,198**	**$435,915**	**$448,287**	**$460,531**	**$472,649**	**$484,643**	**$496,515**	**$508,268**	**$519,902**	**$531,422**	**$542,827**	**$554,121**	**$565,306**	**$576,382**	**$587,353**	**$598,220**	**$608,985**	**$619,650**	**$630,216**	**$640,686**
PV (2000)	**$3,076,198**	**$421,173**	**$418,480**	**$415,372**	**$411,886**	**$408,056**	**$403,915**	**$399,494**	**$394,820**	**$389,921**	**$384,821**	**$379,543**	**$374,110**	**$368,541**	**$362,856**	**$357,072**	**$351,205**	**$345,271**	**$339,284**	**$333,257**
Cumulative PV	**$3,076,198**	**$3,497,372**	**$3,915,852**	**$4,331,225**	**$4,743,111**	**$5,151,167**	**$5,555,082**	**$5,954,576**	**$6,349,396**	**$6,739,316**	**$7,124,137**	**$7,503,680**	**$7,877,790**	**$8,246,331**	**$8,609,187**	**$8,966,259**	**$9,317,464**	**$9,662,735**	**$10,002,019**	**$10,335,276**
Disc. Ann. COE ($/kWh)	**$0.3080**	**$0.0425**	**$0.0425**	**$0.0425**	**$0.0424**	**$0.0423**	**$0.0422**	**$0.0420**	**$0.0418**	**$0.0416**	**$0.0413**	**$0.0411**	**$0.0408**	**$0.0404**	**$0.0401**	**$0.0397**	**$0.0394**	**$0.0390**	**$0.0386**	**$0.0381**
Levelized COE ($/kWh)	**$0.3080**	**$0.1751**	**$0.1316**	**$0.1100**	**$0.0970**	**$0.0884**	**$0.0823**	**$0.0777**	**$0.0742**	**$0.0714**	**$0.0691**	**$0.0672**	**$0.0656**	**$0.0642**	**$0.0630**	**$0.0619**	**$0.0610**	**$0.0601**	**$0.0594**	**$0.0587**
High Economic Growth	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Installation	$6,343,620	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Incentive	$1,153,385	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
CA Incentive	$2,537,448	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
O&M	$95,985	$95,313	$94,646	$93,983	$93,325	$92,672	$92,023	$91,379	$90,739	$90,104	$89,474	$88,847	$88,225	$87,608	$86,994	$86,386	$85,781	$85,180	$84,584	$83,992
Fuel	$239,104	$244,078	$249,156	$254,339	$259,631	$265,032	$270,546	$276,174	$281,920	$287,785	$293,772	$299,884	$306,122	$312,491	$318,992	$325,628	$332,403	$339,318	$346,377	$353,583
Deficit Power Purchased	$75,405	$85,389	$95,293	$105,116	$114,861	$124,526	$134,113	$143,623	$153,055	$162,411	$171,692	$180,897	$190,027	$199,083	$208,066	$216,975	$225,812	$234,577	$243,271	$251,894
Demand Charges	$9,331	$10,572	$11,804	$13,028	$14,243	$15,449	$16,648	$17,837	$19,019	$20,192	$21,357	$22,514	$23,663	$24,803	$25,936	$27,061	$28,178	$29,287	$30,388	$31,482
Customer Charge	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588	$3,588
COE	**$3,076,198**	**$438,940**	**$454,486**	**$470,055**	**$485,647**	**$501,267**	**$516,918**	**$532,601**	**$548,321**	**$564,081**	**$579,882**	**$595,729**	**$611,625**	**$627,573**	**$643,576**	**$659,638**	**$675,761**	**$691,950**	**$708,208**	**$724,539**
PV (2000)	**$3,076,198**	**$424,096**	**$424,268**	**$423,962**	**$423,214**	**$422,054**	**$420,513**	**$418,620**	**$416,402**	**$413,883**	**$411,089**	**$408,042**	**$404,763**	**$401,273**	**$397,589**	**$393,731**	**$389,715**	**$385,557**	**$381,272**	**$376,873**
Cumulative PV	**$3,076,198**	**$3,500,295**	**$3,924,563**	**$4,348,525**	**$4,771,739**	**$5,193,792**	**$5,614,305**	**$6,032,925**	**$6,449,327**	**$6,863,210**	**$7,274,299**	**$7,682,342**	**$8,087,105**	**$8,488,378**	**$8,885,967**	**$9,279,698**	**$9,669,414**	**$10,054,971**	**$10,436,243**	**$10,813,116**
Disc. Ann. COE ($/kWh)	**$0.3080**	**$0.0428**	**$0.0431**	**$0.0434**	**$0.0436**	**$0.0438**	**$0.0439**	**$0.0440**	**$0.0441**	**$0.0441**	**$0.0442**	**$0.0441**	**$0.0441**	**$0.0440**	**$0.0439**	**$0.0438**	**$0.0437**	**$0.0435**	**$0.0433**	**$0.0431**
Levelized COE ($/kWh)	**$0.3080**	**$0.1765**	**$0.1329**	**$0.1112**	**$0.0983**	**$0.0898**	**$0.0838**	**$0.0793**	**$0.0759**	**$0.0732**	**$0.0710**	**$0.0693**	**$0.0678**	**$0.0665**	**$0.0655**	**$0.0645**	**$0.0637**	**$0.0630**	**$0.0624**	**$0.0619**

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