APPLYING FUEL CELLS TO DATA CENTERS FOR POWER AND COGENERATION

by

AMY L CARLSON

B.S., Kansas State University, 2009

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Architectural Engineering and Construction Science
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2009

Approved by:

Major Professor
Fred Hasler

Copyright

AMY L CARLSON

2009

Abstract

Data center space and power densities are increasing as today's society becomes more dependent on computer systems for processing and storing data. Most existing data centers were designed with a power density between 40 and 70 watts per square foot (W/SF), while new facilities require up to 200W/SF. Because increased power loads, and consequently cooling loads, are unable to be met in existing facilities, new data centers need to be built. Building new data centers gives owners the opportunity to explore more energy efficient options in order to reduce costs. Fuel cells are such an option, opposed to the typical electric grid connection with UPS and generator for backup power.

Fuel cells are able to supply primary power with backup power provided by generators and/or the electric grid. Secondary power could also be supplied to servers from rack mounted fuel cells. Another application that can benefit from fuel cells is the HVAC system. Steam or high-temperature water generated from the fuel cell can serve absorption chillers for a combined heat and power (CHP) system. Using the waste heat for a CHP system, the efficiency of a fuel cell system can reach up to 90%. Supplying power alone, a fuel cell is between 35 and 60% efficient. Data centers are an ideal candidate for a CHP application since they have constant power and cooling loads.

Fuel cells are a relatively new technology to be applied to commercial buildings. They offer a number of advantages, such as low emissions, quiet operation, and high reliability. The drawbacks of a fuel cell system include high initial cost, limited lifetime of the fuel cell stacks, and a relatively unknown failure mode. Advances in engineering and materials used, as well as higher production levels, need to occur for prices to decrease. However, there are several incentive programs that can decrease the initial investment.

With a prediction that nearly 75% of all 10 year old data centers will need to be replaced, it is recommended that electrical and HVAC designer engineers become knowledgeable about fuel cells and how they can be applied to these high demand facilities.

Table of Contents

List of Figures vi
List of Tables vii
Acknowledgements viii
Dedication ix
CHAPTER 1 - Introduction 1
CHAPTER 2 - Background Information 2
2.1 History of Fuel Cells 2
2.2 Types of Fuel Cells & How They Work 3
2.2.1 Phosphoric Acid Fuel Cell 6
2.2.2 Molten Carbonate Fuel Cell 8
2.2.3 Proton Exchange Membrane Fuel Cell 9
2.2.4 Solid Oxide Fuel Cell 10
2.2.5 Summary of Fuel Cell Types 11
CHAPTER 3 - Data Center Power 13
3.1 Reliability & Availability of Power 13
3.2 Typical Power Distribution in Data Centers 14
3.3 Using Fuel Cells for Data Center Power 16
3.3.1 Fuel Cells as Primary Power 17
3.3.2 Fuel Cells as Secondary Power 19
CHAPTER 4 - Fuel Cell Combined Heat and Power Systems 24
4.1 Typical HVAC Systems in Data Centers 25
4.2 Fuel Cell Combined Heat and Power System Applications 27
4.2.1 Using Absorption Chillers in a Fuel Cell CHP System 28
4.2.1.1 Absorption Chillers versus Electric Chillers 31
4.2.1.2 Absorption Chillers Serving CRAC Units 32
4.2.2 Domestic Water Heating in a Fuel Cell CHP System 33
CHAPTER 5 - Advantages of Fuel Cells used in Data Centers 34
5.1 Low Noise Levels 34
5.2 Low Emissions 35

5.3 Increased Reliability 36
5.3 High Efficiency 37
5.4 Modularity 38
5.5 Minimal Maintenance 39
5.6 Tax Incentives 39
5.7 Obtainable LEED Points 40
5.7.1 Obtainable LEED Points with NC Version 2.2 40
5.7.2 Obtainable LEED Points with Environmental Performance Criteria Guide for Data Centers Draft 41
CHAPTER 6 - Disadvantages of Fuel Cells used in Data Centers 44
6.1 High Initial Cost 44
6.2 Unknown Failure Rate 44
6.3 Life of Fuel Cell Stacks 44
6.4 Large Footprint & Weight 45
CHAPTER 7 - Future Predictions for Fuel Cells 46
7.1 Decreased Initial Cost 46
7.2 Increased Demand 49
7.3 Applying Renewable Energy Resources to Fuel Cells 49
CHAPTER 8 - Conclusions 51
8.1 Fuel Cell System Design Procedure Recommendations 51
8.2 Conclusion 54
References Cited 55
Graphics References 66
Appendix A - Relevant Codes and Standards 68
Appendix B - Data Sheets for Stationary Fuel Cells 70
DFC300 Data Sheet 70
PureCell Model 400 System 72
InfraStruXure Data Sheet 74
Appendix C - Fuel Cell Items in the American Recovery and Reinvestment Act 76

List of Figures

Figure 2-1 Fuel Cell System Components 4
Figure 2-2 Fuel Cell Diagram 5
Figure 2-3 UTC Power's PureCell Model 400 Fuel Cell Module 6
Figure 2-4 MCFC Dual Fuel Operation 9
Figure 3-1 One Line Diagram: Typical Data Center Power Distribution 15
Figure 3-2 One Line Diagram: Typical Data Center Power with Partial Emergency Power 16
Figure 3-3 One Line Diagram: Fuel Cell Providing Primary Power 18
Figure 3-4 Hydrogen Storage Tanks Located Outdoors 20
Figure 3-5 Three APC Fuel Cells Installed in a Server Rack 21
Figure 3-6 One Line Diagram: Utility Primary and Fuel Cell Secondary Power 22
Figure 3-7 One Line Diagram: Fuel Cell Primary and Secondary Power 23
Figure 4-1 Diagram of Condenser and Chilled Water Piping for Electric Chiller 25
Figure 4-2 Hot-Aisle/Cold-Aisle Layout 26
Figure 4-3 Diagram of Waste Heat Applications 27
Figure 4-4 Single-Effect Absorption Chiller Cooling Process 29
Figure 4-5 Diagram of Condenser and Chilled Water Piping with Absorption Chiller 32
Figure 5-1 Sound Level of UTC Power's PureCell Model 400 System 34
Figure 5-2 Reliability of a Well-Maintained Diesel Generator 37
Figure 5-3 UTC Power’s PureCell Model 200 Fuel Cells at Verizon Call Routing Center 38
Figure 7-1 FuelCell Energy Cost Reductions 47

List of Tables

Table 2-1 Fuel Cell Types Comparison 12
Table 4-1 Fuel Cell Low and High Grade Heat Recovery 28
Table 4-2 Waste Heat Required from Fuel Cells to Provide Cooling 30
Table 5-1 Emissions of a PEMFC versus a Diesel Generator 36

Acknowledgements

I would like to thank my supervisory committee, Fred Hasler, Ray Yunk, and Chuck Burton, for the guidance and support they provided me while writing this report. Your knowledge and experience is truly an inspiration.

Dedication

I would like to dedicate this report to my loving and supportive husband and family. Thank you for your continuous encouragement throughout my undergraduate and graduate years.

CHAPTER 1 - Introduction

Data centers have become ever-present in the economy as information management evolves from paper to digital. In fact, data centers are "found in nearly every sector of the economy and are essential to the function of communications, business, academic, and governmental systems" [1, p. 17]. The size of a data center can range from being a server closet within a large commercial building to occupying an entire building specifically constructed for their use. However, large data centers are becoming more common as smaller data centers consolidate and secondary data centers are built to back up primary facilities [1, p. 18].

As would be expected with the high power requirements of IT equipment, data centers have a higher power usage than other commercial buildings. In fact, a data center can be more than 40 times energy intensive than a conventional office building [2, p. 3-76]. This means that data centers more closely resemble an industrial facility than a commercial building in terms of energy use [1, p. 18].

The total energy consumed by servers and data centers, as well as the power and cooling that support them, doubled from the year 2000 to 2006. Owners of existing data centers are being forced to build new facilities due to the lack of power and cooling capacity available in their facilities required to support new IT equipment. In fact, nearly 75% of data centers that are only 10 years old are projected to be replaced entirely, much like other forms of computer technology [3, p. 27]. The increased power usage of data centers has become a concern as well as an incentive to make energy efficiency improvements. Among the options for a more efficient power source is the stationary fuel cell.

The intent of this report is to inform engineers designing electrical and heating, ventilation, and air conditioning (HVAC) systems for data centers about the advantages and disadvantages that fuel cells offer for primary and secondary power and combined heat and power (CHP) applications. A review of the history, operation, types, and future predictions for the use of fuel cells will also be discussed.

CHAPTER 2 - Background Information

The background information of fuel cells is important to understand before discussing their useful applications. In this chapter, the history, operation, and types of fuel cells are explained.

2.1 History of Fuel Cells

The technology of fuel cells has been around for more than 170 years. William Robert Grove is credited with making the first fuel cell in 1838. Grove devised a wet-cell battery that produced 12 amps of current at approximately 1.8 volts. He called them “gas batteries” [4, para 1].

Over fifty years later in 1889, Charles Langer and Ludwig Mond were the first to apply fuel cell technology to a practical use using air and coal gas. However, further fuel cell advancements were set aside in the early 1900s with the introduction of the internal combustion engine [5, para 1].

Francis Bacon developed perhaps the first successful fuel cell in 1939 [5, para 2]. The fuel cell used nickel electrodes and alkali electrolytes. In 1958, Bacon developed an alkali fuel cell (AFC) for Britain’s National Research Development Corporation. His fuel cell proved to be reliable, although very expensive [6, para 4].

In the late 1950s and early 1960s, interest in fuel cells was raised due to the upcoming manned space flights. NASA needed a way to power the flights, and batteries were considered too heavy, solar power too expensive, and nuclear power too risky [7, para 6]. With a sponsorship from NASA for fuel cell technology, the first proton exchange membrane fuel cell (PEMFC) was developed. From the results of the work of two General Electric (GE) scientists, Willard Grubb and Leonard Niedrach, GE and NASA developed the PEMFC that was used in the Gemini space project. This was the first commercial use of a fuel cell [7, para 6].

Later on in the 1960s, Bacon‘s AFC was patented by Pratt and Whitney, an aircraft engine manufacturer. Bacon’s AFC weighed less and lasted longer than GE’s PEMFC. Pratt and Whitney improved Bacon’s AFC and contracted with NASA to supply these fuel cells for the Apollo space flight [7, para 7]. AFCs were used in subsequent manned US space missions throughout the 1990s. At this time, developments were made on PEMFCs, and they began to be used again [8, para 7].

The improvements to the PEMFCs included the fuel cell being more "powerful, lighter, safer, simpler to operate, and more reliable" [8, para 7]. Also, the improved PEMFC was expected to last longer, perform better, and cost less than the AFCs. They also produced water so pure that it could be used as drinking water for the spacecraft crews [8, para 7].

The oil embargos of 1973 and 1979 in the US encouraged fuel cell research for commercial and residential building applications [7, para 8]. However, to this day, NASA's Glenn Research Center continues to research PEMFCs, SOFCs, and regenerative fuel cells for new flight capabilities [8, para 7].

In more recent history, stationary fuel cells have been applied to commercial buildings. According to the database at www.fuelcells.org, fuel cells were first applied to commercial buildings in the 1980s with installations across the globe. The database records state that several of these first installations were to test the life of fuel cell stacks and efficiency [9].

2.2 Types of Fuel Cells & How They Work

The basic concept of a fuel cell is that it converts chemical energy into electricity and thermal energy. The fuel cell is similar to a battery in that it too has a pair of electrodes and an electrolyte. However, the fuel cell never needs to be recharged because the reactant consumed during the electrochemical reactions in the fuel cell is continuously replenished [10, pp. 1808-1809]. Unlike a battery, the cathode and anode are constantly supplied with air and fuel, respectively [11, p. 45].

Although there are several types of fuel cells, they all have the same basic components. These are the fuel processor, fuel cell stack, air management, water management, thermal management, and power conditioning subsystems [10, p. 1812]. These components are shown in schematic format in Figure 2-1.

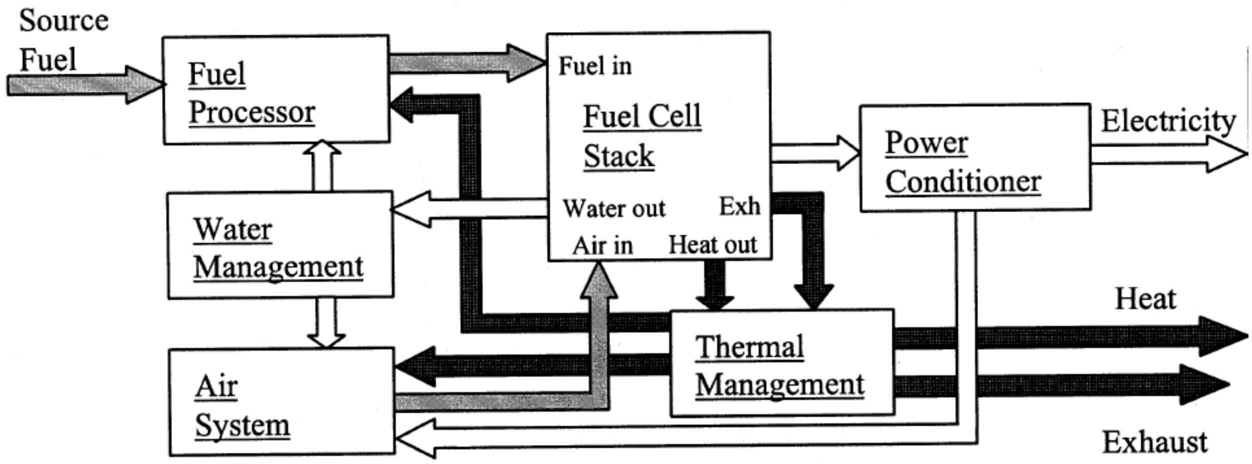


Figure 2-1 Fuel Cell System Components [A]

The fuel cell stack requires hydrogen in order to produce electricity. Hydrocarbon fuels are converted into a hydrogen rich fuel stream in the fuel processor. Therefore, any hydrocarbon fuel can be used in a fuel cell system [10, p. 1812]. Hydrocarbon fuels that are used include natural gas, liquefied petroleum gas, gasoline, methane, landfill gas, and methanol [12, p. iii]. The process to extract the hydrogen from a fuel is a chemical process rather than a combustion process. Therefore, emissions are reduced in comparison to combustion technologies [12, p. iii].

From the processor, the hydrogen fuel is supplied to the fuel cell stack, which is made of several individual fuel cells [12, p. iii]. As shown in Figure 2-2, the fuel enters the fuel cell at the anode. The fuel is oxidized at the anode, which causes the fuel to release an electron. The electron travels through the external circuit to feed the electrical load. Leaving the external circuit, the electrons are consumed due to the oxidant being reduced at the cathode. Ions in the electrolyte are used to balance the flow of electrons through the external circuit. There are several types of fuel cells. They all have varying compositions, direction of flow of the mobile ion, and reactions at the anode and cathode [10, pp. 1809]. For all but the direct methanol fuel cell, the net reaction is

$$H_2 + 1/2O_2 \rightarrow H_20.$$

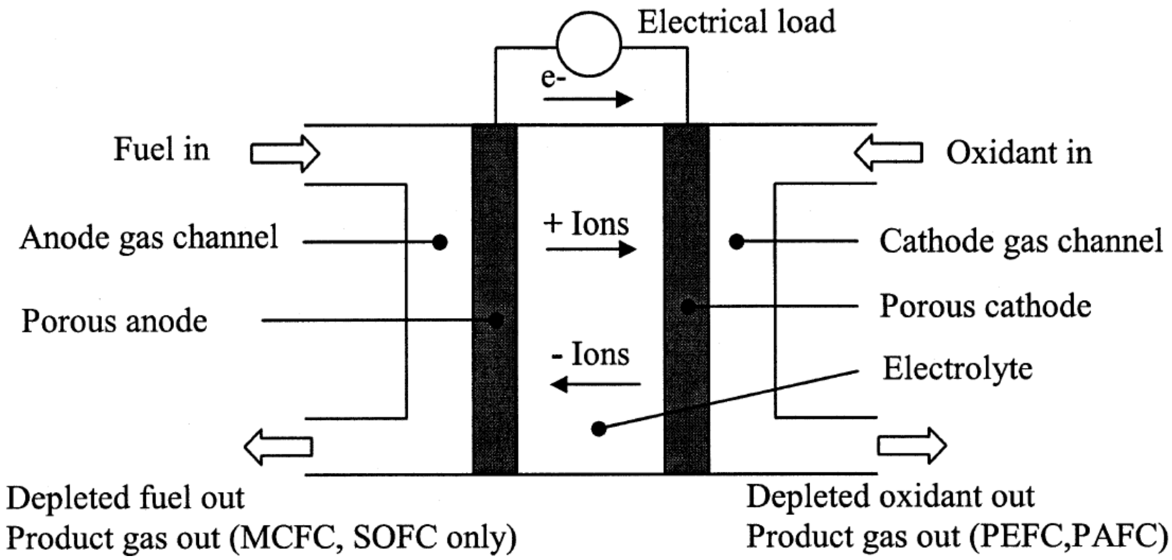


Figure 2-2 Fuel Cell Diagram [A]

The result of a fuel cell's chemical process is water, as stated in the above net reaction equation, and heat. The water produced, as well as some of the heat, is used in the fuel reforming process. Water may also be used for humidification of the oxidant. The remainder of the thermal energy generated by the fuel cell process can be recovered for a CHP application [13, p. 5]. The use of the waste heat for CHP applications will be discussed more in Chapter 4.

As mentioned above, the fuel is oxidized as it enters the fuel cell. This requires an oxidant, which is typically air. Most fuel cell stack designs require operating pressures between 1 and 8 atmosphere. Air can be supplied at high pressure using an air compressor or at low pressure using a blower. As the pressure of the air is increased, the kinetics of the electrochemical reactions are improved. This results in a higher power density and higher stack efficiency. The drawback of using a compressor to provide high pressurized air is that the compressor itself decreases the net power from the fuel cell. Also, at low loads, the performance of the compressor is usually poor [10, p. 1812].

Power conditioning is another necessary component in order for a fuel cell to supply power to a building. Fuel cells produce a low, variable voltage and require a power converter in order to boost and regulate the voltage. The power converter also converts direct current (DC) power from the fuel cell to alternating current (AC) power to serve the building [14, p. 643].

All of the components that make up a fuel cell system are housed within one enclosure. Figure 2-3 shows a view of the UTC Power's PureCell Model 400 fuel cell module and its components.

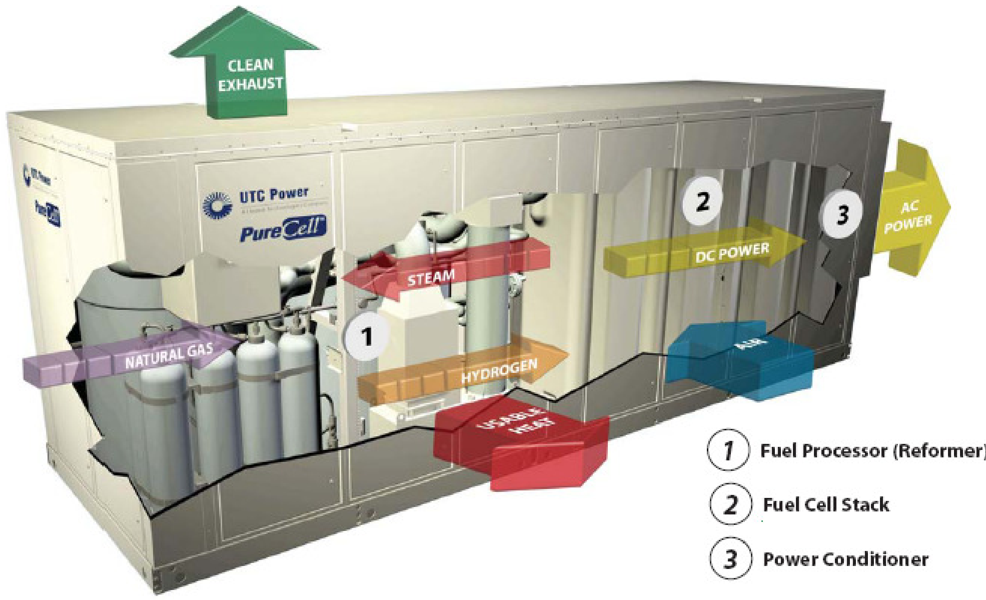


Figure 2-3 UTC Power's PureCell Model 400 Fuel Cell Module [B]

There are eight different types of fuel cells, and they are classified in accordance with the electrolyte used [15, p. 1.1173]. They are the alkaline fuel cell, molten carbonate fuel cell (MCFC), direct methanol fuel cell, phosphoric acid fuel cell (PAFC), proton exchange membrane fuel cell, solid oxide fuel cell (SOFC), metal hydride fuel cell, and regenerative fuel cell. The different fuel cell types vary in operating characteristics, construction materials, and potential application [10, p. 1809]. PAFCs are generally used for commercial building applications. However, MCFCs, PEMFCs, and SOFCs are also used [16, p. 1]. Few manufacturers are exploring alkaline fuel cells for the building sector because of their electrolyte's sensitivity to carbon dioxide (CO_2) [12, p. iv; 13, p. 2].

PAFCs, MCFCs, PEMFCs, and SOFCs have proven to be attractive for stationary use through their commercialization, demonstrated operating hours, and support from continued research and development. [12, p. 3]. Therefore, these four fuel cells will be the focus of the remainder of the report.

2.2.1 Phosphoric Acid Fuel Cell

The phosphoric acid fuel cell has a liquid phosphoric acid electrolyte and porous carbon electrodes that contain a platinum catalyst. The operating temperature of a PAFC can reach 430ºF (220ºC). Because of their high operating temperatures, PAFCs are less sensitive to carbon monoxide poisoning compared to PEMFCs. This simplifies fuel processing, although sulfur must still be removed from the fuel. The operating temperature also allows for the use of moderately priced high-temperature materials [17, p. 50; 18, p. 18].

PAFCs are mostly applied to stationary power generation. They were the first fuel cell commercially available and have the longest record of all the fuel cells types with over 300 systems installed in over 15 countries. Most of these installations are located in Japan, and the US. Individual units have operated up to 65,000 hours with an average availability greater than 95%. One characteristic of PAFCs that has made them successful is their ability to quickly respond to changing loads [17, p. 50].

Beginning in 1991, the only stationary fuel cell commercially available for several years was the UTC Power PC25C, which was a PAFC able to generate 200 kilowatts (kW) of power [19]. However, from the years 2002 to 2004, manufacturer and developers lost interest in PAFCs and actually stopped production. One reason their interest decreased was concerns that the cost of PAFCs would be inherently too large in comparison to other fuel cell technologies being developed. Another reason was due to the limited potential for higher electric generation efficiencies that was needed for widespread use of distributed generation (DG) applications. And lastly, manufacturers and developers had concerns with the reliability and the life of the fuel cell's electrolyte [17, p. 50].

Because other fuel cell technologies had yet to demonstrate competitive costs and the ability to perform consistently, the interest to develop and manufacture PAFCs was rejuvenated in 2004. There was also an increase in interest from specific niche-markets. where high reliability is required and in regions where electricity prices are high and natural gas prices are low. This niche-market had a power requirement range between 100 and 1000kW [17, p. 50; 20, p. 5-12].

Since the new interest for PAFCs within the last couple of years, the developer/manufacturer UTC Power has produced a 400kW PAFC. UTC's PureCell 400 Model is able to reach electrical generation efficiencies of 40%, a stack life of 10 years, and an installed cost around $2,500/kW, not including government subsidies [21, p. 4]. UTC Power was able to decrease the capital cost from previous models with the development of less expensive materials, higher power densities, and optimization of stack/system size [17, p. 50].

Favored applications for PAFCs are for the commercial and small industrial sectors. PAFCs are suitable for CHP with applications of at least 100kW, which is typical for a medium to large commercial building [17, p. 50].

2.2.2 Molten Carbonate Fuel Cell

A molten carbonate fuel cell contains an electrolyte made of lithium-potassium carbonate salts. These salts are heated to about 1,200°F (650°C), which causes them to melt into a molten state that is able to conduct ions [22, para 2]. Because these fuel cells operate at such high temperatures, non-precious metals are used. The catalyst and cathode are made of nickel and nickel-oxide, respectively. Because they are made of metallic stack components that are suitable for common manufacturing methods, the initial investment costs of MCFCs are reduced [6, para 12; 23, p. 11].

The MCFC's high operating temperature enables fuel reforming to be done internally, making it a good candidate for heat recovery and steam generation. They are able to produce waste heat at temperatures ranging from 750°F to 840°F (400° to 450°C) [23, p. 11; 6, para 14]. MCFCs are primarily used in industrial and large commercial applications with a typical power output range of 250kW to 2000kW [12, p. 6].

MCFCs are able to reach considerably higher electrical efficiencies compared to the other fuel cell types. Their electrical generation efficiency is 50%. and, when used in CHP applications, efficiencies can reach 90%. The efficiencies are independent of the load and remain high throughout the lifetime of the MCFC [23, p. 11-12; 22, para. 4-5].

MCFCs have a few notable advantages over the PAFC. With higher efficiencies, MCFCs are able to offer significant operating cost reductions over phosphoric acid technology. The less expensive nickel catalyst compared to the pricey platinum catalyst of the PAFC adds to the cost difference of these two fuel cells [23, p. 11; 22, para 4-5].

In case there are concerns with interruptions in the gas grid, MTU CFC Solutions has tested the reaction of their HotModule MCFC when it is switched to a liquid fuel supply, such as methanol and liquefied petroleum gas. Tests showed that the HotModule provided continuous power while switching the fuel supply from natural gas to methanol, as shown in Figure 2-4. These test results prove that a facility can be independent from a single fuel provider and protected from interruptions in the gas grid [23, p. 13].

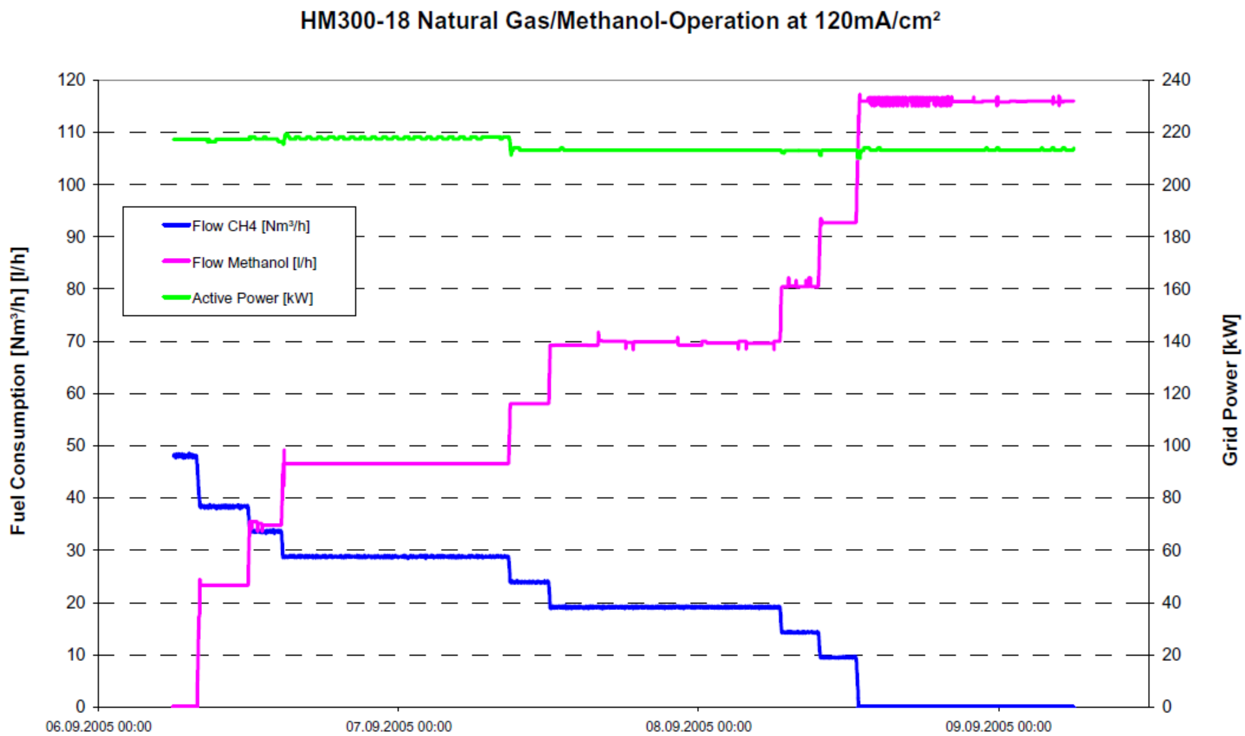


Figure 2-4 MCFC Dual Fuel Operation [C]

Because MCFCs have minimal moving parts to cause wear and a moderate operating temperature, few system interruptions occur. CFC Solutions's field tests have proven that their HotModule MCFC is able to achieve 95% to 98% reliability [23, p. 11-12].

Another manufacturer has found success with their MCFCs. FuelCell Energy's MCFC, labeled the Direct FuelCell (DFC), was certified to meet American National Standards Institute's (ANSI) products safety standard for stationary fuel cell systems, ANSIZ21.83. The DFC was also approved under California's Rule 21, which has standards for distributed generation interconnection, operation, and metering. In addition, the DFC passed the California Air Resources Board's (CARB) certification, a distributed generation emissions standard made in 2007. With these three certifications, the DFCs installation time and cost will decrease as the acceptance of the DFC in the US is expected to increase [22, para 11-13].

2.2.3 Proton Exchange Membrane Fuel Cell

Proton exchange membrane fuel cells contain carbon electrodes, which are bonded to the polymer membrane electrolyte. The membrane is located between two collector plates that provide a path for electrons to the external circuit. Precious metals, such as platinum, are used for the catalyst [10, p. 1809].

This type of fuel cell operates at relatively low temperatures, 140°F to 194°F (60°C to 90°C), resulting in a quick start up time [11, p. 45; 10, pp. 1809-1810]. Because the operating temperatures are so low, the CHP applications with PEMFCs are limited [11, p. 45]. PEMFCs are not likely to produce the high waste heat temperatures that are required for absorption cooling and, in most cases, space heating. However, the low temperatures are ideal for residential water heating [12, p. 4].

The platinum catalysts of PEMFCs can be poisoned from fuel impurities, such as carbon monoxide and sulfur compounds. Therefore, they require very clean hydrogen fuel. Ultra-pure hydrogen (>99.999%) is the recommended fuel for PEMFCs. So, it requires a complex and expensive fuel processor [11, p. 45; 18, p. 18].

Because PEMFCs have a rapid start-up time, high power density, and potential economic competitiveness through low capital and maintenance costs, they are attractive for both stationary and transportation applications [24, p. 533; 11, p. 45]. Additional advantages include simple operation and zero emissions (when pure hydrogen is the fuel) [11, p. 45]. For stationary applications, PEMFCs are predicted to mostly be applied to the residential and small commercial sectors. They are also the most ideal fuel cell type for providing secondary power in data centers, as discussed later on in section 3.3.2.

2.2.4 Solid Oxide Fuel Cell

The solid oxide fuel cell has a solid ceramic electrolyte, rather than a liquid electrolyte [18, p. 18]. An SOFC can use its electrolyte, cathode, or anode to provide structural support and to provide various cell geometries, such as tubular and planar.

The tubular geometry has several advantages. First, it makes the fuel cell less susceptible to mechanical damage from thermally induced stresses. Also, the fuel cell stack can be arranged to avoid the need for high temperature compliant seals. However, the planar geometry is more compact. Therefore, they have higher power densities and reduced material content. Planar geometry SOFCs are less expensive, as well. This is because they operate at lower temperatures, ranging from 1300°F to 1500°F (700°C to 800°C). Because of this cost advantage over the tubular geometry, most of the development of SOFCs is focused on the planar geometry [25, p. 116]. SOFCs with the tubular geometry have the highest operating temperatures of all the fuel cell types, ranging from 1500°F to 1800°F (800°C to 1000°C).

The high operating temperatures of the SOFC may eliminate the need for fuel reforming. However, most SOFCs require that hydrocarbon fuels be processed before entering the fuel cell system. Fuel processing is less complicated for SOFCs in comparison to PEMFCs because they are not poisoned by trace levels of carbon monoxide. Like other fuel cells, the anodes in SOFCs are poisoned by sulfur [17, p. 50; 25, p. 116].

An advantage that SOFCs have over other fuel cell types is that there are no precious metals used in their construction, reducing the overall cost of the fuel cell. Another advantage is that they have high electric generation efficiencies at both full and part loads. Electrical generation efficiencies range from 45% to 60%. SOFCs are able to produce exhaust at around 500°F, making them applicable for CHP systems with absorption cooling. Efficiencies can reach up to 85% for an SOFC used in a CHP system [25, p. 117].

Because fuel cells are one of the most attractive technologies for generating electricity, the Solid-State Energy Conversion Alliance (SECA) was formed by the Department of Energy (DOE) in 1999. The alliance was formed in order to accelerate the commercialization of SOFCs from 3kW to 10kW for stationary, transportation, and military applications [26, para 1]. The goal for SECA is to have factory costs of SOFCs to be $400/kW by 2010. Zogg et. al predicts that the installation costs would be two to three times higher. The cost targets made by SECA were made assuming that there is a successful market introduction with high production volumes around 500,000 units per year by a single manufacturer [25, p. 117].

SOFCs are expected to be used for high heating loads, such as data centers [12, p. 5]. Their maximum power output range is 200kW to 250kW.

2.2.5 Summary of Fuel Cell Types

Table 2-1 compares the PAFC, MCFC, PEMFC, and SOFC. The MCFC is able to obtain the highest electrical generation efficiencies, while the SOFC has the highest possible efficiency in a CHP application. The different characteristics of the fuel cell types are important for a designer to be aware of when making a fuel cell type selection. These characteristics will be referred to throughout the remainder of the report.

Table 2-1 Fuel Cell Types Comparison [D]

	PAFC	MCFC	PEMFC	SOFC
Electrolyte	Liquid phosphoric acid	Molten carbonate salt	Polymer exchange membrane	Solid metal oxide
Operating Temperature	390 - 430ºF (200 - 220ºC)	1200ºF (650ºC)	140 - 194ºF (60 - 90ºC)	1500 - 1800ºF (815 - 985ºC)
Reforming	External	Internal	External	External/Internal
Oxidant	O_2/Air	CO_2/O_2/Air	O_2/Air	O_2/Air
Efficiency (without cogeneration)	35 - 50%	50%	35 - 50%	45 - 60%
Maximum Efficiency (with cogeneration)	80%	90%	60%	85%
Maximum Power Output Range	400kW - 1MW	200kW - 2MW	250kW	200 - 250kW
Waste Heat Uses	Space heating or water heating	Excess heat can produce high-pressure steam	Space heating or water heating	Excess heat can be used to heat water or produce steam

CHAPTER 3 - Data Center Power

The required quality of a data center's power is essential due to society's high reliance on the services that data centers provide and the consequently extreme costs of downtime. This section of the report will discuss the required reliability and availability as well as the typical distribution design of data center power. The implementation of fuel cells into data center primary and secondary power supplies will also be presented.

3.1 Reliability & Availability of Power

Power of high quality is essential for data centers. If a data center experiences downtime, not only will the owner suffer financial losses, but also customer dissatisfaction, decreased brand loyalty, and less potential for future business [27, p. 712]. One hour of downtime can cost $6.45 million for a broker firm and $2.6 million for credit card sales [27, p. 712]. With these statistics, it is understandable that power reliability is a primary issue for data center management [28, p. 808].

Reliability is defined as the ability of a component or system to perform its intended function during a specific time [27, p. 713]. The target for data center reliability is "six nines," or 99.9999% [28, p. 810]. In order to achieve this high level of reliability, a redundant system is required. An analysis comparing the costs of redundant equipment versus the business losses needs to be done in order to determine how much the owner should spend on redundancy [27, p. 712].

Availability is defined as the ratio that describes the percentage of time that a component or system can perform its required function [27, p. 712]. Voltage variations affect computer and communications equipment just as if there were a power outage. Therefore, availability must include the time that the power supplied would not be within the tolerances of the IT equipment. Utility services typically do not include voltage sags, short power outages of less than a minute, or long power outages caused by natural events in their availability calculations. Because IT equipment is typically not able to immediately recover after a lack of power supply, additional downtime will be experienced, and data center owners need to be aware of this possibility. In fact, on average, it takes 16 hours for an internet data center to "completely resume normal operations due to the complexity of re-booting computers, re-starting processes, re-establishing high-speed communication links, re-synchronizing large corrupted databases, and so forth" [29,

p. 172]. The large amount of downtime due to an outage is just the reason why no data center connects to the electric grid without some sort of secondary power source [29, p. 172].

A power system's reliability can be determined by performing a probabilistic risk assessment (PRA). The IEEE Standard 493 "Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems," also known as the "Gold Book," provides data and the processes in which a PRA should be done. A PRA can be used to predict availability, number of failures per year, and annual downtime. This is done by considering the probability of failure of each piece of power equipment [30, para 7]. As may be expected, the opportunity to design a data center with high availability and reliability is greatest with a new facility [3, p. 28].

The NFPA 70 National Electric Code is now addressing the issue of reliability in Article 708. This is due to the Department of Homeland Security's requests to address critical operations (COPS) and how natural and man-made disasters can be survived. In addition, more than 15 technical manuals supporting reliability for government operations have been made by the US Army Corps of Engineers Power Reliability Enhancement Program (PREP) [3, p. 28].

3.2 Typical Power Distribution in Data Centers

Data centers are designed in order to accommodate the computers within them. Therefore, the power supply is backed up, the voltage is regulated, and necessary AC/DC conversions are provided [1, p. 18]. The components used in a typical data center power distribution system are multiple utility feeds, uninterruptible power supply (UPS) devices, automatic transfer switches (ATS), and generators. Diesel or natural gas generators could be used, depending on the reliability of the natural gas source and the space to store the diesel fuel. According to the "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431," more than 99% of network rooms and data centers use a UPS with local generators in their power distribution [1, p. 80].

Multiple utility feeds are often used in order to increase the reliability of the electrical system. Refer to Figure 3-1 for a typical data center's power distribution one line diagram. From the primary and secondary utility feeds and utility transformers (XFMRs), AC power is routed to ATS-1. The ATS-1 switches from the primary service feed to the secondary when it senses a lack of power. From the ATS-1, power is routed to the UPS. At the UPS, power is converted to DC in order to charge the batteries within the UPS. The power from the batteries is then converted back to AC power within the UPS. The UPS acts as a battery backup to the electrical system for short-term power outages and during the startup time required for diesel generators for long-term outages. The UPS is very beneficial for momentary outages, sages, surges, and other deviations from clean, in-phase sinusoidal power. UPS batteries are able to supply power up to 25 or 30 minutes [1, pp. 75 – 76; 31, para 7].

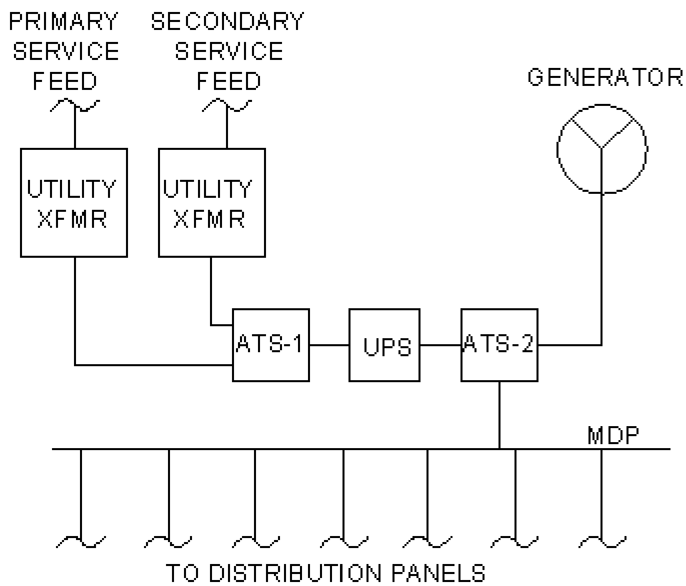


Figure 3-1 One Line Diagram: Typical Data Center Power Distribution

From the UPS, power is routed to the ATS-2, which is also connected to the generator. When the ATS-2 senses that there has been an interruption in utility power, it will automatically signal the generator to start. While the ATS is waiting for the generator to start up, the electrical load is met by the stored power in the batteries of the UPS. Once the generator is running, after about 10 to 30 seconds, the ATS-2 transfers the electrical load from the UPS to the generator. While emergency power is being supplied, the ATS-2 continuously protects against current feedback to the utility's system and monitors the status of the utility's power supply. When the utility power is back to steady state voltage and frequency, the ATS-2 returns the supply power to the utility connection. Then, the generator cools down and automatically shuts off [32, para 2-3; 1, p. 75].

From the ATS-2, power is supplied to a main distribution panel (MDP). The MDP then supplies power to various distribution panels that subsequently provide power for offices and the IT equipment.

The owner of the facility is able to choose whether or not the office area (non-IT equipment) will be supplied with uninterruptible power. This decision is dependent on the reliability requested for office equipment and the budget. Figure 3-2 shows another one-line diagram without the offices on emergency power. This one line diagram is very similar to the one shown in Figure 3-1. However, a UPS, ATS, and generator are serving only the IT equipment through the emergency distribution panel (EDP).

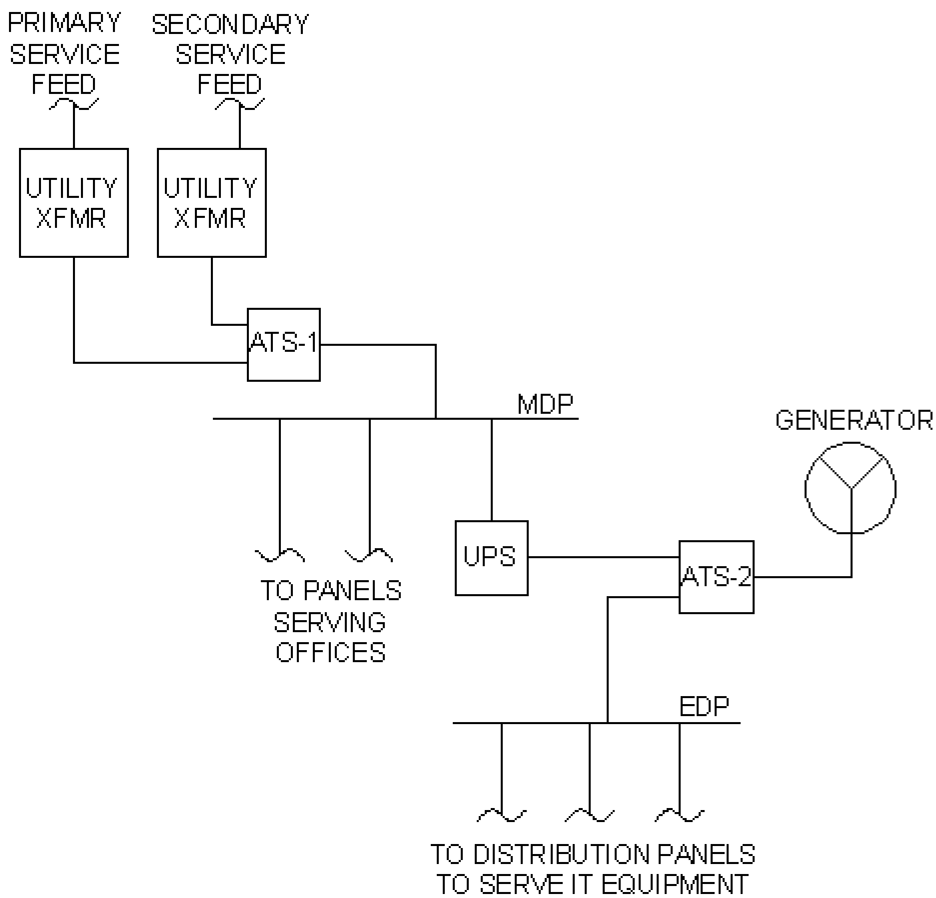


Figure 3-2 One Line Diagram: Typical Data Center Power with Partial Emergency Power

Only supplying emergency power to IT equipment and not offices will result in a smaller load that the generator and UPS batteries must accommodate. Of course, the decrease in size of the generator and UPS is dependent on the electrical loads of the IT equipment and office areas. If the loads of the IT equipment greatly outweigh that of the offices, it may be just as feasible to feed the offices with emergency power, as well.

3.3 Using Fuel Cells for Data Center Power

Fuel cells are able to act as a data center's primary power source or as the emergency power source. This section describes both of these power distribution methods.

3.3.1 Fuel Cells as Primary Power

Data centers have a near constant power demand and require a high degree of reliability, making them a good candidate for on-site power generation, such as a fuel cell system [2, p. 3-80]. A specific application where fuel cells should be considered for data centers is in an urban location, where costs are higher to upgrade power distribution. Utilizing on-site power generation for this type of application avoids grid transmission losses, which can reach 20% and are reflected in the electric utility costs [28, p. 808].

When a fuel cell is used as the primary power source, a utility connection or a generator can be used for backup power during a scheduled shutdown. Throughout the lifetime of a fuel cell, no planned outages are necessary for maintenance because all tasks can be performed during operation of the fuel cell system. The tasks that must be performed are changing fuel and water filters. Although, according to Frank Hagstotz of CFC Solutions GmbH, an MCFC manufacturer out of Munich, a shut down lasting one day is required to replace a fuel cell stack [23, p. 12-13].

A utility connection could be used to backup a generator, as well, in case the generator fails to start. However, the utility grid may not be able to provide the large scale of power neither in an acceptable time frame nor for a reasonable cost. Utility companies have little interest in providing backup power when it is used very infrequently. Therefore, they impose large cost penalties for this type of power use. These rates vary from state to state, and they can be high enough to prevent owners from installing fuel cells [28, p. 810; 1, p. 80].

Figure 3-3 shows a power distribution one line diagram with a fuel cell as the primary source and a generator supplying emergency power. Just like the typical power distribution design, UPS batteries are used to maintain the supply and quality of power during the switch from primary to secondary power [1, p. 80].

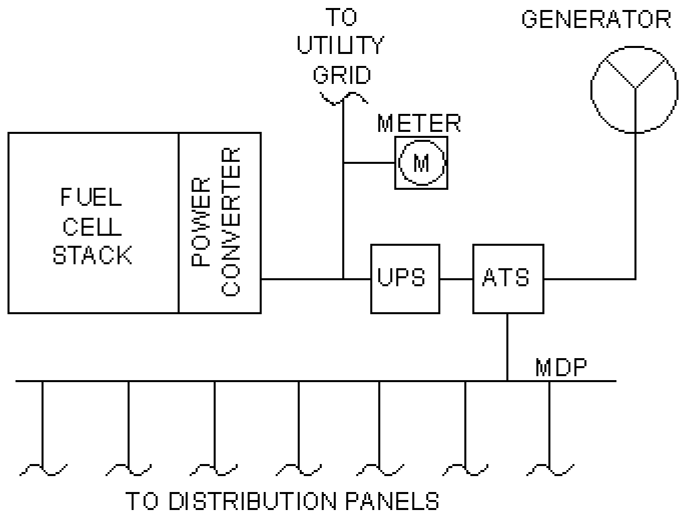


Figure 3-3 One Line Diagram: Fuel Cell Providing Primary Power

Where local utilities allow, a surplus of power produced by a fuel cell is able to be sold back to the grid. A metered utility connection is shown for this purpose in Figure 3-3. In recent years, the controls and coordination of selling back power has been complex. However, efforts are being made in many localities to simplify the process [2, p. 3-80].

When utility customers have on-site power generation that produces an excess of electricity, net metering allows their electricity meters to turn backwards. This means that the customer receives retail price for the excess electricity that they generate. Net metering programs are available in order to be an incentive to utilizing renewable energy generation. If net metering is not available, a meter is installed to measure the flow of excess electricity to the grid. These customers are then paid by the utility provider for the excess power, but at a much lower than retail rate [33, para 1].

With net metering, customers are able to build up credit for power that they can use at another time. This gives the customer more flexibility and allows them to maximize the value of their on-site power generation. Net metering is advantageous to utility providers, as well, when customers are producing excess power during peak use periods [33, para 2].

Net metering is currently available in 35 states [33, para 3]. The states that offer net metering with fuel cell systems are Arkansas, California, Connecticut, Delaware, District of Columbia, Georgia, Idaho, Illinois, Louisiana, Maine, Massachusetts, Montana, New Jersey, New Mexico, Ohio, Oregon, Pennsylvania, Texas, Washington, and West Virginia [34, p. 1-10].

3.3.2 Fuel Cells as Secondary Power

Because of the disadvantages associated with diesel generators, some data center owners are considering fuel cells for emergency power. The disadvantages associated with diesel generators include reduced system reliability from engines failing to start due to a lack of maintenance or testing, high amounts of emissions, and local complaints caused from visible smoke, noise, and odors [1, p. 80].

Fuel cells have a promising application of providing reliable backup power because users in the telecommunications industry may be willing to pay a premium for it. Although fuel cells may be costly compared to other back up power alternatives, the high reliability and ease of siting due to the low emissions of fuel cell systems could make them more attractive than conventional backup power systems [11, p. 48].

With a utility connection as the primary power source and fuel cells providing secondary power, the DOE has concluded that providing hydrogen tanks for the fuel cell's fuel supply is preferable over fuel reforming. Their reasoning is that starting a fuel reformer for backup power for every utility outage would be expensive and energy inefficient. Also, the start up times for all components would be extensive from having to reach operating temperatures. Additional battery storage would be necessary in order to provide power during this long start up time, which would increase capital costs, as well [35, p. 1]. Figure 3-4 shows four hydrogen storage tanks located outdoors. From the storage tanks, the hydrogen is routed in stainless steel tubing to fuel cells providing secondary power [36, p. 1].

Figure 3-4 Hydrogen Storage Tanks Located Outdoors [E]

High temperature fuel cells (>390°F or 200°C) are advantageous for CHP applications. However, low temperature fuel cells (<210°F or 100°C), such as PEMFCs, are advantageous for backup power applications because of their quick start up time and high power density [37, p. 3]. American Power Conversion (APC) manufactures a PEMFC for server backup power, namely the InfraStruXure™ with Integrated Fuel Cells system. They are installed in the server rack, as shown in Figure 3-5, and are available in 10kW modules. Up to three of APC's fuel cell modules can be installed in one rack, reaching a total of 30kW of power generated [36, p. 1].

Figure 3-5 Three APC Fuel Cells Installed in a Server Rack [F]

APC's InfraStruXure^{TM} with Integrated Fuel Cells system is aimed at providing emergency power for data centers where generators are impractical, such as high rise buildings. The maximum start up time of APC's PEMFC is very quick at just 20 seconds [36, p. 1-2].

While APC's fuel cell is operating, it charges the battery of an internal UPS. A single 10 kW fuel cell module requires a total of 13 kW. The UPS batteries are charged with 3 kW and the remaining 10 kW provides power to the IT equipment. One bottle of hydrogen (10 Nm^3) can provide a 10 kW fuel cell with 79 minutes of emergency power. A 30 kW configuration with 10 bottles of hydrogen can provide 4 hours and 24 minutes of runtime [36, p. 1-2].

This emergency power fuel cell system requires air and water management, too. Chilled water is required to cool the system as well as an air handling system to exhaust hot air and hydrogen byproducts from the fuel cell process. A drain line, typically one-inch in diameter, connected to the building's sanitary waste piping is needed in order to dispose of the water produced by the fuel cell. Because the rack mounted fuel cells will be used infrequently and they have low operating temperatures, they will not generate enough waste heat to be used in a CHP application [36, p. 1-2; 10, p. 1809].

Ideal applications for the APC fuel cell are small to medium data centers. These fuel cells are best suited for facilities that are restricted by building codes, emission requirements, or physical constraints [38, p. 1]. The APC fuel cell system is available and sells for $25,000 per 10 kW module, not including installation and setup charge, which is another $25,000. Therefore, a 30 kW setup would cost about $100,000. The average life of an APC fuel cell is 10 years with more than 5,000 stops/starts. They have comparable noise levels to larger fuel cells. At 3 feet away, the fuel cell's noise level at standby, idling, and full load are 45 dB, 60 dB, and 75 dB, respectively [36, p. 2].

Figure 3-6 shows a power distribution one line diagram with a rack-mounted fuel cell providing secondary power. This diagram is similar to Figure 3-2 in that it, too, provides emergency power to only IT equipment. From Distribution Panel 1 (DP1), power is routed to the rack mounted fuel cell. The fuel cell has an internal ATS; therefore, it will turn on automatically when needed. From the fuel cell, power is routed to the rack mounted power distribution unit (PDU), which is a power strip within the rack to plug IT equipment into [36, p. 2].

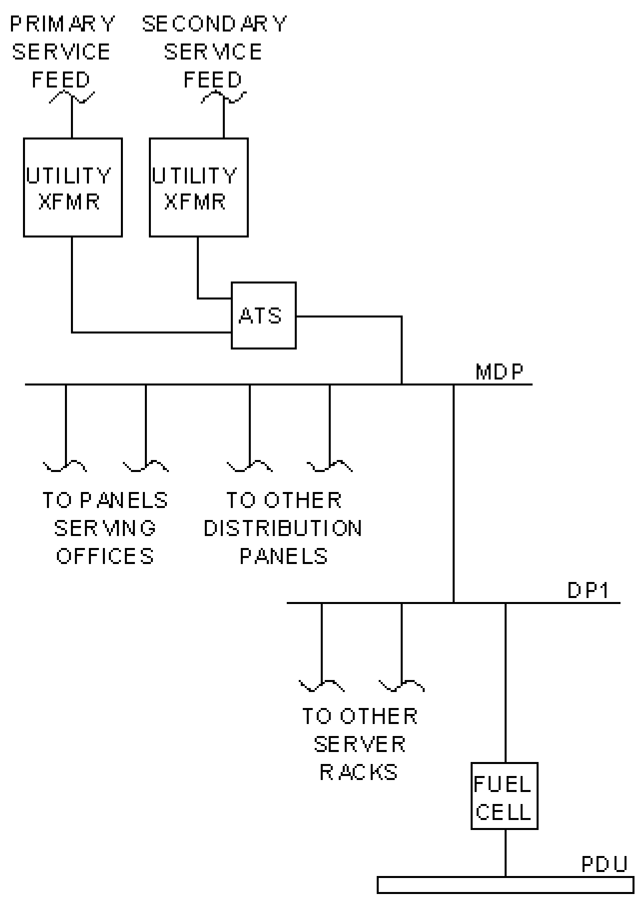


Figure 3-6 One Line Diagram: Utility Primary and Fuel Cell Secondary Power

Rack mounted fuel cells can also provide secondary power to a fuel cell system providing primary power. A one line diagram of this design is shown in Figure 3-7. As with the system shown in Figure 3-3, this design is capable of selling excess power to the utility company through its connection to the grid. Because the fuel reformer is located within the packaged fuel cell stack providing primary power, it would also be shut down during scheduled maintenance. Therefore, bottled hydrogen storage is still required for this design in order to fuel the rack mounted fuel cells.

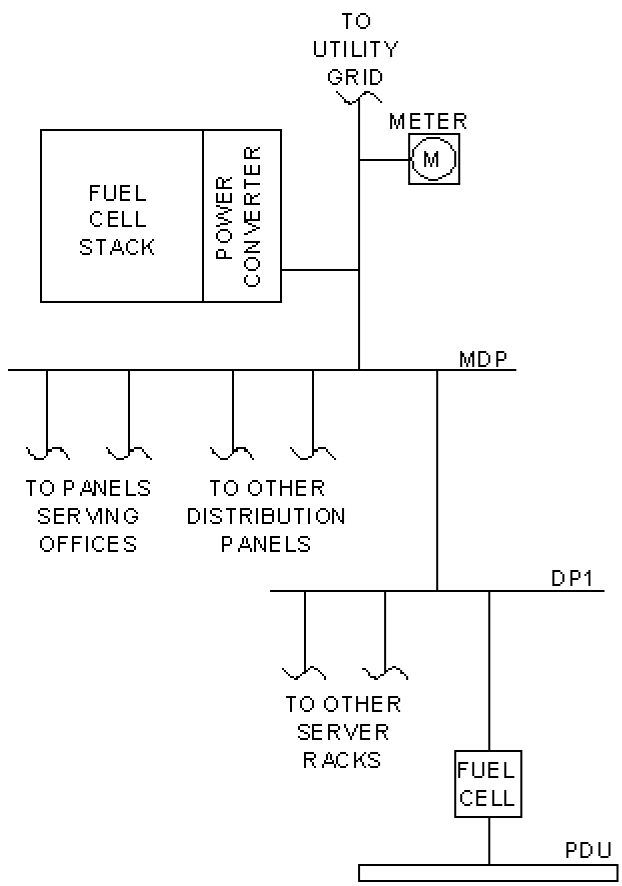


Figure 3-7 One Line Diagram: Fuel Cell Primary and Secondary Power

CHAPTER 4 - Fuel Cell Combined Heat and Power Systems

Combined heat and power systems use similar configurations as typical HVAC systems. However, CHP systems utilize the waste heat produced by the on-site power generation in order to meet heating and cooling loads with thermally-activated equipment. Data centers are an ideal application for CHP because they have constant power and cooling loads [1, pp. 73-74; 20, p. 1-6].

The responsibility of a data center's cooling system is to maintain specific temperature and humidity requirements of the IT equipment. If the requirements are not met, the reliability of the IT equipment is reduced [1, p. 22]. All of the power that is supplied to IT equipment is converted to heat and ejected into the space surrounding the equipment [39, p. 1]. With large heat gains from IT equipment, it is no surprise that the power required for data center HVAC systems is anywhere from 40% to 60% of the total power supplied to the facility [40, para 8].

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Technical Committee 9.9 (TC 9.9) provides recommended design temperatures for data centers. During the 2009 Annual ASHRAE Winter Conference held in Chicago, the ASHRAE TC 9.9 decided that the dry bulb temperature range at the server inlets should be between 65ºF and 80ºF, opposed to the stricter 68ºF to 77°F range they had previously agreed on. According to the technical session "Dissipated Data Center Heat through Polymer Indirect Evaporative Coolers" by Keith Dunnavant at the same ASHRAE conference, servers manufactured by IBM are able to function with supply air temperatures ranging from 60ºF to 90ºF [41]. The ASHRAE TC 9.9 had recommended a relative humidity design level range of 40% to 45% for data centers in the past. However, ASHRAE TC 9.9 is now suggesting that dew point levels, opposed to relative humidity levels, should be measured instead, falling in the range of 42ºF to 59ºF. Also at the 2009 Annual ASHRAE Winter Conference, the committee decided that measuring the dew point is a more accurate measurement for data center facilities. The supply air and dew point conditions are required year round, day and night [42, p. 1].

Heat recovered from fuel cells in the form of hot water or steam can be used to power absorption chillers [20, p. 6-1]. The chilled water produced by absorption chillers can be used to serve computer room air conditioning (CRAC) units in order to condition the data center [1, p. 80]. This application will be discussed later in this chapter. The typical HVAC system applied to data centers will first be reviewed in order to make comparisons to a fuel cell CHP system.

4.1 Typical HVAC Systems in Data Centers

Cooling for data center facilities is typically provided by CRAC units supplied with chilled water from an electric chiller and cooling tower system, as shown in Figure 4-1. During low ambient conditions, the condenser water may not need to be routed through the fill material. In this case, a bypass valve directs the condenser water return directly to the basin of the cooling tower where the water is sufficiently cooled and then returned to the chiller. The condenser water must be treated with glycol or basin heaters must be installed to prevent freezing. Another design alternative is to use CRAC units with "refrigerant to exchange the heat with water cooled condensers that are tied into cooling towers for heat removal" [43, p. 14].

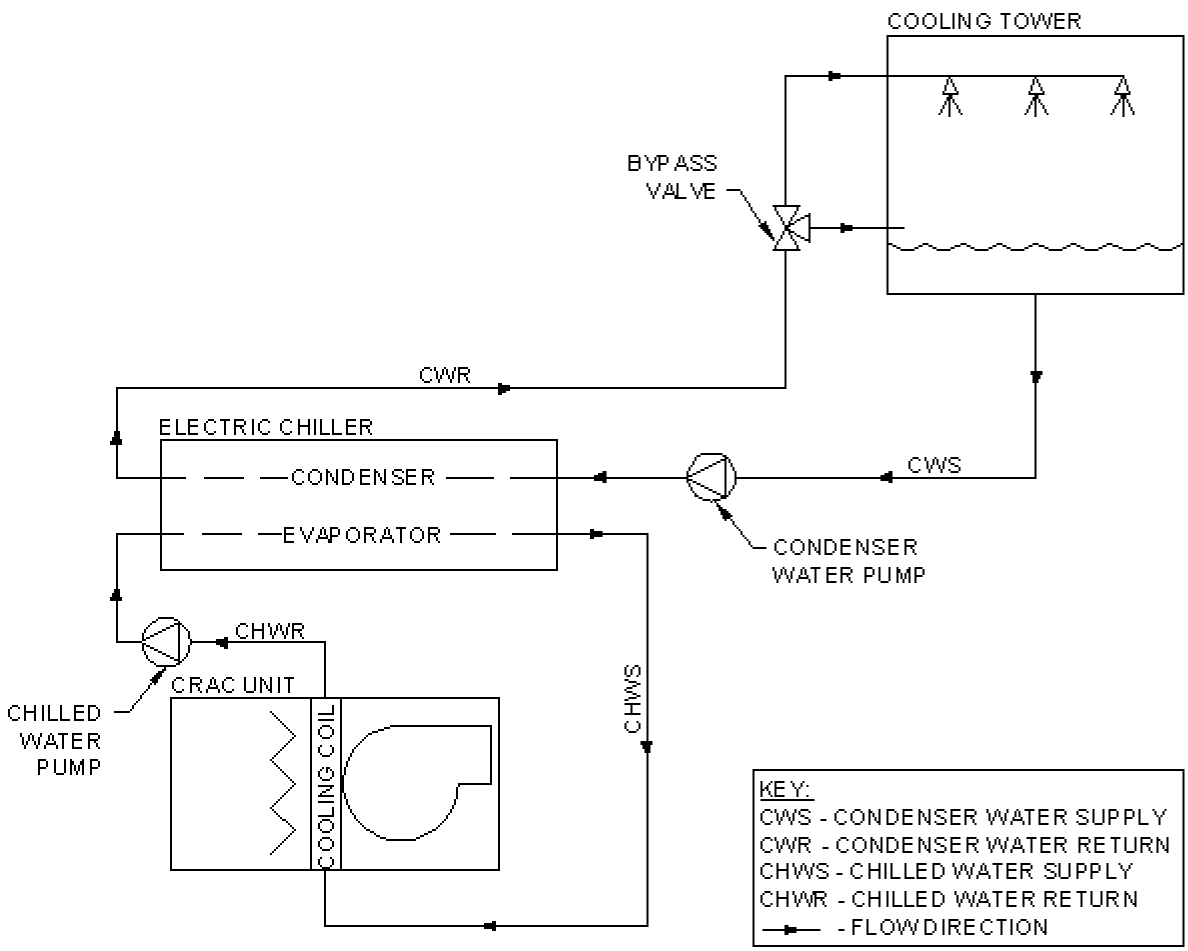


Figure 4-1 Diagram of Condenser and Chilled Water Piping for Electric Chiller

Chilled water supply temperatures vary from 45°F to 50°F, depending on the cooling coil design of the CRAC [39, p. 1]. The down flow CRAC unit is placed inside the data center on a raised floor. Cold air is distributed to the IT equipment below the raised floor and through perforated floor tiles [1, p. 19]. Cooling system backup has typically been N+1 for data centers. However, it may become more common to have a 2N+1 system in the future due to the power density increases in server equipment [44, p. 3].

In order to improve the performance of a data center's HVAC system, the hot-aisle/cold-aisle arrangement is often used. As shown in Figure 4-2, only the cold aisles have perforated tiles to supply air. The backsides of racks, which eject the heat produced by the equipment, face each other to form the hot aisle. This configuration reduces the mixing of cold supply and hot return air, resulting in more efficient cooling [45, p. 4].

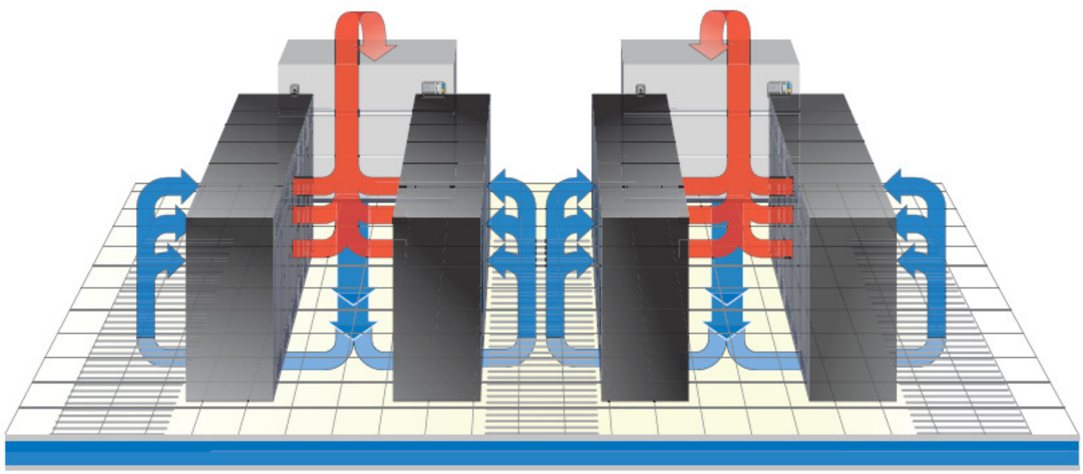


Figure 4-2 Hot-Aisle/Cold-Aisle Layout [G]

Servers quickly overheat and will automatically shutoff in an unconditioned space. Therefore, supplying chillers with backup power is essential. If a chiller is knocked offline, it may take too long for it to reach its cycle in order to provide proper cooling for IT equipment. The best way that redundancy and efficiency is achieved is with multiple, smaller chillers with emergency power supplies [46, para 5].

In a data center facility, ventilation provided can be minimal to none. Generally, the only outdoor air that is supplied to the server areas is through infiltration from adjacent zones, such as offices. This small percentage of outdoor air is necessary in order to create a positively pressurized space [1, p. 19].

4.2 Fuel Cell Combined Heat and Power System Applications

The byproducts of a fuel cell's electrochemical reaction are heat and water. The water produced is minimal and amounts to water vapor that is present in the waste heat [47]. The overall value of the fuel cell system is greatly increased if the waste heat is utilized. A CHP system increases the fuel cell's fuel efficiency while decreasing the power required for air conditioning equipment [24, p. 533]. Supplying power alone, fuel cell efficiencies range from 35% to 50%. When used in a CHP application, fuel cell efficiencies can reach up to 90% [20, p. 5-11].

Fuel cell systems are manufactured with low grade and/or high grade heat exchangers in order to recover the waste heat [48, p. 144]. High grade waste heat is available from high temperature fuel cells, such as the PAFC, MCFC, and SOFC. This high grade waste heat can be used in hot water and steam producing heat recovery applications such as absorption chillers to produce chilled water [48, p. 143]. The low grade waste heat can be applied to supplementary heating of domestic water to serve plumbing fixtures. A schematic showing a fuel cell system with both high and low grade heat exchangers being applied is shown in Figure 4-3.

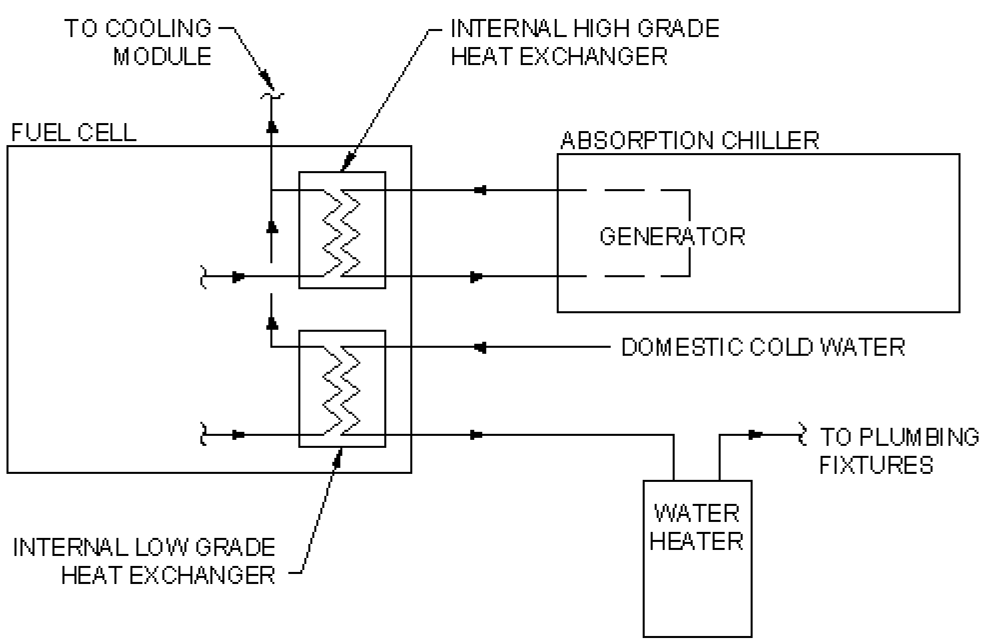


Figure 4-3 Diagram of Waste Heat Applications

From the heat exchangers, excess waste heat is delivered to the fuel cell system's cooling module, where the heat is rejected. For example, UTC Power's PureCell Model 400 has an accompanying dry cooler that rejects unused waste heat.

Table 4-1 shows the waste heat temperatures and available heat recovery from UTC Power's PureCell Model 400 and FuelCell Energy's DFC Model 300.

Table 4-1 Fuel Cell Low and High Grade Heat Recovery [H]

Fuel Cell	Fuel Cell Type	Power Generation (kW)	Heat Recovery			
			Low Grade		High Grade	
			Temperature (ºF)	Heat Available (Btuh)	Temperature (ºF)	Heat Available (Btuh)
PureCell 400	PAFC	400	140	1,708,000	250	785,000
DFC300	MCFC	300	120	808,000	250	480,000

(Btuh = British Thermal Units per hour)

4.2.1 Using Absorption Chillers in a Fuel Cell CHP System

In a fuel cell CHP system, an absorption chiller replaces the electric chiller in the diagram shown in Figure 4-1. Opposed to the vapor compression cycle used by electric chillers, energy from waste heat drives an absorption refrigeration cycle within the absorption chiller [20, p. 2-9]. Thermal energy is transferred from the heat source to the heat sink through an absorbent fluid and a refrigerant. A common refrigerant-absorbent combination used for absorption chillers is water-lithium bromide. The chiller refrigerates by absorbing and releasing water vapor into and out of the lithium bromide solution [49, p.1; 20, p. 7-4].

The cooling process of a single-effect absorption chiller is shown in Figure 4-4. Heat is first supplied to the generator. Water vapor produced at the generator is driven off to the condenser. Cooled water vapor is passed through an expansion valve, which reduces its pressure. From there, the vapor is supplied to an evaporator. The actual cooling takes place in the evaporator where ambient heat is added from the chilled water return. The heated, low pressure vapor then travels to the absorber, where it combines with lithium bromide and becomes a low pressure liquid. This solution is then pumped to a high pressure and into the generator to repeat the process [49, p.1].

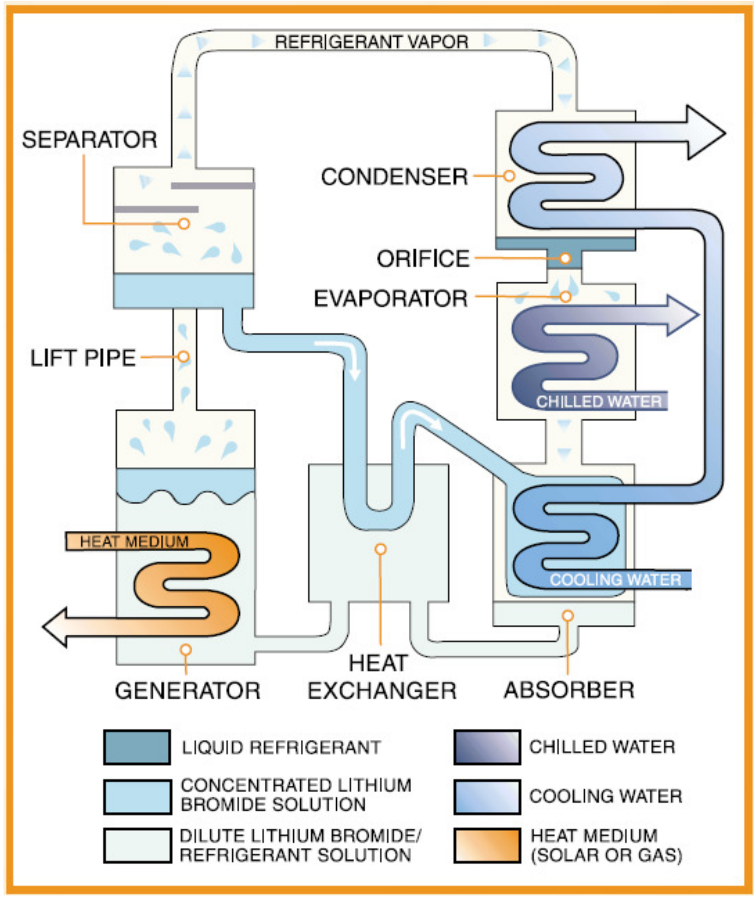


Figure 4-4 Single-Effect Absorption Chiller Cooling Process [I]

Absorption chillers are classified by the number of generators they have. There are single, double, and triple-effect absorption chillers. However, triple-effect absorption chillers are still under development. The selection of an absorption chiller configuration is determined by the waste heat temperature. The waste heat temperature must be high enough to generate refrigerant vapor in the absorption cooling cycle [49, p.1; 20, p. 7-18].

Waste heat in the form of steam or hot water can be supplied to an absorption chiller. A single-effect absorption chiller requires high temperature hot water near or above the boiling point (under pressure). Approximately 17,000 Btuh of high temperature hot water or low pressure steam serving a single-effect absorption chiller is able to produce one ton, or 12,000 Btuh, of cooling. Double-effect absorption chillers require 10,000 Btuh of steam in order to produce one ton of cooling [50, p.1; 1, p. 81].

Fuel cells that produce waste heat capable of producing hot water or steam to be used with either single or double-effect absorption chillers include the SOFC and the MCFC. If the high temperature heat recovery option is selected, UTC Power's Purecell Model 400 can produce 250ºF hot water to be used with a single-effect absorption chiller. PEMFCs do not produce waste heat with high enough temperatures to serve an absorption chiller [1, p. 81; 50, p.1].

The amount of waste heat produced by a fuel cell may not be sufficient for an absorption chiller to meet a data center's cooling needs. Neither of the fuel cells listed in Table 4-1 are able to provide enough waste heat in order to cool a data center. Table 4-2 gives details as to how this conclusion was made.

Table 4-2 Waste Heat Required from Fuel Cells to Provide Cooling

Fuel Cell	Fuel Cell Type	Power Generated (kW)	Heat Generated by Electrical Equipment (Btuh)	Waste Heat Required for Cooling with Single-Effect Absorption Chiller (Btuh)	Heat Recovery Available (Btuh)
					High Grade
PureCell 400	PAFC	400	1,364,800	1,933,467	785,000
DFC300	MCFC	300	1,023,600	1,450,100	480,000

Consider the PureCell 400. First off, it is known that all of the power that is supplied to a building is converted to heat and ejected into the surrounding space. Running at 100% load, this fuel cell would provide 400 kW of power to electrical equipment. This is equal to a cooling load of 1,364,800 Btuh, using a conversion factor of 1 W per 3.412 Btuh. This cooling load is based completely off of the heat gain from electrical equipment. The actual cooling load of the data center would be larger than this value because it would include the heat gain from people and the building's external loads. If a single-effect absorption chiller were to be used with the PureCell 400, a total of 1,933,467 Btuh of waste heat would be necessary to satisfy the electrical equipment cooling load. This value was calculated assuming 17,000 Btuh of waste heat would be necessary to provide 12,000 Btuh of cooling. According to the PureCell 400 data sheet, this fuel cell is only able to produce 785,000 Btuh of high grade waste heat. The values in Table 4-2 were calculated in the same manner for the DFC300. Neither of the fuel cells presented in Table 4-2 are able to provide enough waste heat to serve a single-effect absorption chiller. Therefore, a form of supplementary cooling is necessary.

There are a few options to choose from to supply supplementary cooling. The first option is to install electric chillers. These chillers would be powered by the fuel cells and connected to an emergency power supply. The other option would be to install boilers to make up for the lack of heat needed to power the absorption chillers.

If boilers are used to supply supplementary heat to the absorption chillers, they will cycle on and off as the cooling load varies. When operating parameters are met, the boiler operating controls will shut off fuel flow [51, p. 27.6]. There is a time lag associated with the on-cycle of boilers, which is due to several necessary steps: a firing interval, a post-purge, an idle period, a pre-purge, and then return to firing [52, para 3]. The purge cycle is necessary before each on-cycle because it assures that there is no accumulation of explosive gases in the boiler's fire box. Not only is there a time lag during their start-up, but boilers are least efficient at the start of the on-cycle [53, para 3].

During normal operation of the HVAC system, the fuel cell will always provide waste heat to the absorption chillers, as it must continually operate in order to provide power to the facility. However, if the fuel cells are shutdown for maintenance or fail, their waste heat will not be available to power absorption chillers. If electric chillers are used for supplementary cooling, then boilers could be used to provide heat to absorption chillers during a fuel cell outage. This is a viable option because the boilers would be running continuously, avoiding the on-cycle drawbacks.

4.2.1.1 Absorption Chillers versus Electric Chillers

There are several differences between electric and absorption chillers that data center owners should be aware of if they install this type of fuel cell CHP system. Besides the differences in their compression cycles, the pumping, cooling tower size, and cost of the overall system is effected depending on the chiller type used.

Cooling towers in absorption chiller systems require approximately 3.6 gallons per minute (gpm) of condenser water per ton. The typical difference in condenser water entering and leaving temperatures ranges from 15°F to 20°F with an outdoor wet bulb temperature of 78°F. With electric chillers, 3 gpm of condenser water per ton is common with a 10°F temperature change at a 78°F wet bulb temperature. Therefore, a larger cooling tower capacity and more pumping power are required for absorption chillers in comparison to standard electric chillers [54; 50, p.1; 1, p. 80].

Electric chillers use motor-driven compressors that require a significant amount of power. In fact, electric chillers typically consume the largest percentage of data center power and account for considerable portions of annual energy budgets [46, para 2]. Absorption chillers use less electricity, about 0.02 kW per ton, compared to 0.47 kW up to 0.88 kW per ton for an electric chiller, depending on the type of compressor. However, compared to electric chillers, absorption chillers have higher initial costs and are not as widely available. Between the single and double-effect chillers, first costs are usually the highest with the double-effect type. However, double-effect chillers are more energy efficient than the single-effect type, resulting in lower energy costs [49, p.1; 20, p. 2-9].

Absorption chillers are also advantageous in that they are highly reliable and have quieter operation in comparison to electric chillers. They also have less maintenance due to fewer moving parts [20, 7-18].

4.2.1.2 Absorption Chillers Serving CRAC Units

Using an absorption chiller in a data center's cooling system is very similar to an electric chiller system, as shown in Figure 4-5. In comparison to the electric chiller condenser and chilled water piping diagram in Figure 4-1, the only difference is the type of chiller being used. Cooling during the winter season is done in the same manner as previously described for Figure 4-1.

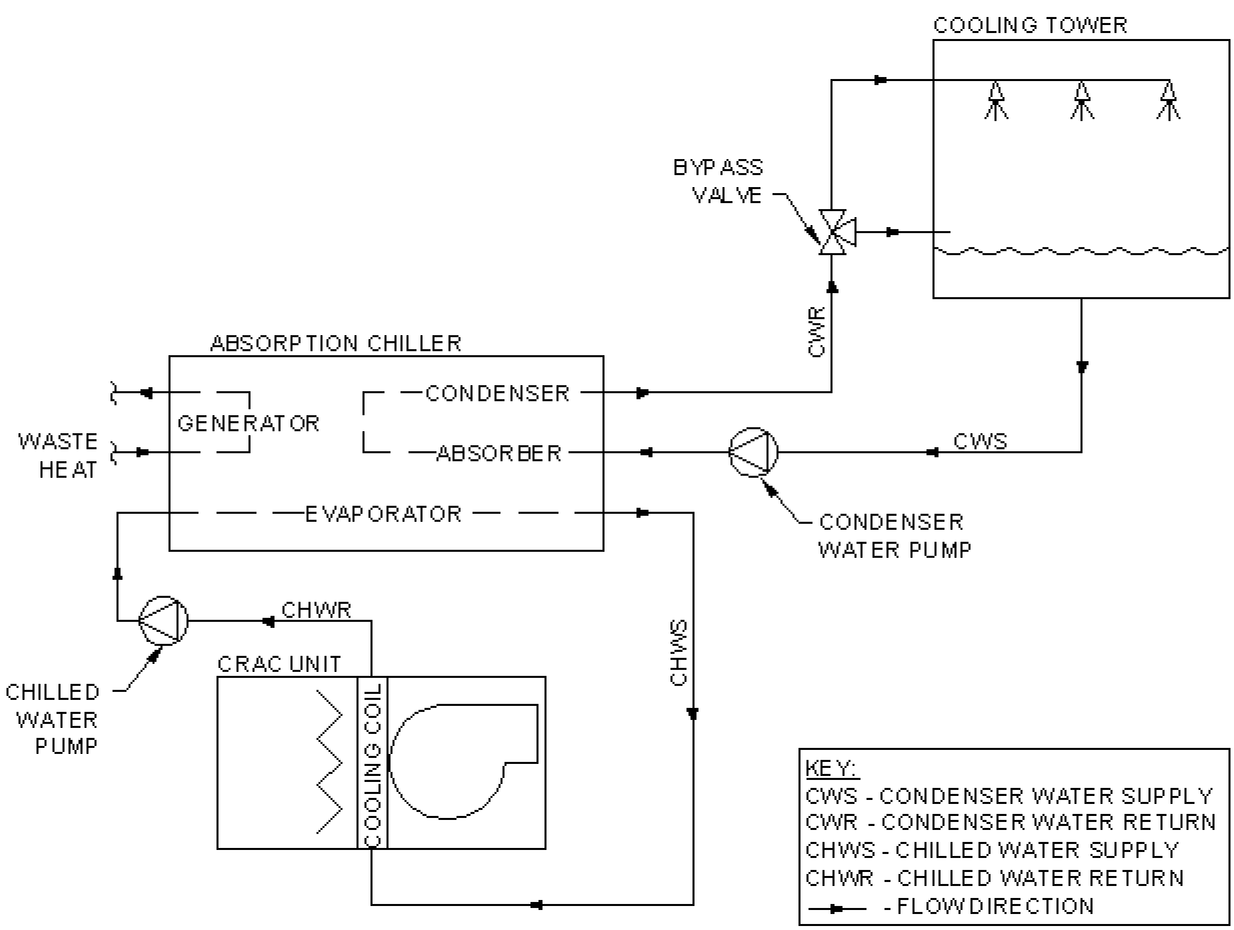


Figure 4-5 Diagram of Condenser and Chilled Water Piping with Absorption Chiller

4.2.2 Domestic Water Heating in a Fuel Cell CHP System

The low grade heat exchanger within a fuel cell system is able to provide pre-heating for domestic hot water. Double wall heat exchangers are available from fuel cell manufacturers in order to ensure that the potable water is not contaminated.

The output temperature of the domestic water from the heat exchanger will vary, depending on the electrical load that the fuel cell is supplying. Data centers may not have very many uses for domestic hot water other than restroom lavatories, service sinks, and break room sinks. In this case, the full heat recovery from the low grade heat exchanger may not be needed. Without the full use of heat recovery, the fuel cell's overall efficiency will not reach the maximum of 85% or 90%, as outlined in section 4.2.

For example, in the book "Combined Heating, Cooling, & Power: Handbook," a hotel's CHP system with a 100kW fuel cell system yields 259,000 Btuh of low-temperature hot water with a temperature ranging from 104ºF to 122ºF. If this system recovers all of the waste heat (both high and low temperature), then the system can reach an efficiency of 89%. Without any low grade waste heat recovered, the CHP system efficiency would drop to 60%. Even in a hotel setting, where there are multiple showers, lavatories, service sinks, and kitchen plumbing fixtures that require hot water, the author states that recovering all of the low temperature waste heat would be difficult. Data center owners and designers alike need to be aware of these lower CHP efficiency levels when determining whether or not a fuel cell CHP system will be installed [55, p. 475].

CHAPTER 5 - Advantages of Fuel Cells used in Data Centers

Fuel cells offer several advantages for data centers in comparison to receiving power from the utility grid. Low noise levels, low emissions, increased reliability, increased efficiency, modularity, low maintenance, tax incentives, and obtainable LEED points are reasons that make fuel cell systems attractive. This chapter will explain each of these advantages.

5.1 Low Noise Levels

Fuel cells have a low noise level that enables them to be located near or inside the data center facility. As seen in Appendix B, UTC Power's PureCell Model 400 has a noise level less than 65 dBA (decibels on the A-weighted scale) at a distance of 33 feet from the equipment. This value decreases to 60 dBA when full heat recovery is utilized [56]. As a reference, that is approximately the same sound level that a vacuum cleaner produces, as shown in Figure 5-1. The noise level of FuelCell Energy's DFC300 can be as low as 72 dBA at 10 feet from the equipment [57, p. 2]. UTC Power suggests that the fuel cells are quiet enough that they could be placed indoors without any soundproofing [58; 59].

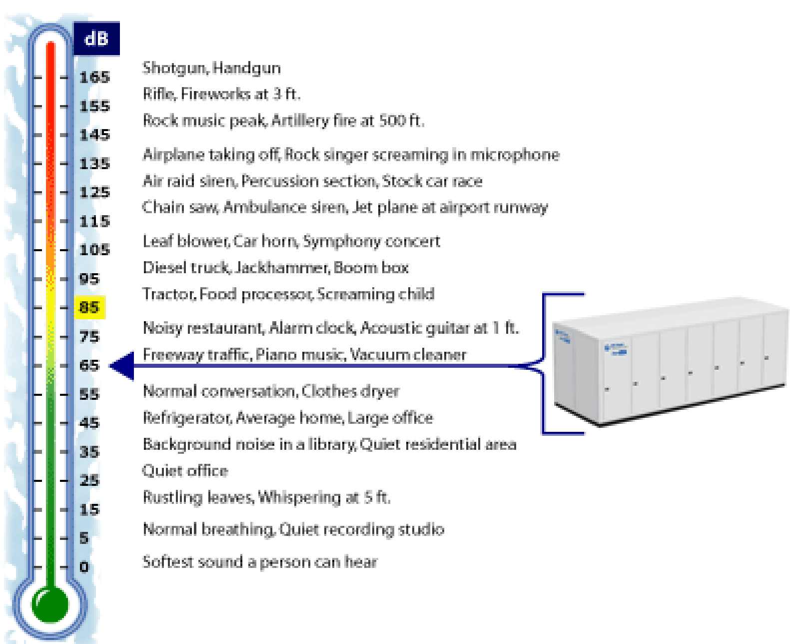


Figure 5-1 Sound Level of UTC Power's PureCell Model 400 System [J]

Low noise levels offer flexibility in data center siting. Because they are so quiet, fuel cells are able to be placed within close proximity of the load. This practice has been proven successful in the designs of hospitals, housing facilities, and New York City's Police Department near Central Park. The low noise levels are also beneficial to maintenance workers because hearing protection is not required [58; 10, p. 7].

5.2 Low Emissions

According to the US Environmental Protection Agency (EPA), emissions from data center energy use has doubled from the year 2000 to 2006 and have risen to be 1.5% of the country's total emissions. If this rate of growth continues, data centers will surpass the airline industry in emissions by the year 2020 [3, p. 30]. With their low emissions, fuel cells are able to slow down the increasing rate of data center emissions.

The low emissions of fuel cells are attributed to the fact that they produce electricity without combustion. The emissions produced from fuel cell systems are given off at the fuel processor. The chemical reactions that occur during the fuel reforming process produce carbon, nitrogen, and sulfur oxides. However, if pure hydrogen is used, there are zero emissions since there would be no need for fuel reforming [11, p. 45; 20, p. 2-6, p. 5-11].

California's Air Resource Board is focused on reducing the air pollution emissions from vehicles, fuels, factories, and power plants. CARB creates standards to increase air quality in order to benefit the health of people and the environment. The CARB standards set limits on the concentration level of air pollutants and the time that a pollutant can be present in the air before it can begin to cause health problems for the general public [60, p. 1]. There are also federal standards given in the Clean Air Act. Currently, the CARB standards are more stringent than those of the Clean Air Act [61, p. 1].

Fuel cell emissions are much lower than those of conventional combustion systems and well within air quality regulations [13, p. 8]. The emissions from fuel cells are dependent on the type of fuel processor and the source of fuel. According to the UTC Power PureCell Model 400 data sheet in Appendix B, this fuel cell meets the 2007 CARB standards. The PureCell Model 400 with natural gas supply emits 0.035 pounds per megawatt-hour (lb/MWh) of nitrogen oxides. The PureCell Model 400's sulfur dioxide emissions are so low that the data sheet doesn't give a value, but rather says that the amount is negligible [56]. According to the DFC300 data sheet, it only emits 0.01 lb/MWh and 0.0001 lb/MWh of nitrogen oxides and sulfur oxides, respectively, when supplied natural gas [57, p. 2]. The emissions of the DFC300 also meet the 2007 CARB standards [22, para 11].

Table 5-1 was taken from the "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431" and compares the emissions of a PEMFC and a diesel generator. The first set of data is the amount of pollutant that would be emitted per hour of equipment use. In one hour, the diesel generator would emit 20.282 lb/MW of nitrogen oxides, while the PEMFC would only emit 0.100 lb/MW. The second set of data is the total emissions that the PEMFC and diesel generator would emit if they were used to backup power for 24 hours in one year. It should be noted that in this comparison, the diesel generator has a much larger power generating capacity of 600 kW compared to the 150 kW of the PEMFC. However, if multiple PEMFCs were used to provide 600 kW of power, the total emissions from the PEMFCs would still be much less than those of the diesel generator [1, p. 78].

Table 5-1 Emissions of a PEMFC versus a Diesel Generator [K]

	PEMFC	Diesel Generator
Capacity, kW	150	600
Heat Rate, Btu/kWh	9,750	10,000
Emissions Factors		
NO_x, lb/MWh	0.100	20.282
SO_2, lb/MWh	0.006	2.900
CO_2, lb/MWh	1,170	1,650
Annual Emissions (based on 24 hours of operation per year)		
NO_x, lb/MW-year	2	487
SO_2, lb/MW-year	0.14	69.60
CO_2, ton/MW-year	14	20

(NO_x = Nitrogen Oxides, SO_2= Sulfur Dioxide, CO_2 = Carbon Dioxide)

5.3 Increased Reliability

As discussed in section 3.1, the reliability of primary and secondary power for data centers is crucial in order to maintain business and avoid major losses. The typical data center is equipped with emergency generators to provide backup power in the case of a grid disturbance or short term outage. However, generators are only designed to provide power for an intermittent use and have reduced reliability from engines failing to start [29, pp. 170-171]. As seen in Figure 5-2 well maintained generators fail to run for 24 hours 15% of the time. In order to increase diesel generator reliability, data centers have redundant generators [62, p. 6].

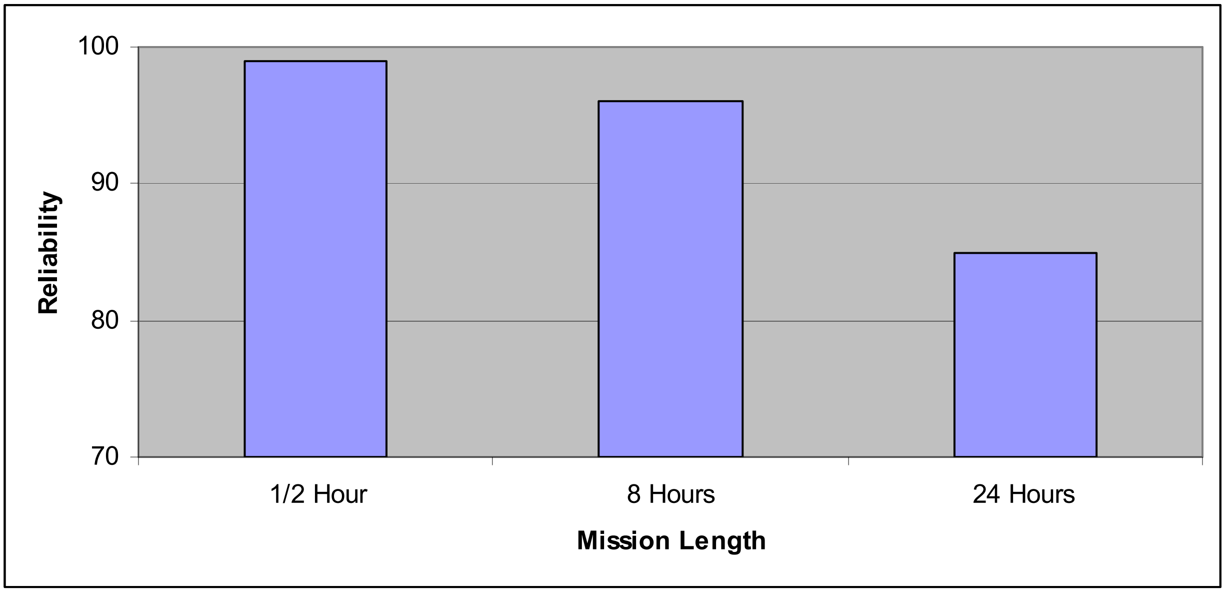


Figure 5-2 Reliability of a Well-Maintained Diesel Generator [L]

Proper maintenance must be done to the generator in order to maintain proper functioning after start up. The maintenance includes changing lubrication oil and replacing oil, fuel, and air filters regularly. This is one advantage that fuel cells have over engine generators. They have minimal moving parts, which increases their reliability because there is low risk of mechanical breakdown. The FuelCells.org website states that, if maintained, fuel cells can reach up to 99.9999% reliability [62, p. 6; 63, para 3;64, para 7].

5.3 High Efficiency

Since the 1960s, the average electrical generation efficiency of power plants in the US has been about 32%. Most of the energy supplied by the fuel is lost in waste heat at the power plant. Additional losses occur as power is distributed on transmission lines, which are reflected in power costs. The inefficiencies of power plants have encouraged development of on-site generation, such as fuel cells, because a greater amount of energy can be extracted from the supplied fuel [12, p. 2; 20, p. 1-1; 65, p. 5; 28, p. 808].

Fuel cell systems have much higher efficiencies than the traditional power plant. As shown previously in Table 2-1, fuel cells have electrical generation efficiencies ranging from 35% to 60%. The fuel-to-electricity efficiency can increase if the fuel cell system is fueled by hydrogen, taking away the need for fuel reforming. In a CHP application, the fuel cell's waste heat can be used instead of exhausted to the atmosphere. Efficiencies can reach as high as

90% with a MCFC CHP system. In addition, the efficiencies of fuel cells remain high even when the loads vary from design loads [64, para 5; 10, p. 1813].

5.4 Modularity

Fuel cell stacks are assembled from individual fuel cells, making them very modular and available in a wide range of capacity. Fuel cell stacks can be linked together until the desired power output is obtained. For example, Verizon chose to install UTC Power's PureCell Model 200 fuel cells in their call routing center in Garden City, NY. Seven of these fuel cells were installed in order to reach an electrical output of 1.4MW. Figure 5-3 shows the installation of these seven fuel cells [10, p. 1813; 66, p. 1].

Figure 5-3 UTC Power's PureCell Model 200 Fuel Cells at Verizon Call Routing Center [M]

In addition to modularity of power output, fuel cells offer data center operators much more flexibility in both expansion and design of new facilities. The utility grid may not be able to offer a large enough power supply to feed a data center's loads. It is becoming more difficult to site new power plant supply infrastructure as a result of congestion and the opposition of transmission line and substation neighbors. It can take years to gain approval for construction of new facilities. Therefore, some transmission and distribution lines are becoming overloaded, which leads to concerns of decreased reliability during the hours of peak electrical demand. Expansion and facility development of a data center may be achievable on a quicker schedule than when relying on an existing utility grid. If a data center is able to minimize their power demand on the utility grid, then utility facility expansions and associated costs could be avoided as well [50, p.1; 12, p. 2].

5.5 Minimal Maintenance

Due to their few moving parts, fuel cell systems require minimal maintenance. This has been demonstrated in multiple PAFC system installations, where maintenance issues associated with the stack were nearly nonexistent. The fuel cell stack does not require maintenance until the end of its life when it needs to be replaced. The fuel reformer and fuel supply system require an inspection and maintenance once a year. The tasks that must be performed are changing fuel and water filters. As mentioned in section 3.3.1, no planned outages for maintenance are necessary throughout the lifetime of a fuel cell because all maintenance can be performed during operation of the fuel cell system. Of course, a planned shutdown must be made for the replacement of the fuel cell stack at the end of its lifetime [14, p. 1.1172; 10, p. 1814; 20, p. 5-11; 23, p. 12].

5.6 Tax Incentives

Fuel cells have a long payback period; therefore, justifying the investment in the system could be difficult. However, incentive programs are available on the federal level and in some states to aid in the feasibility of installing a fuel cell system. Including state and utility incentives, ten years is the estimated payback period for a fuel cell in a CHP configuration. However, some data centers are able to have much shorter payback periods. As an example, Fujitsu received large rebates from their local utility supplier, Pacific Gas and Electric, for their data center in Sunnyvale, California. Because of these large rebates, Fujitsu is expecting to recover the costs of its fuel cell system in 3.5 years [1, p. 73-74; 50, p.1; 67, para 5].

Congress passed, and President Bush signed, an eight year extension to the Investment Tax Credit for fuel cell technology on October 3rd, 2008. This tax credit extension has been a top priority for the fuel cell industry, as it has expected to accelerate the commercialization of fuel cell technology. The extension was influenced by the DOE's report that the commercialization of fuel cells could generate 675,000 new jobs in the US over the next 25 years [68, p. 1; 69, p. 1].

This tax credit gives business property owners credit for 30% of the system cost with a maximum of $3,000 per kW. The fuel cell must have a minimum capacity of 0.5 kW and an electrical efficiency of 30% or more. This tax credit entitles the business owner to subtract the amount of credit, dollar for dollar, from their total federal tax liability. This tax credit is valid until December 31st of 2016 [69, p. 1].

There are currently 24 states plus the District of Columbia that have a renewable portfolio standard policy that requires electricity providers to produce a minimum percentage of their power from renewable energy resources. Rebates are offered for several types of renewable energy technologies, including fuel cells [70, para 2]. For complete and detailed information on fuel cell incentives offered by states, visit the Database of State Incentives for Renewable Energy site, www.dsireusa.org [71]. Areas of the US that have high electricity costs and/or high demand fees may still be able to benefit economically without state or utility supplier incentives [1, p. 80].

5.7 Obtainable LEED Points

There are several federal agencies, including the EPA, the DOE, and the General Services Administration, that are focused on the development of data centers. There are also programs such as Energy Star, US Green Building Council (USGBC), Green Globes, and Green Grid that are focused on the energy use and efficiency of data centers [3, p. 30].

In December of 2008, Lawrence Berkeley National Labs (LBNL) released a draft for a USGBC Leadership in Energy and Environmental Design (LEED) rating system for data centers. The credits in this data center rating system are more specific to the energy and environmental impact of this type of facility. The draft, named the Environmental Performance Criteria (EPC) Guide for Data Centers, consists of credits and prerequisites based off of the LEED New Construction (NC) Version 2.2. The LBNL is encouraging the USGBC to move forward with a LEED NC rating system specifically for data centers in 2009 [72, p. 3].

This section of the report will present credits that designers may be able to earn with the current LEED NC Version 2.2 and the draft for EPC Guide for Data Centers when designing a fuel cell CHP system with absorption chillers for a data center.

5.7.1 Obtainable LEED Points with NC Version 2.2

LEED NC Version 2.2 credits that design teams could strive for with a fuel cell CHP system with absorption chillers are listed below.

- Energy & Atmosphere Prerequisite 3: Fundamental Refrigerant Management

  This credit requires that no chlorofluorocarbons (CFC) refrigerants are used in the HVAC system in order to reduce ozone depletion. Absorption chillers use no CFC refrigerants, therefore, aiding a designer to fulfill this required prerequisite [73, p. 32; 74, para 10].

- Energy & Atmosphere Credit 1: Optimize Energy Performance

  This credit is intended to increase levels of the building's energy performance. One option to earn points for this credit is to exceed a baseline building performance rating per ASHRAE/IESNA (Illuminating Engineering Society of North America) Standard 90.1-2004. A maximum of 10 points is attainable from this credit, which would be awarded if a new building surpassed the ASHRAE/IESNA Standard 90.1-2004 by 42% or 35% for an existing building. Stimulations for a baseline model and the proposed project are necessary to determine the amount that the building would exceed ASHRAE/IESNA 90.1-2004 requirements [73, p. 33-35].

- Energy & Atmosphere Credit 4: Enhanced Refrigerant Management

  One point is available from this credit that requires either no refrigerants be used or limits the use of refrigerants to those that minimize or eliminate the emission of compounds that contribute to ozone depletion and global warming [73, p. 39-40].

Overall, a maximum of eleven points could be awarded under the LEED NC Version 2.2 rating system. Although, an additional point may be earned under the Innovation and Design Process Credit 1: Innovation in Design, which rewards points for innovative performance not specifically addressed by the LEED NC rating system [73, p. 77]. The LEED NC Version 2.2 rating system does not have a credit to reward for non-renewable on-site power generation or designs that have equipment with low emissions or low sound levels, such as fuel cell systems. These issues are presented as individual credits in the EPC Guide for Data Centers draft.

5.7.2 Obtainable LEED Points with Environmental Performance Criteria Guide for Data Centers Draft

The following credits may be obtainable under the EPC Guide for Data Centers draft when applying a fuel cell CHP system with absorption chillers to a data center.

- Sustainable Sites Credit 5.4: Site Development, Noise Impacts

  This is a new credit to the NC Version 2.2 rating system. One point is available if the sound level at the property line is at least 10% less than the locally mandated requirement during normal and emergency operations of the data center. The draft suggests adding retaining walls to decrease equipment sound levels.

However, retaining walls may not be necessary with the low noise levels of fuel cell systems. In fact, the EPC recommends fuel cells for power generation in order to obtain these points [72].

- Sustainable Sites Credit 5.5: Site Development, Air Quality and Emissions Impact

  This credit is also new to the NC Version 2.2 rating system. In order to reduce emissions and the negative impact on air quality, the EPC recommends installing a fuel cell power system. In order to receive a point for this credit, calculations for NO_x and CO emissions must be submitted and be a minimum of 10% better than the local code requirement. It must also be shown that the emissions meet or exceed the EPA Tier 2 standards [72].

- Energy & Atmosphere Credit 2: Optimize Energy Performance

  This credit is a modification of the Energy & Atmosphere Credit 1: Optimize Energy Performance in the LEED NC Version 2.2 rating system. The range of points available for this credit is 10 to 34 points. These points correlate with an energy performance improvement over ASHRAE/IESNA Standard 90.1-2007 of 5% to 17.5% and 2% to 14% for new and existing buildings, respectively. The draft states that since data centers can be 10 to 100 times as energy intensive as an office building, it can be very difficult and expensive to reach the percentage thresholds for commercial buildings as required by the NC Version 2.2 rating system. Therefore, the EPC has decreased the thresholds and increased the amount of points attainable [72].

- Energy & Atmosphere Credit 4: On-Site Generation

  This is another new credit added by the EPC Guide for Data Centers. This credit encourages the use of on-site power generation in order to "reduce the environmental and economic impacts associated with fossil fuel energy use and transmission losses from utility power plants" [72]. The EPC also recommends applying fuel cells for this credit. Up to three points are available for this credit, depending on a percentage of improvement over ASHRAE/IESNA Standard 90.1-2007 in annual source energy [72].

The EPC Guide for Data Centers draft also includes the Energy & Atmosphere prerequisite for fundamental refrigerant management and the one point credit for enhanced refrigerant management. Therefore, having a fuel cell CHP system with absorption chillers could assist in being awarded a maximum of 40 points with the EPC Guide for Data Centers draft rating system.

CHAPTER 6 - Disadvantages of Fuel Cells used in Data Centers

There are several disadvantages associated with installing a fuel cell system in data center applications. These disadvantages include the initial cost, life of fuel cell stacks, unknown failure rate, and a large footprint and weight. This chapter discusses each of these disadvantages.

6.1 High Initial Cost

Fuel cells are more expensive in comparison to other distributed generation technologies that are being considered for CHP applications, such as combustion turbines and engines. However, UTC Power's PureCell Model 200 fuel cell has been successful in regions where electricity prices are high and natural gas prices are low as well as niche markets, like data centers, that require high reliability [20, p. 5-11].

Fuel cell systems' high initial cost is due to their expensive materials and fuel reformers. Advances in engineering and materials used, as well as higher production levels, need to occur in order for prices to decrease [1, p. 82; 12, p. iv].

6.2 Unknown Failure Rate

Fuel cells are at a disadvantage compared to other on-site generation technologies because their failure mode is not completely known. This is due to their short operating history. As mentioned previously, large monetary losses can occur from a data center experiencing a power outage. Therefore, many data center owners are hesitant to deviate from the typical UPS and generator system, as stated in the "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431." However, demonstration systems have been installed across the US in order to prove reliability and improve operational practices [1, p. 82; 20, p. 5-11].

6.3 Life of Fuel Cell Stacks

Another uncertainty with a fuel cell system due to the lack of their operating history is the estimation of the fuel cell stack life. This is an important factor for owners to understand because stack replacement is another cost that they will incur. According to the "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431," fuel cells have not been around long enough to be able to estimate fuel cell stack life" [1, p. 82].

UTC Power, FuelCell Energy, and CFC Solutions report their fuel cell stack life anywhere from 3 to 10 years. UTC Power's PureCell Model 400 has a 10 year stack life. This is a huge improvement compared to the listed 5 year life in 2007 [75, p. 9]. As previously stated in section 3.3.2, APC's PEMFC for backup server power also has an estimated 10 year lifetime [36, p. 2]. According to FuelCell Energy's website, they are currently working on improving the DFC's stack life from 3 years to 5 years. They state that this will reduce operating costs and increase availability [76, para 2]. In 2007, CFC Solutions achieved 30,000 hours of life with their HotModule MCFC, which is nearly 3.5 years [77, p. 18].

6.4 Large Footprint & Weight

Although fuel cell systems may be easy to site due to their low emissions and noise levels, the large footprint and weight that the systems require could cause architects and engineers a few setbacks. For example, the UTC Power PureCell Model 400's fuel cell module is 8.5 feet wide, 27.5 feet long, and 10 feet high. The cooling module of the PureCell Model 400 is approximately 7.75 feet wide, 13.5 feet long, and 6.25 feet high. The typical site layout of the UTC Power PureCell Model 400 fuel cell and cooling modules, including all required clearances, is 34.5 feet wide by 38.5 feet long. The PureCell Model 400 fuel cell module is also heavy, weighing in at 60,000 pounds [56, p. 1].

FuelCell Energy's DFC also requires a large area. As shown in Appendix B, the overall width, length, and height of this system is 20 feet, 28 feet, and 15.1 feet, respectively. The weights of the DFC's modules are considerably less than those of the PureCell Model 400. The Mechanical Balance of Plant, Electrical Balance of Plant, and Fuel Cell Module weigh 27,000 lbs, 15,000 lbs, and 35,000 lbs respectively [57, p. 2].

Rack weight capacity must be considered if rack-mounted fuel cells, such as the PEMFC by APC, are to be used for backup power. One of APC's InfraStruXure modules weighs 880 lbs [36, p. 2].

CHAPTER 7 - Future Predictions for Fuel Cells

As shown in Chapter 6, there are several obstacles for fuel cell manufacturers to overcome in order to make fuel cell systems more attractive to owners and designers alike. Many manufacturers and engineers see fuel cells as a promising technology for the future. According to Shipley et al., “fuel cells have the potential to revolutionize the nation’s energy and transportation infrastructure” [12, p. 16].

In order for fuel cell systems to become more appealing, adjustments in initial cost and advances in engineering need to occur. Other fuel cell applications that will benefit from these advancements are mobile power systems in vehicles and electronic equipment such as portable computers, mobile telephones, and military communications equipment [78, p. 13-1; 79, p. 23-24].

7.1 Decreased Initial Cost

A large hindrance to on-site fuel cell systems is their high initial cost. The research from this report revealed that the installed costs of stationary fuel cells have already dropped over the last couple of years. In February of 2007, David Kozlowski wrote that the installed cost of stationary fuel cells was approximately $4 per watt [80, para 24]. In an article written by Dr. Kerry-Ann Adamson in August of 2008, installed costs of UTC Power’s PureCell were $2.50 per watt [21, p. 4]. Kozlowski predicts that the price per watt needs to drop to $1.50 or less for on-site generation to be practical [80, para 24].

According to Adamson’s article, UTC Power calculates that their 400 kW PureCells will produce electricity at an unsubsidized cost of $0.12 per kW/h. Adamson also wrote that FuelCell Energy is reporting $0.15 per kW/h electricity costs from their DFC units and that they are striving for an installed cost of $2.00 per watt. In December 2008, the average cost of electricity for the commercial sector in the US was $0.995 per kW/h [81]. Although fuel cell electricity costs are currently higher than the national average, the gap is narrowing. In Figure 7-1, FuelCell Energy shows Connecticut commercial electricity rates surpassing those of their DFC units in the year 2009. The average rate for commercial electricity in Connecticut in December of 2008 was $0.1583 per kW/h [81].

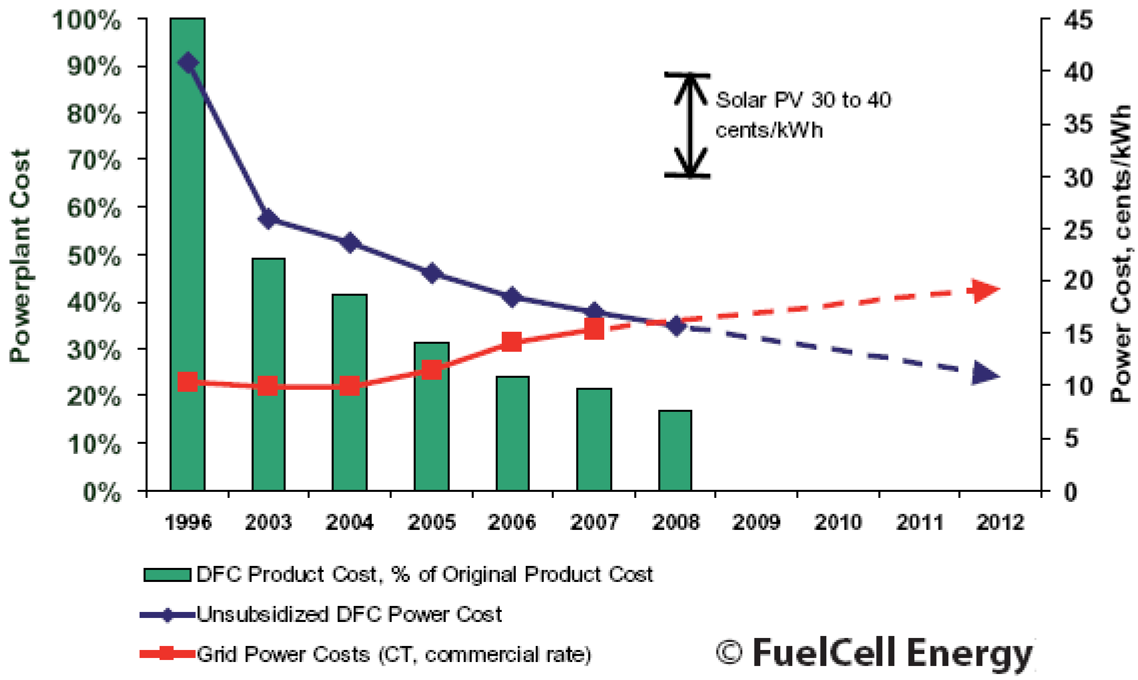


Figure 7-1 FuelCell Energy Cost Reductions [N]

As mentioned previously, in order for fuel cell prices to continue to decrease, higher production levels need to occur as well as advances in engineering and materials applied. In his February 2007 article, Kozlowski predicted that it may be 10 years before the US has general commercialization of fuel cells [80, para 24].

The automotive industry has immense expertise in reducing production costs for new products. Currently, PEMFCs are applied to automotive applications due to its quick start, high power densities, and potential for cheap mass production. Shipley et al. predicts that an expansion of the stationary fuel cell market will be closely tied to an increase in the commercialization of mobile fuel cell systems for vehicles [12, p. 20-21; 78, p. 8-2].

Although not necessary for the stationary fuel cell market, the commercialization of mobile fuel cells will require an expansion of the hydrogen infrastructure. Stationary fuel cell systems require hydrogen or a hydrogen-rich fuel, such as natural gas, at the site. The stationary fuel cell systems that do not operate at high enough temperatures to internally reform the natural gas are packaged and sold with a reformer. Because of the included fuel reformer, building a hydrogen infrastructure is not necessary for the stationary market. However, the mobile market is much more limited on space. Therefore, they do not have the luxury of having a reformer within its fuel cell system. With an expanded hydrogen infrastructure, the mobile fuel cell market will grow and subsequently support the development of stationary fuel cells [12, p. 20 -21].

Currently, the hydrogen infrastructure is very limited in the US. According to data on the FuelCells.org website, presently there are 82 hydrogen filling stations for fuel cell cars in the US [82]. There are approximately 170,000 gasoline fueling stations in the US. In order to make fuel cell vehicles more widely accepted, an increase in hydrogen fueling stations is needed. However, the cost of expanding the hydrogen infrastructure for fuel cell vehicle use will not be cheap. HowStuffWorks.com predicts that the government will need to spend $500 billion to expand the infrastructure [83]. Greg Blencoe, CEO of Hydrogen Discoveries, Inc., estimates a total cost of $405 billion. This estimation includes building one hydrogen fueling station for every gasoline fueling station. Blencoe approximates the average cost per hydrogen fueling station to be $1.5 million. The polymer hydrogen pipelines to supply the hydrogen to these stations would cost around $500,000 per mile [84, para 3-5].

The Hydrogen Fuel Initiative (HFI) is supportive of the automotive industry's efforts to manufacture fuel cell vehicles. The HFI began in 2003 as an effort to develop hydrogen, fuels, and infrastructure technologies in order to make fuel cell vehicles practical and cost effective by the year 2020. As of 2008, the US has spent more than one billion dollars on fuel cell research and development in response to the HFI [48, p. 137].

The American Recovery and Reinvestment Act signed by President Obama on February 17th, 2009 is also supportive of the use of fuel cell vehicles. A total of $300 million establishes a grant program through the DOE Clean Cities program. There will be 30 grants awarded for projects researching emerging vehicle technologies, such as fuel cells [85, para 11]. This act also supports hydrogen fueling stations. The tax incentive for hydrogen fueling stations will be 30%, or up to $200,000, until January 1, 2011. The tax incentive was previously capped at $30,000 [86, p. 2]. Refer to Appendix C for additional "Fuel Cell Items in the American Recovery and Reinvestment Act of 2009" [86, p. 1-2].

In addition to increasing production levels, the high initial cost of fuel cells could be reduced with engineering advancements. Shipley et al. recommends that electrical densities need to increase in order for installation costs to be more competitive with current power generation technologies [12, p. 17]. The Massachusetts Technology Collaborative (MTC) website suggests several other engineering advancements that would cause fuel cell systems to be more widely accepted. MTC recommends engineers focus on making fuel cell systems smaller, weigh less, and less sensitive to fuel impurities. In addition, MTC says that fuel cell system components, such as the fuel cell stack, need to be developed to have a longer lifespan or to be easily and cheaply replaced. They also state that fuel cells would be more competitive in the automotive industry if they had a longer lifespan [63, para 4].

7.2 Increased Demand

The demand for fuel cells is expected to rise as some states continue to have increasing constraints on the utility grid's transmission and distribution capacity. This would cause fuel cell on-site power and cogeneration systems to become more attractive. In addition, the market for fuel cells is expected to rise as the environmental cost of fossil-fuel based generation technologies increases. Shipley et al. states that "this may begin to become more of a factor in parts of the country where NO_x emissions trading begins and in severe NO_x non-attainment areas, such as the Houston-Galveston, TX region" [12, p. 17]. There are several other major US cities that are considered non-attainment areas, where air pollution levels continuously exceed the national ambient air quality standards. These cities include Atlanta, Indianapolis, St. Louis, New York City, Dallas-Fort Worth, and Los Angeles [87].

7.3 Applying Renewable Energy Resources to Fuel Cells

Currently, hydrogen is supplied to stationary fuel cells by reforming natural gas. A fuel cell's greenhouse gas emissions are from this reforming process. As mentioned in section 5.2, if pure hydrogen is supplied to the fuel cell, the greenhouse gas emissions are eliminated. In an effort to provide the quantities of pure hydrogen needed for stationary fuel cells and fuel cell cars, a project by the National Renewable Energy Laboratory (NREL) in partnership with Xcel Energy began in 2007. The project utilizes wind-generated electricity to produce and store hydrogen [88, para 3].

The NREL project consists of wind turbines, electrolyzer stacks, hydrogen compressors, and hydrogen storage tanks. The AC electricity produced by the wind turbines is converted to DC and then routed to electrolyzers. There, the electricity passes through water to split the liquid into hydrogen and oxygen. The hydrogen is then compressed and stored for later use in either hydrogen internal combustion engines or fuel cells. Wind power has been characterized as being unreliable due to unpredictable wind speeds. By storing hydrogen for later use, the variable nature of wind power is overcome because the hydrogen can be used at any time, whether the wind is blowing or not. Refer to Appendix A for safety concerns and codes related to hydrogen storage and infrastructure. On NREL's website, the "Wind2H2 Animation" mentions that electricity generated from photovoltaic panels could also be utilized in this process [88, para 3; 89].

The goal of NREL and Xcel Energy's project is to improve the efficiency of producing hydrogen from a renewable resource. NREL and Xcel Energy are continuously seeking to improve the wind-to-hydrogen conversion process. This includes identifying areas for cost and efficiency improvements and evaluating safety controls and systems for the safe production of hydrogen. In addition, NREL and Xcel Energy seek to be able to produce large enough quantities of hydrogen, at a low enough cost, in order to compete with traditional energy sources, such as coal, oil, and natural gas. NREL and Xcel Energy continue to pursue this goal today [88, para 3-7; 89, para 10].

If NREL and Xcel Energy's wind energy recovery project to produce hydrogen is successful, the fuel cell market as well as the US will benefit. The HydrogenCarsNow website states that "when hydrogen cars become the status quo, the US can lessen its dependence upon foreign oil, achieve lower prices at the fuel pumps and cut down on greenhouse gases" [90, para 1].

CHAPTER 8 - Conclusions

Fuel cells are an exciting technology that many design engineers are just now learning about. To end the report, recommendations on the fuel cell system design procedure are made to the benefit of engineers contemplating the use of fuel cells in a data center application.

8.1 Fuel Cell System Design Procedure Recommendations

When considering a fuel cell system to power a data center, the design engineer must make considerations for all that a fuel cell system requires. There are many questions that must be asked and answered when designing a data center's electrical and HVAC systems. In the case of an electrical and/or HVAC engineer that has never worked with a fuel cell system, many more questions are sure to arise. Which type of fuel cell should be used? Is cogeneration applicable? Should the fuel cell be used for primary power, secondary power, or both? How much more is this system going to cost? These are all viable questions that must be considered when selecting and designing a fuel cell system. This section of the report provides engineers with several recommendations on the fuel cell system design procedure based on the information that has been presented in this report. Refer to Appendix A for relevant codes and standards to be followed in the design and installation of stationary fuel cells.

To begin the design procedure, a decision must be made as to what systems will provide primary and secondary power, whether it be the utility grid, fuel cells, or generators. High tariffs enforced by local utilities may push an owner to avoid using a utility grid connection to supply either primary power or secondary power, as discussed in section 3.3.1. In the case that fuel cells are used for primary power, the engineer must research the local regulations on interconnection and possibilities for net metering. As mentioned previously in section 3.3.2, large, mega-watt fuel cells are not recommended to be used for backup power because it would be expensive, inefficient, and the system would have a long start up time. Alternatively, rack-mounted, quick-starting PEMFCs are recommended as a secondary power source for server racks.

In the beginning stages of design, the engineer must research and determine what type of fuel cell they would like to use. With data center applications, reliability certainly plays an important role. As of the writing of this report, the PAFC has the longest record for stationary applications. The information gained from this fuel cell's history would aid in calculating the electrical system's overall reliability. There are other aspects gained from this fuel cell's history that would give more insight to the designer. For example, the designer would be able to more precisely predict the intensity of required maintenance and associated lifecycle costs.

In addition to reliability, a fuel cell's efficiency, initial costs, and waste heat applications must be taken into account when selecting a fuel cell type. The costs of a fuel cell system will be a concern for every owner as they strive to make a profit from the operation of their facility. The different fuel cell types presented in this report have electrical and CHP efficiencies ranging from 35 to 60% and 60 to 90%, respectively. However, keep in mind that there may not be a need in the facility for all of the low grade waste heat produced by the fuel cell system. Without a use for this waste heat, the fuel cell system efficiencies will not reach the maximum 90% value. The operating costs of the fuel cell system will be greatly influenced by the system's efficiency.

The differences in initial cost of fuel cells are influenced by their construction materials. For example, the SOFC uses less expensive non-precious metals for its catalyst, while the PEMFC and PAFC have pricey platinum catalysts. This report did not include any sort of cost analysis for fuel cell systems. However, a cost analysis would be necessary to properly compare different fuel cell types, taking into account initial costs, operating costs, lifetime expectancy, federal and state incentive programs, net metering, and tariffs imposed by the local utility company. In addition, a cost analysis comparison may be necessary in order to determine whether or not a fuel cell system should be used over a typical utility grid connection with generator backup.

If a combined heat and power system is desired, then a fuel cell with high grade waste heat, such as the PAFC, MCFC, or SOFC, will be necessary. With a data center's constant cooling needs, it is recommended that a combined heat and power system be applied when using a fuel cell system as the primary power source. If not, the waste heat would be exhausted, and the owner would not be able to benefit from the higher efficiencies that are obtainable with a cogeneration system.

One last consideration to make when selecting a fuel cell type is the fuel sources available to the data center and the fuel source options available from a fuel cell manufacturer. Both the DFC300 and the PureCell Model 400 are able to operate with a natural gas fuel supply, as seen on the equipment data sheets in Appendix B. The PureCell Model 400 is also able to operate with an anaerobic digester gas (ADG) supply. Be aware that some fuel options, such ADG with the PureCell 400, require additional equipment. Other fuel cells, such as APC's InfraStruXure™ with Integrated Fuel Cells system, require pure hydrogen.

Before going any further into the procedure, the electrical loads of the facility need to be calculated. Knowing the electrical demands of the data center will aid the engineer in determining how many fuel cells will be required. Using this information, the engineer will be able to estimate the number of fuel cells needed to meet the facility's electrical demand. The number of fuel cells will be affected by which fuel cell is used because the maximum power outputs from large, packaged fuel cells vary from manufacturer to manufacturer. As mentioned in section 6.4, fuel cell systems require a large area. Before continuing in a fuel cell system design, it must be determined if and where there is adequate space to locate this large equipment, whether it be outdoors, in an electrical room, or on the racks. Coordination is necessary between the electrical and structural engineers as well as the architect and building owner in this process.

The type and number of fuel cells being used will also aid in the HVAC design if a combined heat and power system is being applied. After calculating the heat gains of the data center, the mechanical engineer can use this information to progress in the HVAC design. The mechanical engineer should also calculate the amount of energy needed to heat the data center's domestic water. With this value, the fuel cell system's efficiencies can be determined and a more precise cost analysis completed.

The engineer will have to provide a means of supplementary cooling in their HVAC design if the fuel cell is unable to produce enough waste heat to power an absorption chiller to offset the facility's heat gains. Either electric chillers or boilers to provide supplementary heat for absorption chillers can be used in this situation. It is recommended that electric chillers be used for supplementary cooling and that boilers be used to provide backup heat for the absorption chillers while the fuel cell system is shutdown for maintenance or in case the fuel cell system fails.

In addition to area and weight, noise levels may be a concern when siting a fuel cell system. The noise levels produced by fuel cell systems are considered low, at around 65 dBA 33 feet from the equipment. However, the engineer needs to ensure that there are no concerns about the noise for neighbors if the system is located outdoors or for data center employees if the system is located indoors near offices. And, if there are concerns, precautions must be made to reduce the noise levels. For example, the walls separating the fuel cell system and offices may need to be upgraded to have a higher sound transmission loss [91, p. 161].

Another concern that must be considered is who will be responsible for maintaining the system. There are now several community colleges that offer fuel cell technician training programs [92]. These programs teach students to install, maintain, troubleshoot, and repair fuel cells. There may be a local fuel cell technician available. If not, employees of the data center will need to take on the responsibility. Training classes are available from fuel cell manufacturers [93, para 9-10].

Each data center will have unique design dilemmas based on its location. Therefore, every data center must be analyzed independently in order to provide the owner with the design best suited for their facility.

8.2 Conclusion

Fuel cells have a long history dating back to 1838, and the technology has experienced a multitude of advancement over the years. In fact, there has been so much advancement that they are considered reliable enough to power energy-intensive data centers that the American society relies on for everyday life. Among high reliability, fuel cells offer data center owners low noise levels, low emissions, high efficiencies, increased reliability, modularity, minimal maintenance, cost reductions through tax incentives, and the opportunity to obtain LEED points. However, further development is necessary in order to decrease initial costs, reduce their large foot print and weight, and increase the life of the equipment. With these advancements, data center owners and design engineers are expected to be more accepting of the technology.

If anything, engineers designing electrical and/or HVAC systems should be aware of and keep updated on fuel cell technology. There are advancements being made as well as more fuel cells being installed every year. As fuel cell development continues, an engineer's opportunity to apply fuel cells to an electrical or CHP system design is on the horizon.

References Cited

[1] "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431," U.S. Environmental Protection Agency, Energy Star Program, Aug. 2, 2007.

[2] S. Greenberg, E. Mills, B. Tschudi, P. Rumsey, B. Myatt, "Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers," *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings,* pp. 3-76 – 3-87, 2006.

[3] C. Coyle and R. Arno, "Data Centers for Uncle Sam," Pure Power Magazine, pp. 26-31, Fall 2008.

[4] "Data Centers," www.gulfcoastchp.org/Markets/Commercial/DataCenters Accessed Jan. 23, 2009.

[5] "Cogeneration and the datacenter," http://www.datacenterdynamics.com/ME2/Sites/dirmod.asp?sid=&nm=&type=Publishing&mod=Publications%3A%3AArticle&mid=8F3A7027421841978F18BE895F87F791&tier=4&id=58E639697ABE41C8AFFB5E2045BEF8D7&SiteID=2008%20Sydney Accessed Jan. 23, 2009.

[6] *Data Center Cooling Strategies.* Hewlett-Packard Development Company, L.P., Aug. 2007.

[7] "DSIRE – Database of State Incentives for Renewables & Efficiency," www.dsireusa.org Accessed Feb. 2, 2009.

[8] "Wind-to-Hydrogen Project," http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html Accessed Feb. 28, 2009.

[9] "Hydrogen Cars," http://www.hydrogencarsnow.com/ Accessed Mar. 11, 2009.

[10] M. Ellis, M. Von Spakovsky, and D. Nelson, "Fuel Cell Systems: Efficient, Flexible Energy Conversion for the 21st Century," *IEEE Journal* , vol. 89, no. 12, pp. 1808-1818, Dec. 2001.

[11] S. Lasher, R. Zogg, E. Carlson, P. Couch, M. Hooks, K. Roth, and J. Brodrick, "PEM Fuel Cells For Distributed Generation," *ASHRAE*, vol. 48, no. 11, pp. 45-48, Nov. 2006.

[12] A.M. Shipley and R.N. Elliott, "Stationary Fuel Cells: Future Promise, Current Hype", American Council for an Energy-Efficient Economy, Report Number IE041, Mar. 2004.

[13] M. Ellis and M.B. Gunes, "Status of Fuel Cell Systems for Combined Heat and Power Applications in Buildings," *ASHRAE*, vol. 108, no. 1, pp. 1-12, Jan. 2002.

[14] X. Yu, M.R. Starke, L.M. Tolbert, and B. Ozpineci, "Fuel Cell power conditioning for electric power applications: a summary," *Electric Power Applications, IET,* vol. 1, no. 5, pp. 643-656, Sept. 2007.

[15] R.J. Fiskum, "Fuel Cells in Residential and Commercial Building Applications," in *Proceedings – Intersociety Energy Conversion Engineering Conference*, pp. 1171-1176, Atlanta, GA, Aug. 8-13, 1993.

[16] "Fuel Cells: Stationary Power – Industrial Applications," http://usfcc.com/about/Fuel_Cells_for_Industrial_Applications.pdf Accessed Dec. 11, 2008.

[17] E. Carlson, R. Zogg, S. Sriramulu, K. Roth, and J. Brodrick, "Using Phosphoric-Acid Fuel Cells For Distributed Generation," *ASHRAE*, vol. 49, no. 1, pp. 50-51, Jan. 2007.

[18] R.M. Ormerod, "Solid Oxide Fuel Cells," *The Royal Society of Chemistry,* vol. 32, pp. 17-28, 2003.

[19] "FAQs," http://www.fuelcellmarkets.com/united_technologies_utc/5,1,420,1174.html Accessed Jan. 12, 2009

[20] *Cooling, Heating, and Power for Buildings (CHP-B) Instruction Module*. Mississippi State, Department of Mechanical Engineering, 2004.

[21] K.A. Adamson, "2008 Large Stationary Survey," http://www.fuelcelltoday.com/media/pdf/surveys/2008-LS-Free.pdf Accessed Mar. 26, 2009.

[22] "Molten Carbonate Fuel Cell Technology," http://www.fossil.energy.gov/programs/powersystems/fuelcells/fuelcells_moltencarb.html Accessed Dec. 12, 2008.

[23] F. Hagstotz, "Permanent Premium Power for Data Centers – The Fuel Cell Power Station Type HotModule," in *Proceedings of the Telecommunications Energy Conference*, pp. 11-14, Rome, Italy, Sept. 30 – Oct. 4, 2007.

[24] A. Jalalzadeh-Azar, "Investigating Methods of Heat Recovery from Low-Temperature PEM Fuel Cells in CHP Applications," *in Proceedings of IMECE04 – 2004 ASME International Mechanical Engineering Congress and Exposition*, pp. 533-542, Anaheim, CA, Nov. 13-20, 2004.

[25] R. Zogg, S. Sriramulu, E. Carlson, K. Roth, and J. Brodrick, "Using Solid-Oxide Fuel Cells For Distributed Generation," *ASHRAE*, vol. 48, no. 12, pp. 116-118, Dec. 2006.

[26] "Solid State Energy Conversion Alliance (SECA)", www.seca.doe.gov/ Accessed Jan. 14, 2009.

[27] M. Wiboonrat, "An Optimal Data Center Availability and Investment Trade-Offs," in *Ninth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing*, pp. 712-719, Phuket, Thailand, Aug. 6-8, 2008.

[28] K.E. Herold, "Integrated Power and Cooling Systems for Data Centers," Presented at ITHERM 2002 – Eighth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, pp. 808-811, San Diego, CA, May 30 – Jun. 1, 2002.

[29] W. Allen, D. Fletcher, and K. Fellhoelter, "Securing Critical Information and Communication Infrastructures Through Electric Power Grid Independence," in *INTELEC*, pp. 170-177, Yokohama, Japan, Oct. 19-23, 2003.

[30] W. Valstrom, "A Practical Guide for Electrical Reliability," http://ecmweb.com/mag/electric_practical_guide_electrical/ Accessed Jan. 3, 2009.

[31] R. Mitchell, "Flywheel technology puts new spin on power," http://www.computerworld.com/action/article.do?command=printArticleBasic&articleId=264715 Accessed Feb. 2, 2009.

[32] "Automatic Transfer Switches," http://www.gensetcentral.com/ASCO_automatic_transfer_switch.htm Accessed Jan. 14, 2009.

[33] "Net Metering Policies," http://apps3.eere.energy.gov/greenpower/markets/netmetering.shtml Accessed Feb. 14, 2009.

[34] "Interstate Renewable Energy Council (IREC) "Connecting to the Grid" Project, State and Utility Net-Metering Rules, Regulations, and Programs," http://www.irecusa.org/fileadmin/user_upload/ConnectDocs/October_2008_NM_table.doc Accessed Feb. 14, 2009.

[35] "Topic 7A Question," https://e-center.doe.gov/iips/IIPSquestions.nsf/546e13ab78bdef1f8525693c00670246/98b467b45146a2c6852574a900770b5c?OpenDocument Accessed Jan. 16, 2009.

[36] "Fuel Cell Solutions for InfraStruXure Systems," http://www.apcmedia.com/pdf_downloads/litpdfs/996-2856C.pdf Accessed Jan. 17, 2009.

[37] M. Perry and E. Strayer, "Fuel-Cell Based Back-up Power for Telecommunication Applications: Developing a Reliable and Cost-Effective Solution," in *INTELEC 2006 Proceedings,* pp. 1-8, San Diego, CA, Sept. 14-18, 2006.

[38] "New OK Fuel Cell APC Solution OK-ISX-FCXR10-30", http://www.oksolar.com/0_n_cart/htm/724930.htm Accessed Jan. 17, 2009.

[39] G. Whitmore, "Green HVAC Designs for Data Centers," www.hpac.com/mag/green_hvac_designs/ Accessed Jan. 23, 2009.

[40] "Data Centers," www.gulfcoastchp.org/Markets/Commercial/DataCenters Accessed Jan. 23, 2009.

[41] K. Dunnavant, *Notes for Dissipated Data Center Heat through Polymer Indirect Evaporative Coolers Presentation*, ASHRAE Winter Convention, Chicago, IL, Jan. 26, 2009.

[42] M. Fontecchino, "Data center temperature range expaded: Who cares?," http://searchdatacenter.techtarget.com/news/article/0,289142,sid80_gci1346115,00.html Accessed Feb. 1, 2009.

[43] K. Darrow and B. Hedman, "Opportunities for Combined Heat and Power in Data Centers," http://www1.eere.energy.gov/industry/saveenergynow/pdfs/chp_data_centers.pdf Accessed Mar. 28, 2009.

[44] *Power and Cooling in the Data Center.* Advanced Micro Devices Inc., 2005

[45] *Liebert XD – Flexible, Energy-Saving Cooling Solutions for High Heat Density Applications*. Columbus, OH: Liebert Cooperation, 2005.

[46] "Data Center Chiller," http://searchdatacenter.techtarget.com/sDefinition/0,,sid80_gci1293992,00.html Accessed January 31, 2009.

[47] Personal communication with Bernard Kolanowski, author of *Small-Scale Cogeneration Handbook*, February 16, 2009.

[48] B.F. Kolanowski, *Small-Scale Cogeneration Handbook*. Lilburn, Georgia: The Fairmont Press, Inc., 2008.

[49] "Thermally Activated Technologies: Absorption Chillers for Buildings", http://www.eere.energy.gov/de/pdfs/thermally_activated_absorption_chillers.pdf Accessed January 26, 2009.

[50] A. Preston, "Cogeneration and the datacenter," http://www.datacenterdynamics.com/ME2/Sites/dirmod.asp?sid=&nm=&type=Publishing&mod=Publications%3A%3AArticle&mid=8F3A7027421841978F18BE895F87F791&tier=4&id=58E639697ABE41C8AFFB5E2045BEF8D7&SiteID=2008%20Sydney Accessed Jan. 23, 2009.

[51] *ASHRAE Hand Book 200, HVAC Systems and Equipment I-P Edition*. American Society of Heating, 2000.

[52] "Minimized Boiler Short Cycling Losses," http://www1.eere.energy.gov/industry/bestpractices/pdfs/steam16_cycling_losses.pdf Accessed March 23, 2009.

[53] "Boiler Turndown," http://www.energysolutionscenter.org/boilerburner/Eff_Improve/Operations/Boiler_Turndown.asp Accessed March 23, 2009.

[54] R. Wilkinson, *Notes for ARE734 Thermal Systems Design,* Kansas State University, Manhattan, KS, Spring Semester, 2008.

[55] N. Petchers, *Combined Heating, Cooling, & Power,* Lilburn, Georgia: The Fairmount Press, Inc., 2003.

[56] "PureCell Model 400 System: Data Sheet, Typical Site Layout," http://energyreinvented.com/phpworx/index.php?cmd=controller&action=download_section&usr=c9d4e2b16e72a9fa2bf45390ec73f1d2&section=toolbox#toolbox Accessed February 9, 2009.

[57] "DFC 300 Product Brochure," http://www.fuelcellenergy.com/files/FCE%20DFC300_Product_Sheet_032508.pdf Accessed February 9, 2009.

[58] "Purecell Model 400 System Features", http://www.utcfuelcells.com/fs/com/bin/fs_com_Page/0,11491,0250,00.html Accessed September 17, 2008.

[59] "Decibel Table – Comparison Chart," http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm Accessed February 1, 2009.

[60] "Cleaning up the Air," http://www.arb.ca.gov/knowzone/students/airpollu/airpolpage/cleanup.htm Accessed February 7, 2009

[61] "Ambient Air Quality Standards," http://www.arb.ca.gov/research/aaqs/aaqs2.pdf Accessed February 7, 2009.

[62] H. Nordin, B. Lindemark, "System Reliability, Dimensioning and Environmental Impact of Diesel Engine Generator Sets used in Telecom Applications," in *Proceedings of the Telecommunications Energy Conference,* p. 6, June 6-9, 1999.

[63] "Fuel Cells: Reliability and National Security," http://www.masstech.org/cleanenergy/fuelcell/impactnatsecurity.htm Accessed February 8, 2009.

[64] "Fuel Cell Basic – Benefits," http://www.fuelcells.org/basics/benefits.html Accessed February 8, 2009.

[65] *Data Center Cooling Strategies.* Hewlett-Packard Development Company, L.P. August 2007.

[66] "Installation Profile Verizon," http://www.energyreinvented.com/phpworx/index.php?cmd=controller&action=download_section&usr=f17dc4164a35000d12c5a68d2862fc8a&section=toolbox#toolbox Accessed February 8, 2009.

[67] R. Miller, "Hydrogen Fuel Cells Power Bank Data Center," http://www.datacenterknowledge.com/archives/2008/12/30/hydrogen-fuel-cells-power-bank-data-center/ Accessed February 14, 2009.

[68] "US Fuel Cell Council Lauds Congressional Action," http://www.businesswire.com/portal/site/home/permalink/?ndmViewId=news_view&newsId=20081003005758&newsLang=en Accessed December 11, 2008.

[69] "Federal Fuel Cell Tax Incentives; An investment in clean and efficient technologies," http://www.usfcc.com/ITC-TaxQA10-2008%20_2_.pdf Accessed February 2, 2009.

[70] "States with Renewable Portfolio Standards," http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm Accessed February 2, 2009.

[71] "Database of State Incentives for Renewables & Efficiency," www.dsireusa.org Accessed February 2, 2009.

[72] "Environmental Performance Criteria, Guide for New Data Centers," http://hightech.lbl.gov/dc-epc/DC-EPC-AppGuide-04-22-09.doc Accessed January 23, 2008.

[73] "LEED-NC Green Building Rating System for New Construction & Major Renovations, Version 2.2," http://www.usgbc.org/ShowFile.aspx?DocumentID=1095 Accessed February 14, 2009.

[74] "Absorption Chillers," http://www.energytechpro.com/Demo-IC/Gas_Technology/Absorption_Chillers.htm Accessed February 14, 2009.

[75] R. Tierney, "Fuel Cells: Cost-Effective, Reliable, and Ready Now," http://www.govenergy.com/2008/pdfs/technology/TierneyTech6.pdf Accessed January 12, 2009.

[76] "Service," http://www.fuelcellmarkets.com/fuel_cell_energy/5,1,11275,1379.html?subsite=11275&language=1 Accessed February 9, 2008.

[77] S. Rolf, "The HotModule System, Advancement in Stationary Fuel Cells," http://www.fuelcellseminar.com/pdf/2007/Presentations/1C/72%20Stefan%20Rolf%20FuelCellSeminar2007.ppt.pdf Accessed February 9, 2009.

[78] G. Hoogers, *Fuel Cell Technology Handbook*. Boca Raton, FL: CRC Press, 2003.

[79] J. Larminie, A. Dicks, *Fuel Cell Systems Explained*. West Sussex, England: John Wiley & Sons Ltd, 2003.

[80] D. Kozlowski, "Ready for Prime Time?," *Building Operating Management*, vol. 54, no. 2, pp. 23-26, February 2007.

[81] "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State," http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html Accessed March 29, 2009.

[82] "Worldwide Hydrogen Fueling Stations," http://www.fuelcells.org/info/charts/h2fuelingstations.pdf Accessed March 11, 2009.

[83] "Fuel Cell Quiz," http://auto.howstuffworks.com/fuel-cell-quiz10.htm, Accessed February 28, 2009.

[84] G. Blencoe, "What will it cost to build the entire US hydrogen infrastructure? The answer is $405 billion," http://hydrogendiscoveries.wordpress.com/2008/05/09/what-will-it-cost-to-build-the-entire-us-hydrogen-infrastructure-the-answer-is-405-billion/ Accessed March 11, 2009.

[85] M. Antich, "Obama's Stimulus Package Offers Funds for Fleet," http://www.businessfleet.com/Blog/Market-Trends/Story/2009/02/Obama-s-Stimulus-Package-Offers-Funds-for-Fleet.aspx Accessed March 29, 2009.

[86] "Fuel Cell Items in the American Recovery and Reinvestment Act of 2009," http://www.usfcc.com/AmericanRecovery&ReinvestmentAct.pdf Accessed March 28, 2009.

[87] "Counties Designated Nonattainment," http://www.epa.gov/air/oaqps/greenbk/mapnpoll.html Accessed March 25, 2009.

[88] T. Hansen, "NREL, Xcel Energy Partner to Wind-to-Hydrogen Project," http://pepei.pennnet.com/display_article/313195/6/ARTCL/none/none/1/NREL,-Xcel-Energy-Partner-on-Wind-to-Hydrogen-Project/ Accessed February 28, 2009.

[89] "Wind-to-Hydrogen Project," http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html Accessed February 28, 2009.

[90] "Hydrogen Cars," http://www.hydrogencarsnow.com/ Accessed March 11, 2009.

[91] A Goodman, *Notes for ARE537, Acoustic Systems,* Kansas State University, Spring Semester, 2007.

[92] S. Curtin, "Fuel Cell Technician," http://www.fuelcells.org/ced/career/fuelcelltechnician.pdf Accessed March 27, 2009.

[93] "Fuel cell study provides answers to OPPD, clean power for zoo," http://www.wapa.gov/ES/pubs/esb/2008/jun/jun081.htm Accessed March 26, 2009.

[94] "Hydrogen Safety," http://www.hydrogenassociation.org/general/factSheet_safety.pdf Accessed March 25, 2009.

[95] "Hydrogen/Fuel Cell Codes & Standards," http://www.fuelcellstandards.com/hydrogen_apps.html Accessed March 29, 2009.

[96] “PureCell Model 400 System Guide Specification,” http://energyreinvented.com/phpworx/index.php?cmd=controller&action=download_section&usr=c9d4e2b16e72a9fa2bf45390ec73f1d2&section=toolbox#toolbox Accessed February 8, 2009.

[97] B. Walsh, R. Wichert, “Fuel Cell Technology”, http://www.wbdg.org/resources/fuelcell.php Accessed October 28, 2008.

Graphics References

[A] M. Ellis, M.B. Gunes, “Status of Fuel Cell Systems for Combined Heat and Power Applications in Buildings,” *ASHRAE*, vol. 108, no. 1, pp. 1-12, January 2002.

[B] http://www.energyreinvented.com/phpworx_images/88a5b0841519cd62f81c680756d86099.png Accessed February 6, 2009.

[C] F. Hagstotz, “Permanent Premium Power for Data Centers – The Fuel Cell Power Station Type HotModule,” *Proceedings of the Telecommunications Energy Conference,* pp. 11-14, Rome, Italy, Sept. 30 – Oct. 4, 2007.

[D] http://fuelcellsworks.com/Typesoffuelcells.html Accessed October 28, 2008

[E] http://www.apc.com/products/moreimages.cfm?partnum=ISX-FCXR10-30&aPos=3 Accessed January 17, 2009

[F] http://www.apc.com/products/moreimages.cfm?partnum=ISX-FCXR10-30&aPos=1 Accessed January 17, 2009

[G] *Liebert XD – Flexible, Energy-Saving Cooling Solutions for High Heat Density Applications*. Columbus, OH: Liebert Cooperation, 2005.

[H] “PureCell Model 400 System Features”, http://www.utcfuelcells.com/fs/com/bin/fs_com_Page/0,11491,0251,00.html Accessed September 17, 2008.

[I] *Thermally Activated Technologies: Absorption Chillers for Buildings*, Distributed Energy Resources, Washington D.C.: US Department of Energy.

[J] http://www.utcfuelcells.com/fs/com/Images/M400/GX2_M400_dBA.gif Accessed February 7, 2009.

[K] “Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431,” U.S. Environmental Protection Agency, Energy Star Program, August 2, 2007.

[L] W. Allen, D. Fletcher, K. Fellhoelter, “Securing Critical Information and Communication Infrastructures Through Electric Power Grid Independence,” in INTELEC, pp. 170-177, Oct. 19-23, 2003.

[M] “Installation Profile Verizon,” http://www.energyreinvented.com/phpworx/index.php?cmd=controller&action=download_section&usr=f17dc4164a35000d12c5a68d2862fc8a&section=toolbox#toolbox Accessed February 8, 2009.

[N] K.A. Adamson, “2008 Large Stationary Survey,” http://www.fuelcelltoday.com/media/pdf/surveys/2008-LS-Free.pdf Accessed March 26, 2009.

Appendix A - Relevant Codes and Standards

“Hydrogen is no more or less dangerous than other flammable fuels, including gasoline and natural gas” [94, p. 1]. Like natural gas, hydrogen is odorless, colorless, and tasteless. However, unlike natural gas, an odorant is not added to hydrogen to make it easy for people to detect it. An odorant is not added because it could contaminate fuel cells. Therefore, hydrogen sensors must be used to aid in detecting leaks [94, p. 1]. The FuelCellStandards.com website lists several codes that apply to hydrogen infrastructure safety [95]. They are shown below.

1. US Department of Labor Occupational Safety & Health Administration (OSHA): 29 CFR 1910 Subpart H and 1910.103
2. American Institute of Aeronautics and Astronautics (AIAA): G-095 (2004) Guide to Safety of Hydrogen and Hydrogen Systems
3. Compressed Gas Association (CGA): P-12 Safe Handling of Cryogenic Liquids

The following is a list of relevant codes and standards to use in the design and installation of stationary fuel cells [96, p. 4; 97].

1. ASCE/SEI 7 – Minimum Design Loads in Buildings and Other Structures
2. NFPA 70 – National Electric Code, Article 692 Fuel Cell Systems
3. Code of Federal Regulation Title 47 OSHA – General Industry Standards, Part 1920, Subpart 0, Machine Guarding
4. Code of Federal Regulation Title 47 Telecommunications, Part 15, EMI Generation
5. NFPA 853 – Standard for the Installation of Fuel Cell Power Plants
6. NFPA 54 – National Fuel Gas Code
7. NPFA 110 – Standard for Emergency and Standby Power Systems
8. IBC – International Building Code
9. IPC – International Plumbing Code
10. IFGC – International Fuel Gas Code
11. IEEE1547 – 2003 – Standard for Interconnecting Distributed Resources with Electric Power Systems

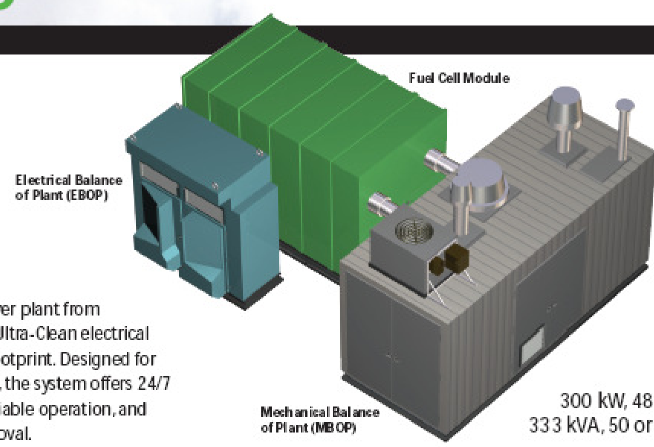
12. IEEE 1547.1 – 2005 – Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
13. Grid Interconnect Standards: A) California Requirements Rule 21, B) New York Standard Interconnect Requirements (NYSIR)
14. UL 1741 - Underwriters Laboratories Standard for Safety Inverters, Converters, and Controllers for Use in Independent Power Systems
15. ASME PTC 50 –Performance Test Code for Fuel Cell Power Systems Performance
16. American National Standards Institute (ANSI)—ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems

Appendix B - Data Sheets for Stationary Fuel Cells

DFC300 Data Sheet [57]

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

DFC300



300 kW, 480 VAC, 333 kVA, 50 or 60 Hz

Key Features

- High Efficiency
- Low Environmental Impact
- Fuel Flexibility
- High Reliability
- Quiet Operation

Advantages

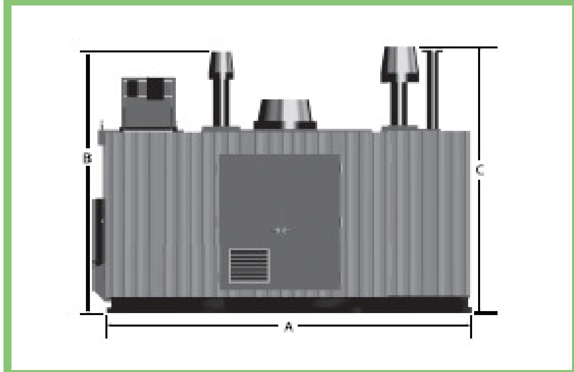
The DFC®300™ stationary fuel cell power plant from FuelCell Energy provides high-quality, Ultra-Clean electrical power with 47% efficiency in a small footprint. Designed for commercial and industrial applications, the system offers 24/7 operation, easy transport, quiet and reliable operation, and easy site planning and regulatory approval.

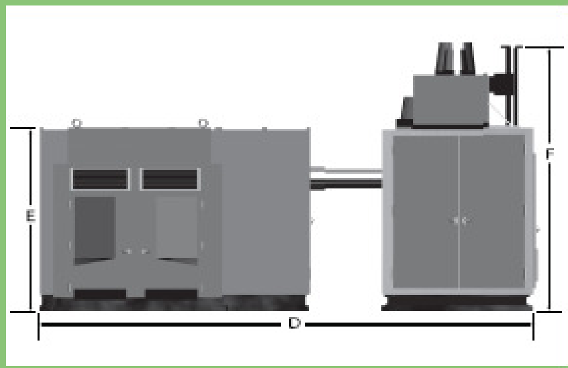
Performance

Power Output	
Power @ Plant Rating	300 kW
Standard Output AC Voltage	480 V
Standard Frequency	60 Hz
Optional Output AC Voltages	460, 440, 420, 400, 380 V
Optional Output Frequency	50 Hz
Efficiency	
LHV	47 +/- 2 %
Available Heat	
Exhaust Temperature	700 +/- 50 °F
Exhaust Flow	3,950 lb/h
Allowable Backpressure	5 iwc
Heat Energy Available for Recovery	
(to 250°F)	480,000 Btu/h
(to 120°F)	808,000 Btu/h

Fuel Consumption	
Natural gas (at 930 Btu/ft³)	39 scfm
Heat rate, LHV	7,260 Btu/kWh
Water Consumption	
Average	0.9 gpm
Peak during WTS backflush	10 gpm
Water Discharge	
Average	0.45 gpm
Peak during WTS backflush	10 gpm
Pollutant Emissions	
NOx	0.01 lb/MWh
SOx	0.0001 lb/MWh
PM10	0.00002 lb/MWh
Greenhouse Gas Emissions	
CO_2	980 lb/MWh
CO_2 (with waste heat recovery)	520-680 lb/MWh

Specifications





Dimensions

Front View

A	Overall Width	20.0 ft
B	Height of Air Intake Filter	15.1 ft
C	Height of Exhaust Stack (Required on units with no heat recovery)	14.5 ft

Side View

D	Overall Length	28.0 ft
E	Height of EBOP	11.8 ft
F	Height of Discharge Vent	14.5 ft

Weights

Mechanical Balance of Plant	27,000 lb
Electrical Balance of Plant	15,000 lb
Fuel Cell Module	35,000 lb

Noise Level

Standard	72 dB(A) at 10 feet
Optional	65 dB(A) at 10 feet

Experience & Capabilities

With more than 35 years of experience, FuelCell Energy is recognized as a world leader in the development, manufacture, and commercialization of fuel cells for stationary electric power generation. The result of years of research and the investment of more than $530 million, our patented, carbonate Direct FuelCell products have generated more than 200 million kilowatt hours of electrical energy to date at more than 50 locations worldwide.

This brochure provides a general overview of FuelCell Energy products and services. This brochure is provided for informational purposes only. Warranties for FuelCell Energy products and services are provided only by individual sales and service contracts, and not by this brochure. This brochure is not an offer to sell any FuelCell Energy products and services. Contact FuelCell Energy for detailed product information suitable for your specific application. FuelCell Energy reserves the right to modify our products, services, and related information at any time without prior notice.

FuelCell Energy's fleet of Direct FuelCell power plants are certified to or comply with a variety of commercial and industrial standards: ANSI/CSA America FC-1, UL 1741, CARB 2007, OSHA 29 CFR Part 1910, IEEE 1547, NFPA 70, NFPA 853, and California Rule 21.

©2008 FuelCell Energy, Inc.

FuelCell Energy, Inc.
3 Great Pasture Road
Danbury, CT 06813-1305
203 825-6000

www.fuelcellenergy.com

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

PureCell Model 400 System [56]

Model 400

UTC Power
A United Technologies Company

MODEL 400
PureCell® System

Introducing a new generation of fuel cell technology: The PureCell® Model 400 Energy Solution.

UTC Power is a world leader in developing and producing fuel cells for on-site power, transportation, space and defense applications. We are committed to providing high quality solutions for the distributed energy market that increase energy productivity, energy reliability and operational savings for our customers. Building on our unmatched operational experience and a technology platform proven at more than 260 sites worldwide, UTC Power is pleased to offer an advanced fuel cell energy solution for the commercial marketplace.

The ultra clean and quiet PureCell® Model 400 fuel cell can provide up to 400 kW of assured electrical power, plus up to 1.7 million Btu/hour of heat, for combined heat and power applications. And with energy efficiencies more than double those of traditional power sources, the PureCell® Model 400 system is an energy solution that will not only help you conserve precious resources, it will save you money, shield you from operational interruption, and secure your place at the forefront of environmentally sustainable business practices.

Performance Characteristics

Power

Electric power	400 kW/400 to 471 kVA initial 400 kW lifetime average 360 kW initial (ADG)
Voltage/frequency	480VAC/60 Hz/3 phase** 400VAC/50 or 60 Hz/3 phase

Efficiency

Electrical (LHV)	42% initial/40% nominal (5 yr)
Overall (LHV)	90%***

Fuel

Supply	Natural gas or ADG†
Consumption (HHV)	3.60 MMBtu/hr (1,054 kW) initial 3.79 MMBtu/hr (1,110 kW) average 3,493 scfh (98.9 Nm^3/hr) initial 3,678 scfh (104.2 Nm^3/hr) average
Pressure	4 to 14 in. water (1.0 to 3.5 kPA)‡

Heat Recovery

Low grade (60°C/140°F supply)§	1.537 MMBtu/hr (450 kW) initial 1.708 MMBtu/hr (500 kW) nominal
High grade (121°C/250°F supply)§	0.683 MMBtu/hr (200 kW) initial 0.785 MMBtu/hr (230 kW) nominal

Emissions*

NO_x	0.035 lb/MWh (0.016 kg/MWh)
CO	0.008 lb/MWh (0.004 kg/MWh)
CO_2	1120 lb/MWh (508 kg/MWh) average
SO_x	Negligible
Particulate matter/VOCs	Negligible

Water

Consumption	None (up to 86°F/30°C ambient)
Discharge	None (normal operating conditions)

energy
Reinvented

Other

Noise	<65 dBA at 33 ft (10m) with no heat recovery <60 dBA at 33 ft (10m) with full heat recovery
Overhaul interval	10 yr

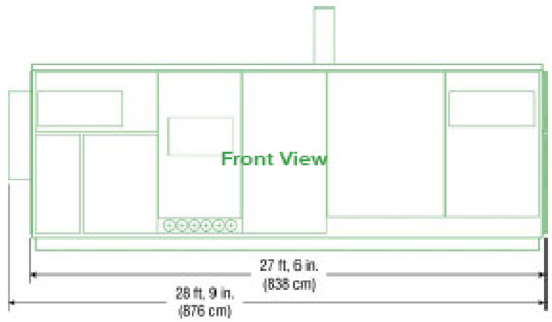
* Emissions meet 2007 California Air Resources Board standards. ** Operating range from -20° to 113°F (-29° to 45°C) at up to 492 ft (150m). *** Overall efficiency as given assumes full thermal utilization. † All given characteristics are for a natural gas application, unless otherwise noted. Maximum allowable levels for natural gas components are documented separately in the PureCell® Model 400 System Installation Design Guide. ADG applications require an additional gas processing unit. ‡ Gauge pressure.
§ Available heat at rated power. Low-grade heat assumes a return temperature of 80°F (27°C); high-grade heat assumes a return temperature of 194°F (90°C). If high-grade heat is utilized, the remaining value will be available as low-grade heat.

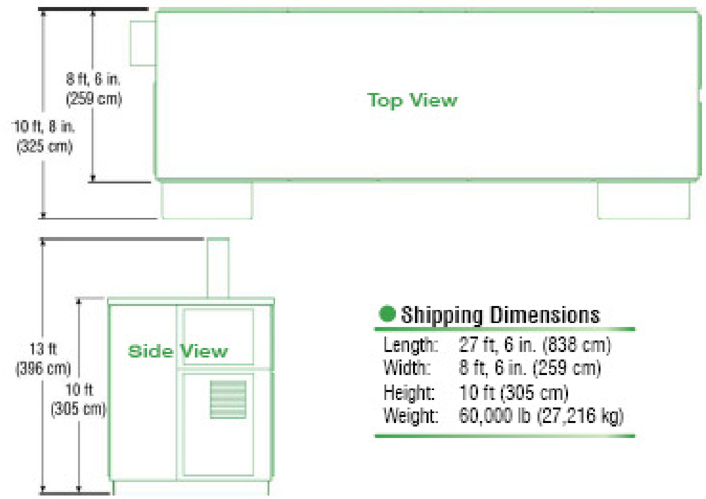
MODEL 400
PureCell® System

Model 400

Physical Characteristics

Power Module

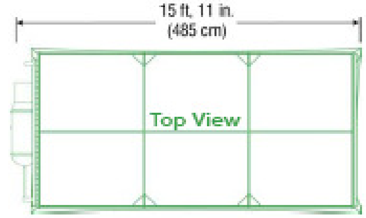


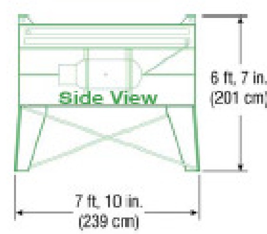


Shipping Dimensions

Length: 27 ft, 6 in. (838 cm)
Width: 8 ft, 6 in. (259 cm)
Height: 10 ft (305 cm)
Weight: 60,000 lb (27,216 kg)

Cooling Module





Shipping Dimensions

Length: 15 ft, 11 in. (485 cm)
Width: 7 ft, 10 in. (239 cm)
Height: 6 ft, 7 in. (201 cm)
Weight: 3,190 lb (1,447 kg)

The manufacturer reserves the right to change or modify, without notice, the design or equipment specifications without incurring any obligation either with respect to equipment previously sold or in the process of construction. The manufacturer does not warrant the data on this document. Warranted specifications are documented separately.

UTC Power
A United Technologies Company
195 Governor's Highway . South Windsor, CT 06074 . Phone: (866) 900-POWER . Fax: (860) 727-2319 . www.utcpower.com
Copyright ® 2008 by UTC Power Corporation. All rights reserved.

DS0012 R06/10/08

InfraStruXure Data Sheet [36]

Fuel Cell Solutions for InfraStruXure™ Systems

Fuel Cell technology for increased availability and runtime – a green alternative to batteries and generators

Designed for InfraStruXure systems and other network-critical applications with the highest availability requirements, the APC Proton Exhange Membrane (PEM) Fuel Cell solution is a new alternative to batteries and generators.

The fuel cells are contained in 10-kW modules for rack-integration in ISX systems. As the architecture of racks and modules is scalable, it is easy to add more power.

The hydrogen fuel is contained in standard bottles. For extended system runtime, simply increase the number of bottles.

As the next step towards commercialization this new system is now made available for evaluation in your InfraStruXure installation.
Contact in Europe, Middle East and Asia: *lars.malmrup@apcc.com*
Contact in North and South America: *gary.rumsey@apcc.com*

Typical applications

InfraStruXure Solutions with high availability requirements

Features & Benefits:

AVAILABILITY

- Increased runtime
- Pre-engineered system
- Minimum of moving parts

ENVIRONMENT

- Hydrogen fueled
- By-products: heat and water only
- Low audible noise
- Easy to install

SCALABLE ARCHITECTURE

- Modular design
- Rack-integrated
- InfraStruXure compatibility
- Scalable runtime

SERVICEABILITY

- Simple mechanical design
- Minimum maintenance
- Indoor installation
- Standard bottled hydrogen

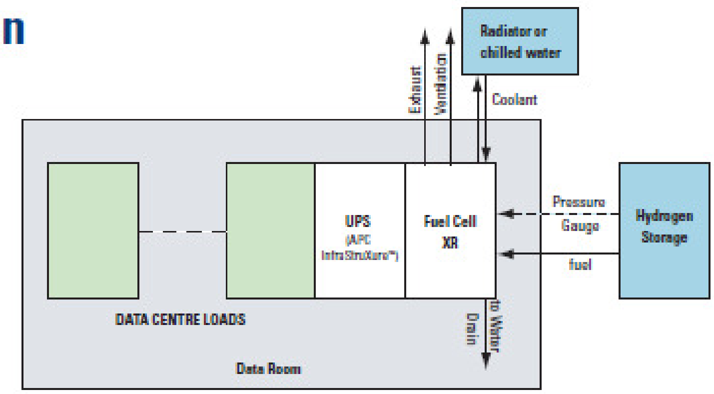
InfraStruXure™
DATA CENTERS ON DEMAND

On-Demand Architecture for Network-Critical Physical Infrastructure

APC
Legendary Reliability®

The Fuel Cell Installation

- Indoor installation close to the load
- Hydrogen stored outside in standard bottles is fed through a pipe system to the fuel cells.
- A Fuel Cell Management system handles control, monitoring and safety functions.
- The installation should include a water drain and hot air ventilation.
- During operation a heat radiator cools the Fuel Cells (FC). Install the radiator indoor or outdoor.



Fuel Cell Specifications

Fuel Cell	Fuel Cell Solutions for InfraStruXure™ Systems
Net AC power	Multiples of 10 kW
Design life	10 years and >5000 stop/starts
DC current	2 x 28 A per module
DC voltage	Matches the InfraStruXure battery bus voltage (2 x 192 V)
Configurations	
Fuel cells	1, 2 or 3 modules per rack
DC/DC converters	One converter module per fuel cell module
Start-up	
Fuel cell start-up	Maximum 20 seconds @ cold start
Fuel	
Composition	99.99% dry gaseous hydrogen
Storage	Pressurised bottles
Environment	
Emissions	Water and heat
Audible noise @ 1m	45 db (stand by), 60 db (idling), 75 db (full load)
Installation	
Fuel cell	InfraStruXure racks integrated with InfraStruXure
Hydrogen bottles	Outdoor
Heat dissipation	Radiator or chilled water <15 kW @ full load (1 module)
Dimensions	
Rack	207.01 x 109.19 x 59.69 cm (H x D x W) (42 U) / 81.5 x 42.99 x 23.5 inch (H x D x W)
Volume	1.35 m³/47.6 cft
Weight	
With 1 module	< 400 kg/880 lbs
Additional modules	125 kg/275 lbs per module
Runtime	
10 kW @ 1 bottle	79 minutes (1 bottle = 10 Nm³ hydrogen)
30 kW @ 10 bottles	4 hours 24 minutes (10 bottles = 100 Nm³ hydrogen)
Regulatory	
Compliance	CE, UL

For more information call: Tel: 800 800 4APC - US & Canada Tel: 401 789 0204 - World wide

APC Corporate Corporate Headquarters 132 Fairgrounds Road West Kingston RI 02892 USA Call: 401 789 5735 Fax: 401 789 3710

APC Latin America 5301 Blue Lagoon Drive Dr. Suite Suite #610 Miami, FL 33126 USA Call: 305 266 5005 Fax: 305 266 9695

APC Europe APC Ireland Ballybrit Business Park Galway, Ireland Call: +353 91 702000 Fax: +353 91 756909

APC Asia Pacific APC Australia 100 Miller Street Level 27 Northpoint North Sydney, NSW 2060 Call: +61 2 9955 9366 Fax: +61 2 9955 2844

Visit: www.apc.com **E-mail:** apcinfo@apc.com **Web Support:** support@apc.com **PowerFax™:** 800-347-FAXX

APC is certified by ISO9001 (Quality standards), and by ISO14001 (Environmental standards).

ISO9001 ISO14001

Legendary Reliability®

©2005 All rights reserved. All APC trademarks are property of American Power Conversion. Other trademarks are property of their respective owners. Specifications are subject to change without notice. PART # 996-2856C

Appendix C - Fuel Cell Items in the American Recovery and Reinvestment Act [86]

US Fuel Cell Council

Fuel Cell Items in the American Recovery and Reinvestment Act of 2009

The AARA, signed into law on February 17th, 2009 contains two parts. Division A: Appropriations Provisions and Division B: Tax, Unemployment, Health, State Fiscal Relief, and Other Provisions. Fuel cell and hydrogen technologies will likely benefit from program items noted below.

Division A: Appropriations

Title III - Department of Defense:
Provides **$75 Million for every RDT&E** ($300 million total) program managed by the Army, Navy, Air Force as well as Defense Wide programs. Fuel cells are eligible for funding under this program as noted in the report language as well as wind, solar, biofuels and bioenergy.

Title IV - Department of Energy:

EERE
Provides $16.8 billion for EERE of which **$2.5 billion will benefit applied research, development, demonstration and deployment activities** ($1.2B carve out for biomass and geothermal). The remainder of the funding will be determined by the Secretary of Energy

Energy Efficiency and Conservation Block Grants - $3.2 Billion. Of the total, $400 million will be competitively awarded. Eligible projects include fuel cells in buildings and $3.1 Billion for State Energy Program.

State Energy Program – $3.1 Billion. The State Energy Program (SEP) provides grants to states to address their energy priorities and program funding to adopt emerging renewable energy and energy efficiency technologies.

Alternative Fueled Vehicles Pilot Grant Program - $300 Million (Clean Cities) Designed to help acquire motor vehicles with a higher fuel economy, including hybrid vehicles, electric vehicles, commercially available plug-in hybrid vehicles and the necessary infrastructure. A total of 30 grants, based on geography, will be awarded on a competitive basis.

Transportation Electrification - $ 400 million to benefit a variety of vehicle platforms including fuel cells and fuel cell plug-in vehicles. Priority will be given to large-scale projects including programs at airports, material handling facilities, etc.

Electricity delivery and Energy Reliability - $4.5 billion for Smart Grid applications. Of the total, $10 million to implement section 1305 of EISA which directs the National Institute of Standards and Technology to establish protocols and standards to increase the flexibility of use for Smart Grid equipment and systems.

1100 H Street NW, Suite 800 | Washington, DC 20005 | T. 202.293.5500 | F. 202.785.4313 | www.usfcc.com

Fossil
The committee provided $3.4 billion for FE R&D $1billion for fossil energy research and development programs; $800million for additional amounts for the Clean Coal Power Initiative Round III Funding Opportunity Announcement. Fuel cell work has been incorporated into this suite of programs in the past.

Science

Advanced Research Projects Agency-Energy (ARPA-E), $400 million for RDT&E. Created under the America COMPETES Act of 2006, ARPA-E was designed to fast-track high-risk/high-reward technologies.

Title V—Financial Services and General Government

General Services Administration:

Federal buildings fund - $5.5 billion for high-performance Green Federal buildings.

Energy Efficient Federal Motor Vehicle Fleet Procurement - $300 million for market support for advanced, efficient and lower carbon Federal vehicles.

<u>Division B: Tax Credits</u>

Repeal of Limitation on Property Financed by Subsidized Energy Financing -
Eliminates reduction of grants and subsidizes on fuel cells to allow for maximum tax credit impact.

Increased Limit on Issuance of Clean Renewable Energy Bonds
Increases limit on Clean Renewable Energy bonds to $1.6 billion. Bonds can be issued by power provides, governments electric coops. Qualified facilities include those eligible for the Investment Tax Credit.

Modification of Credit for Residential Energy Efficient Property
Modifies existing Investment Tax Credit residential fuel cells (placed in service in January 2009 and limited to joint occupancy dwellings) by increasing dollar cap to $3,334/kW.

Temporary Increase in Credit for Alt. Vehicle Refueling Property
Until January 1, 2011 the tax incentive for hydrogen fueling stations will be 30% up to $200,000. (This was increased from $30,000).

Grants for Energy Property in Lieu of Tax Credits
Between 2009 and 2010, facilities with insufficient tax liability can apply for a grant instead of claiming the ITC. Only tax-paying entities are eligible.