The Role of Distributed Generation and Combined Heat and Power (CHP) Systems in Data Centers

U. S. Environmental Protection Agency
Combined Heat and Power Partnership

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Foreword

The U.S. Environmental Protection Agency (EPA) Combined Heat and Power (CHP) Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. CHP is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. CHP can increase operational efficiency and decrease energy costs, while reducing the emissions of greenhouse gases, which contribute to global climate change.

The CHP Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new projects and promote their energy, environmental, and economic benefits. The partnership provides resources about CHP technologies, incentives, emission profiles, and other information on its Web site at: www.epa.gov/chp.

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1 Overview

This report reviews how distributed generation (DG) resources such as fuel cells, reciprocating engines, and gas turbines—particularly when configured in combined heat and power (CHP) mode—can offer powerful energy efficiency savings in data centers, especially when integrated with other energy efficiency measures.

The growing need for reliable, cost-effective power is a key issue for the data center industry, as indicated as follows:

- Electricity consumption for servers (includes servers and cooling and auxiliary infrastructure) doubled in the United States between 2000 and 2005 and represents about 1.2 percent of total U.S. power use (Koomey, 2007).
- A single data center can house hundreds or thousands of servers. Continued growth in the server population is expected as companies look to expand data center capabilities.
- As server densities also increase to squeeze more computing power into less space, the energy consumption estimates of a single server rack can exceed 20 kilowatts (kW).
- According to AFCOM (2006), power failures and limits on power availability will halt data center operations at more than 90 percent of all companies at some point over the next five years.
- A survey conducted by Ziff-Davis Media (2006) revealed that more than 70 percent of operators identify information technology power and cooling as a primary issue in data center management.
- With rising energy costs and fears of inadequate energy supply and reliability on the horizon, businesses are looking for efficient solutions to address these trends.

DG resources in CHP systems that use waste heat to provide cooling can offer the greatest benefits and lowest paybacks throughout the supply chain and are ideally suited to the steady power and cooling loads of data centers. For instance, in a CHP configuration, fuel cell systems can have paybacks approaching 10 years when state and utility incentives are included; gas turbine and microturbine systems can have financial paybacks of less than five years. Clean DG—whether fuel cells or other clean energy prime movers—can also provide environmental benefits regionally, in the reduction of criteria pollutants that otherwise would be emitted by grid-generated electricity, and globally, in the reduction of greenhouse gas emissions. In addition to these financial and environmental benefits, DG systems can also significantly improve the reliability of power supply for data centers.

The DG technologies discussed in this report include fuel cells (typically 10 kW to 2 megawatts [MW] in size), microturbines (30 kW to 250 kW), gas turbines (500 kW to 20 MW), and reciprocating engines (100 kW to 3 MW). Solar photovoltaic power (PV) could be a supplementary source of power as well, but due to the intermittent and as-available nature of PV, it would not be considered a reliable, primary source of power for a data center. The focus of this report is on DG that can be dispatched on demand to support both the energy and reliability needs of data centers. It is also important to note that the optimal use of DG/CHP in data centers

requires that all cost-effective efficiency improvements in server and building operations be implemented before considering a DG/CHP investment.
The report is organized into the following sections:

- ***Chapter 2 - Data Center Energy Use Characteristics:*** Describes the power usage, reliability, and quality requirements and air conditioning requirements that affect the application of DG and CHP in this market.

- ***Chapter 3 - Benefits of Clean Distributed Generation and Combined Heat and Power:*** Provides a discussion of the benefits of DG/CHP to data center operators and the rest of the energy supply chain.

- ***Chapter 4 - Distributed Generation Applications at Data Centers:*** Describes in what applications DG/CHP can be used at data centers and includes case study examples of three CHP applications.

- ***Chapter 5 - Issues Affecting Implementation of Distributed Generation at Data Centers:*** Describes barriers that are limiting the widespread application of DG/CHP in data centers and areas where the U.S. Environmental Protection Agency (EPA) CHP Partnership can help.

2 Data Center Energy Use Characteristics

Data centers are characterized by very high energy utilization intensities, and the internal heat load creates a nearly constant demand for air conditioning to maintain equipment within a narrow range of temperature and humidity necessary for proper operation. This chapter describes common features of data centers as they relate to power consumption and power security and quality requirements.

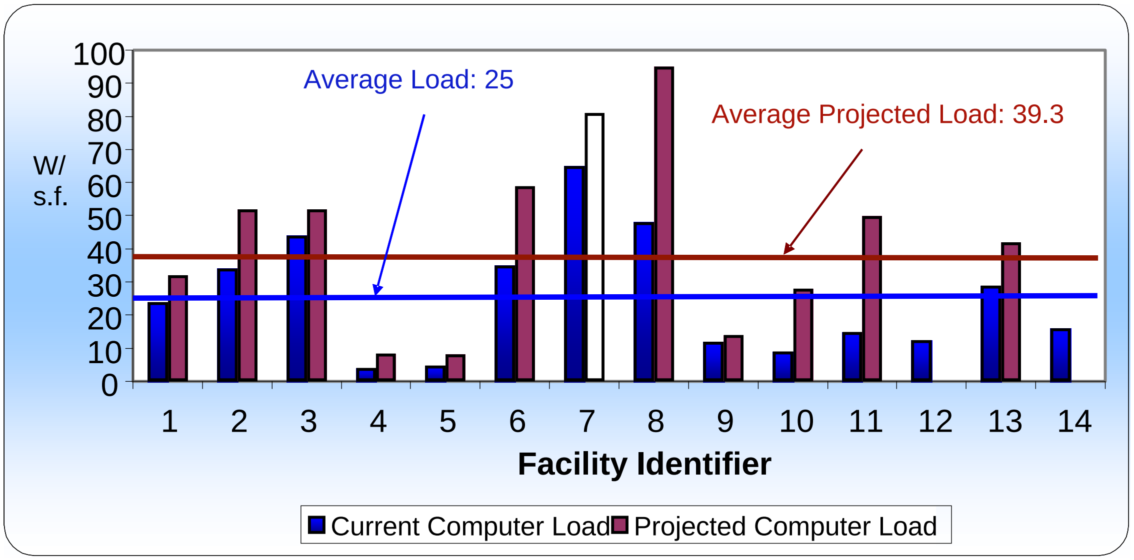
2.1 Power Capacity Requirements

Data centers have much higher energy utilization intensities (20 to 100 watts per square foot [W/s.f.]) than typical commercial buildings, which average 2 W/s.f. based on annual consumption data for all commercial buildings (EIA, 2006). Nationally, data centers represent approximately 1.2 percent of total U.S. power use—or about 5,000 MW (Koomey, 2007). The energy consumption estimates of a single-server rack can exceed 20 kW (Hughes, 2005).

As Internet commerce and traffic began exploding in the late 1990s, the industry experienced general concern that power demand in data centers would become a significant share of power demand in the United States and other countries. A Lawrence Berkeley National Laboratory (LBNL) benchmarking study (2003) found considerable variation in power use among data centers depending on their design and intended use (see Figure 1). The LBNL study found that energy usage intensity averaged 25 W/s.f. across the 14 examined data centers and projected increased energy intensity to 39 W/s.f.

In fact, however, predictions of runaway energy consumption in data centers have not come true. Energy intensities in data centers have been increasing but at a much slower rate than originally expected. While the energy density of individual rack components that make up data center equipment has increased greatly, rated loads for server equipment tend to be much higher than typical usage levels. Additionally, typical facilities contain a mix of high and low power consumption equipment. Some designers predict a 500-W/s.f. data center in just a few years (Hughes, 2005), but these claims are not universally accepted within the industry.

Figure 1. Average Energy Usage Intensity of Select Data Centers, 2003



Source: LBNL, 2003

For new or expanding data center facilities, power requirements can range from 1 MW up to 50 MW. In some circumstances, electric utilities cannot provide this level of power without considerable advance notice and planning—on the order of one to two years or more. Compounding the difficulty of receiving needed capacity in a timely manner, data centers have developed a reputation for requesting much more power than they actually use and are therefore sometimes charged for all of the upgraded facilities requested (e.g., substations, transformers, power lines).

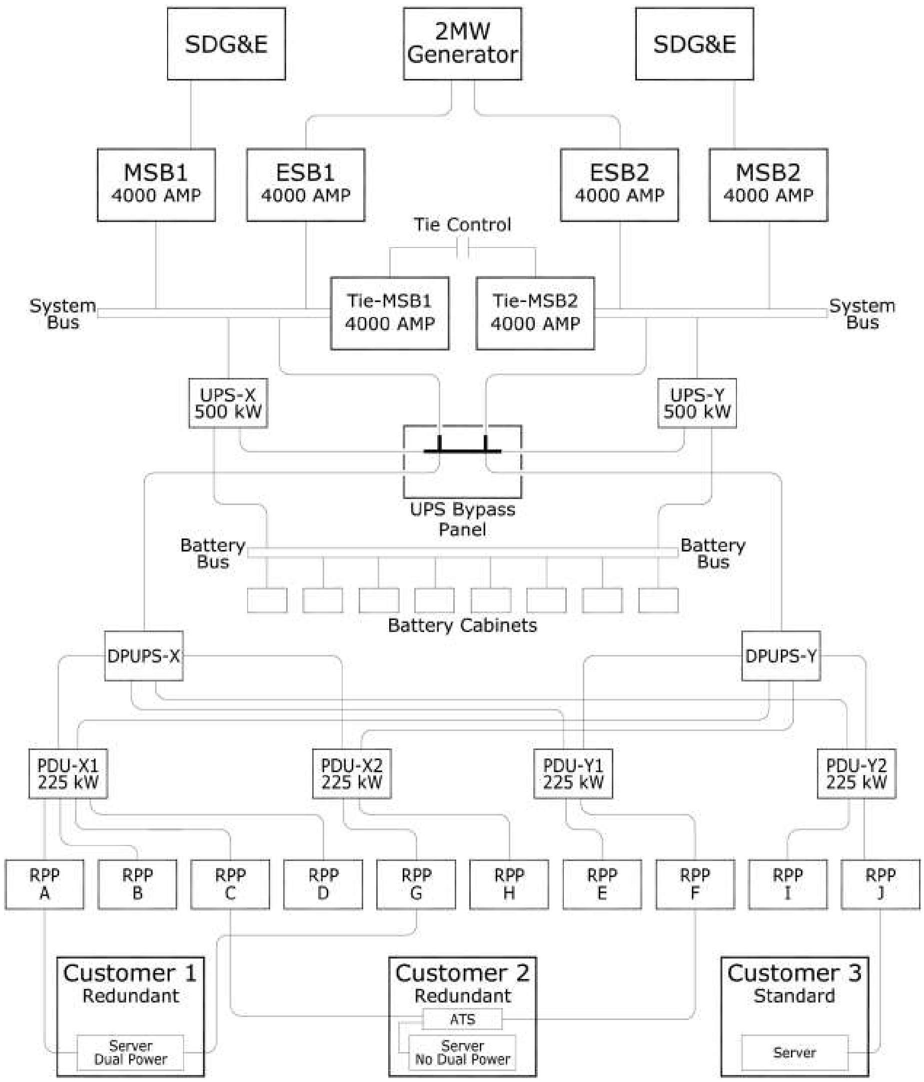
2.2 Power Quality Requirements

A continuous supply of premium power is essential to all data centers to avoid equipment downtime. For such highly critical equipment, the cost of being offline, even for a short period, can run well into the millions of dollars.

Figure 2 shows a schematic of the power supply for a 25,000-s.f. co-location data center in San Diego. The system is an example of 2N architecture—all required power services are backed up into two separate and redundant systems that are each capable of meeting the entire facility load. The facility has two separate 4,000-amp, 480-volt feeds from the utility—each to an individual master supply bus (MSB). This system provides automatic switching between the two independent transformers located on the property. In the event of an extended power outage, diesel generators capable of supplying either of two independent emergency supply buses (ESBs) provide input power to the facility. Three thousand five-hundred gallons of onsite diesel stored on the facility are capable of providing fuel for more than 24 hours at maximum power. The system can also be refueled while operating (American Internet Services, n.d. (a)).

The facility has 1 MW of redundant uninterruptible power supply (UPS) power and a fully redundant 2,400-amp, 48-volt, positive ground direct current (DC) battery power plant and distribution system. UPS power is fed into redundant power distribution units (PDUs) and from there into remote power panels (RPPs). Each RPP is monitored to the circuit breaker level to ensure early warning overload protection (American Internet Services, n.d., (a)).

Figure 2. Power Layout for a 25,000-Square Foot Data Center in San Diego, California



Source: American Internet Services, n.d. (b)

2.3 Air Conditioning Needs[1]

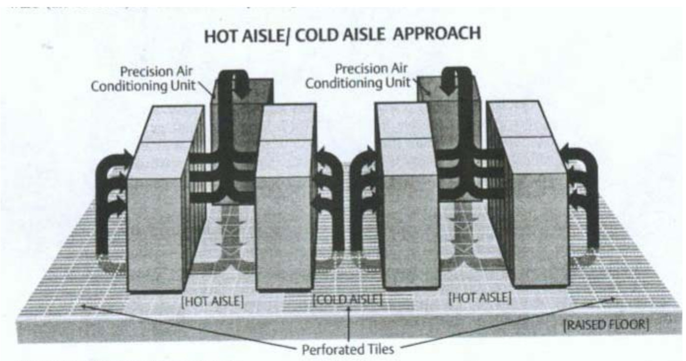
The primary goal of data center air conditioning systems is to keep the server components at the board level within the manufacturer's specified temperature/humidity range (Hughes, 2005). Air

[1] Information in this section is from Hughes, 2005.

conditioning is critical because electronic equipment in a confined space generates much excess heat and tends to malfunction if not adequately cooled. Air conditioning systems also help keep humidity within acceptable parameters. The presence of too much humidity could cause water to begin to condense on internal components; with too little humidity, static electricity can damage components. Generally, temperature should be kept around 68°F to 72°F; humidity should be kept between 35 and 65 percent relative humidity. To put the cooling load in perspective, an IBM series Bladecenter server requires 24 kW of power in a 2 x 3.5 x 6 foot space. All of this power is converted to heat. Therefore, each of these racks requires 6.8 tons of air conditioning.

The typical configuration of a data center air conditioning system is called a hot aisle/cold aisle layout (see Figure 3). The computer rooms are on a raised floor that serves as the conditioned air delivery system.[2] Computer room air conditioning units (CRACs) deliver cold air under the floor in alternating aisles; the hot air is removed overhead.

Figure 3. Typical Data Center Air Conditioning (Hot Aisle, Cold Aisle) Layout

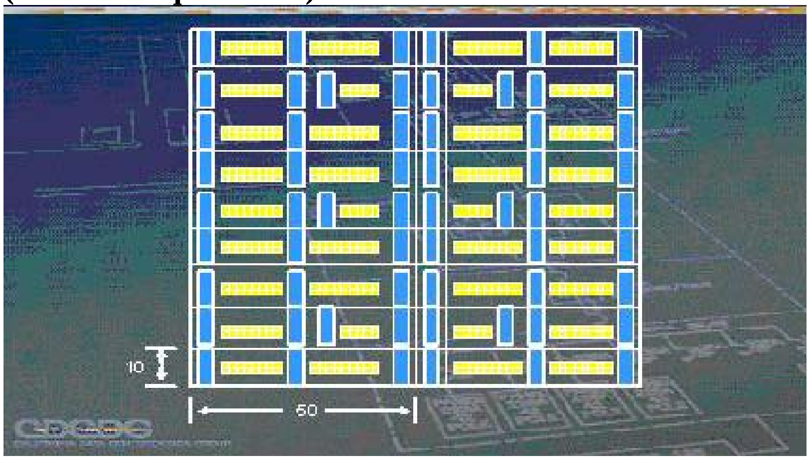


Source: Pouchet, 2007

Figure 4 illustrates the number of CRAC units required for a 10,000-square foot data center at 500 W/s.f. As power densities go up, the space required for air handling and air conditioning equipment also goes up, reducing the available floor space for the servers. CRAC units typically use water-cooled condensers that are tied into cooling towers for heat removal. In other configurations, the CRACs are replaced by computer room air handling units (CRAH) that are tied into a central water chiller.

[2] In fact, it is standard terminology to refer to the actual square footage of a data center that is devoted to computer equipment as the *raised floor area.*

Figure 4. Server Rack and Air Conditioning Layout for a 10,000-Square Foot Data Center (500 watts/square foot)



Source: Hughes, 2005

Integrating the cooling loads with a combined heat, cooling, and power system would require the use of a central chiller and CRAHs. Alternately, water cooling for the racks could meet cooling requirements and would be would be more space and energy efficient than traditional systems. Water cooling design would also be tied into a central chiller system using the heat from a CHP system.

3 Benefits of Distributed Generation and Combined Heat and Power for Data Centers

DG and CHP applied in data centers can provide cost savings to the facility operator in the form of:

- Reduced energy-related costs and enhanced economic competitiveness─from reduced fuel and electricity purchases, resulting in lower operating costs.
- Increased reliability and decreased risk from outages─due to reliable onsite power supply.
- Increased ability to meet facility expansion timelines─by avoiding the need for utility infrastructure upgrades.

In addition to these cost savings, DG/CHP provides the following benefits to the energy supply chain:

- Increased economic development value─through energy cost savings, businesses can be more economically competitive in a global market, maintaining local employment and economic health.
- Increased energy efficiency from generating electricity and useable thermal energy from a single fuel source.
- Reduced emissions of greenhouse gases─reduced fuel use results in lower levels of fossil fuel combustion and reduced emissions of carbon dioxide (CO_2).
- Reduced emissions of criteria air pollutants─reduced fuel use and cleaner technology results in lower air emissions of carbon monoxide (CO), nitrogen oxides (NO_X), and sulfur dioxide (SO_2).
- Increased reliability and resource adequacy for the grid─customer-sited generation can provide support and stability to the distribution grid and reduce or defer the need for regional power plant and transmission construction.

3.1 Reduced Energy Costs

Due to their very high electricity consumption, data centers have high power costs. Installing CHP systems with absorption cooling can often reduce energy costs by producing power more cheaply on site than can be purchased from the utility supplier. In addition, waste heat from the power generation can drive absorption chillers that displace electric air conditioning load.

Table 1 shows simple annual savings and paybacks for four actual CHP systems installed in California and the Northeast. Capital costs for the first three DG systems were based on average capital costs for completed installations under the California Self Generation Incentive Program (SGIP), plus an assumed capital increase for absorption cooling of $1,200/ton based on the cooling capacity required for each system. Capital costs for the gas turbine were estimated based on an estimated price for a complex installation with a double effect absorption chiller

($350/ton), selective catalytic reduction (SCR) and CO control with a continuous emissions monitoring system (CEMS) and average U.S. construction costs.

Given the performance of these systems and a favorable differential between the price of fuel and the price of electricity (called the spark spread) that can be found in California or the Northeast, annual energy cost savings of between $239/kW and $697/kW are available. For example, one data center in New York recently installed a 1.4 MW fuel cell CHP system that saves the company $680,000 per year on its energy costs.

Fuel cell DG systems offer many attractive qualities, such as DC power output, for use in data centers. But fuel cells, as a new-market entrant, attract a price premium over more traditional DG systems. So while DG systems based on traditional gas turbine or engine technologies can be considered cost effective without incentives, fuel cells, in some cases, will need financial incentives to be cost effective. Very generous incentive programs are available in some areas, such as the California SGIP fuel cell incentive of $2,500/kW, which can be combined with the federal tax credit for fuel cells of $1,000/kW. Microturbines are eligible for smaller incentives under both of those programs.

Table 1. Energy Cost Savings Comparison for Combined Heat and Power in Data Centers

CHP System	Molten Carbonate Fuel Cell/ Chiller	Phosphoric Acid Fuel Cell/ Chiller	Microturbine/ Chiller Package	Gas Turbine/ Chiller
Capacity, kW	1,000	200	200	3,364
Heat Rate, Btu/kWh	8,060	9,480	14,300	13,930
Capital Cost, $kW	$7,238	$7,805	$4,088	$2,312
Total Capital Cost	$7,238,000	$1,560,900	$817,600	$7,778,200
O&M Cost*, $/kilowatt hour	$0.032	$0.029	$0.022	$0.022
Annual O&M Cost	$266,304	$48,268	$36,617	$615,895
Annual Gas Cost**	$503,065	$118,339	$178,507	$2,924,767
Annual Avoided Electricity** Savings	($1,103,497)	($220,756)	($354,668)	($5,153,526)
California SGIP	($2,500,000)	($500,000)	($160,000)	($800,000)
Federal Fuel Cell Tax Credit	($1,000,000)	($200,000)	($40,000)	
Net Capital Cost	$3,738,000	$860,900	$617,600	$6,978,200
Net Unit Capital Cost, $/kW	$3,738	$4,305	$3,088	$2,074
Payback without Incentives, years	21.7	28.8	5.9	4.8
Payback with Incentives, years	11.2	15.9	4.4	4.3

*Operations and maintenance (O&M) costs are based on having an annual service contract in place, as is typical; no facility staff would be required to provide system maintenance or service.

**Based on gas price of $7.50/million British thermal units (MMBtu) and electricity price of $0.13/kWh reflective of electricity price in California and the Northeast.

3.2 Increased Reliability

As described in Chapter 2, data centers require both high quality and extremely reliable power. Of all customer types, data centers, telecommunication facilities, and other mission-critical computer systems have the highest costs associated with power outages or lapses in power quality, ranging from $41,000 for cellular communications to as high as $30 million per minute for data center operations during peak periods. (Bryson, et al., 2001; Ziff-Davis Media, 2006); Digital Realty Trust, 2007).

Data centers almost always have UPS systems to condition power and eliminate momentary outages, sags, surges, and other deviations from a clean, in-phase sinusoidal power signal. Data centers often have more than one utility feed and associated seamless switching equipment to increase the reliability of service. Battery backup is generally used to provide a short term outage ride-through of a few minutes to an hour. Longer term outages are typically handled with standby diesel generators.

Onsite power generation, whether it is an engine, fuel cell, microturbine, or other prime mover, supports the need for reliable power by protecting against long-term outages beyond what the UPS and battery systems can provide. DG/CHP systems that operate continuously provide additional reliability compared to emergency backup generators that must be started up during a utility outage. Backup generators typically take 10 to 30 seconds to pick up load in the case of an outage. The increased reliability provided by continuously operating DG/CHP can be used to reduce the amount of battery backup that is typically designed into premium secure power systems. For example:

- A DG system that is already running during a grid power disturbance does not need to be started. Therefore, the likelihood of a non-start is eliminated.
- A continuously operating DG system serves the function of a second power feed, significantly reducing non-available power times and reducing the need for battery backup.
- A continuously operating DG system can provide voltage support for the facility, reducing the likelihood of voltage sags and other power quality disturbances from the grid.

The availability factor[3] of DG/CHP systems is an important component in determining the overall system reliability. The most recent comprehensive report of DG/CHP availability was conducted for Oak Ridge National Laboratory in 2003 (Energy and Environmental Analysis, 2004). Of the systems studied, reciprocating engines showed availability factors averaging 96 to 98 percent. Gas turbines had availability factors from 93 to 97 percent. Fuel cells, which are a new market entrant, have demonstrated the potential to achieve comparable availability factors as the sales and service infrastructure matures in the fuel cell market.

[3] The availability factor is the proportion of hours per year that a unit “could run” (based on planned and unplanned maintenance) divided by the total hours in the year.

Reliability of power supply to the facility can be increased by using parallel utility feeds and onsite DG/CHP generation (see Table 2). A typical onsite DG/CHP system, as described previously, could have an availability factor of 97 percent; a utility service feed availability is roughly 99.7 percent. The availability of power with onsite DG/CHP plus one independent utility feed would therefore be 99.97 percent, resulting in 43 minutes of expected outages per year. With two independent utility feeds plus CHP, the availabilities would be at a level of 99.99998 percent, with only 7 seconds of expected outages per year. These short-term power supply outages can be handled with onsite energy storage, typically batteries.

Table 2. Effect of Distributed Generation/Combined Heat and Power and Multiple Utility Feeds on System Reliability

Power Source	Availability	Outage Time Per Year
Utility Feed 1 (UF 1)	99.7%	24 hours
Utility Feed 2 (UF 2)	99.7%	24 hours
DG/CHP	97.0%	263 hours
System Availability With Multiple Feeds		
UF 1 + DG/CHP	99.97%	43 minutes
UF 1 + UF 2	99.999%	4 minutes
UF1 + UF2 + DG/CHP	99.99998%	7 seconds

DG/CHP can increase reliability and resource adequacy for the power grid as a whole, not just for the facility operator. Rapid growth in local power demand can create localized shortages of power and impact power quality and reliability of the grid. Considerable concern emerged about the concentration of data centers in the Silicon Valley area of California during the power and fuel crises of 2001. The problems led to local concerns of pollution from overuse of diesel generators and to migration of new and some existing data centers out of the region in search of more reliable power supplies. Based on the ability of utilities to expand supply, transmission, and substation capacity, it could take several years before such shortages are eliminated. DG/CHP can reduce or delay infrastructure investments, making the grid more reliable for all customers.

3.3 Facility Expansion

Developing onsite power sources provides data center operators with increased flexibility in both the expansion and design of new facilities. Upgrading older, smaller data centers with new equipment can require a large increase in power demand to the facility that might not be able to be met by the utility in the near term. Incorporating continuous prime power DG/CHP options can facilitate expansion and facility development on a more rapid schedule than can sometimes be possible by relying solely on the existing utility grid. Minimizing external power demand also reduces additional utility infrastructure requirements and associated costs that might be required for new or expanded facilities.

3.4 Economic Development

By reducing operating costs and providing other economic value to a facility, such as reduced outage costs, the facility becomes more economically competitive. This economic development value can be important to facilities that are competing on a global basis. Reduced operating costs translate into greater profitability and more competitive pricing of services.

Increasing the economic competitiveness of a facility's operation benefits not only the facility operator but also the employees and the surrounding economy. Money generated by the facility in terms of wages and materials purchased creates a multiplier effect for the local economy.

3.5 Increased Energy Efficiency

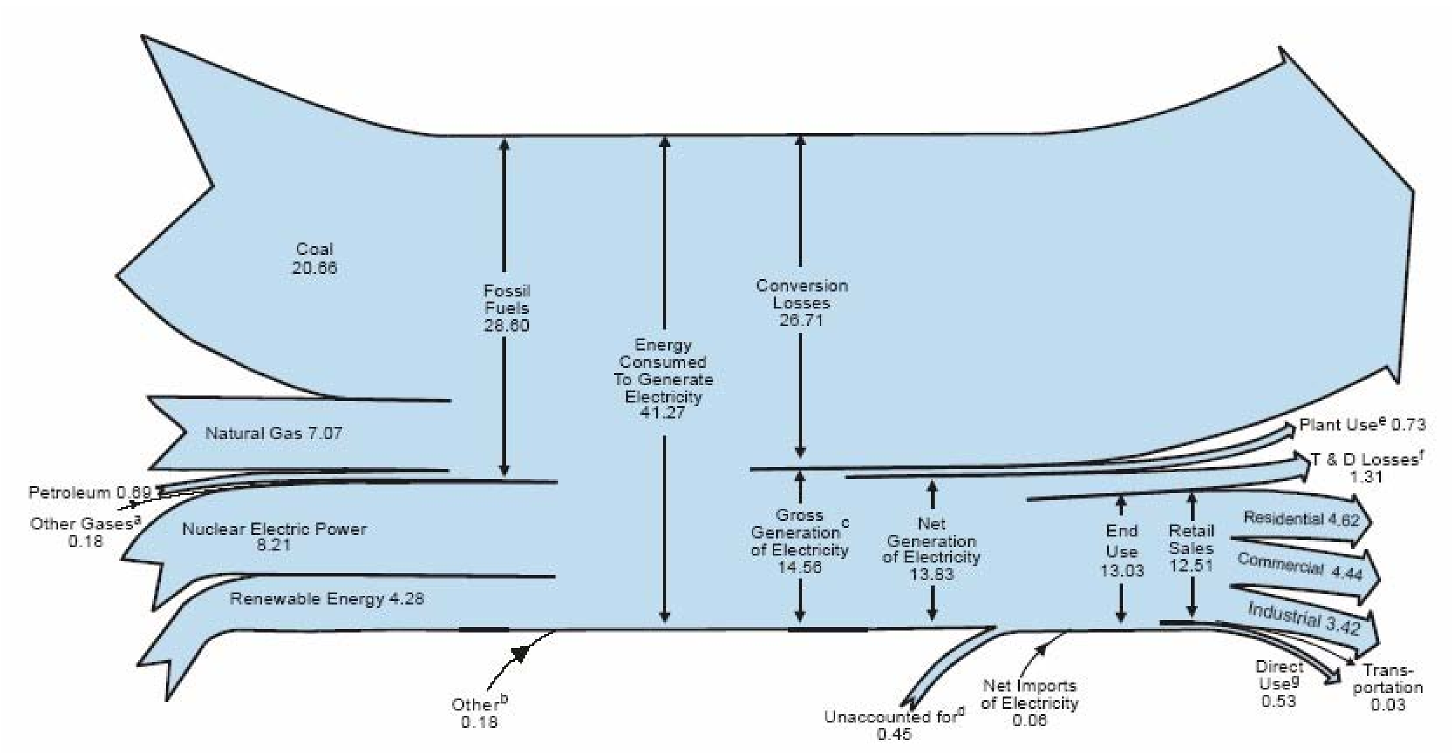
Energy efficiency is valued for a number of reasons: reducing dependence on fossil fuels, decreasing emissions of greenhouse gases and other air pollutants, reducing pressure on energy prices, and increasing economic viability and sustainability.

In the United States as a whole, nearly 40 quads[4] of primary resource energy are consumed each year to generate electric power. For the most part, this energy is released in the form of heat that provides the motive force to drive the electric generators. Of the 40-quad energy input that goes into electric power generation nationally (Figure 5), about 26 quads of heat energy literally goes up the stack in the form of heat losses. With large central station power plants located far away from demand centers, there is no way to utilize or economically transport this heat energy—it is simply wasted. The energy content of this unutilized resource is equal to the U.S. annual imports of oil. To put this quantity in further perspective, it is more than equal to the entire energy requirements of Japan, the fourth largest energy user in the world.

As shown in the figure, roughly two-thirds of the energy input is released as heat to the environment. Even the most efficient thermal electric generation process available today releases about 40 to 45 percent of its energy as waste heat. In fact, central station power generation creates even more losses. In addition to the heat losses, about 5 to 10 percent of the electricity generated is lost and converted back to heat as a result of resistance losses in the transmission and distribution (T&D) system. The alternative to this approach is to generate electricity at or near the customer load centers so that the heat energy can be used by industries, commercial buildings, and other users. In addition, with distributed energy resources, T&D line losses are eliminated.

[4] One quad = one quadrillion, or 10^{15}, British thermal units (Btu) and is roughly equivalent in energy to 1 trillion cubic feet of natural gas.

Figure 5. 2006 Energy Use in the U.S. Electric Power Sector Shows Energy Conversion Losses

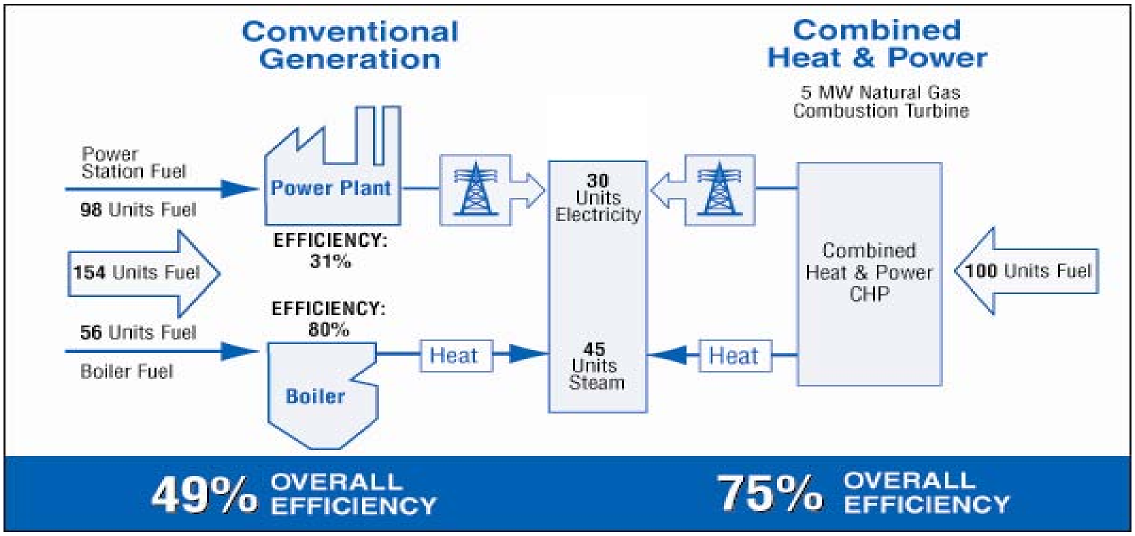


Source: Energy Information Administration, 2007

The average efficiency of fossil-fueled power plants in the United States is 33 percent and has remained virtually unchanged for four decades. This means that two-thirds of the energy in the fuel is lost—vented as heat—at most power plants in the United States. In addition to heat losses, about 5 to 10 percent of the electricity generated by central plant power stations is lost before it reaches an end user as a result of resistance in the T&D system.

The alternative to this approach is to generate electricity at or near the customer load centers to avoid line losses and use the heat energy resulting from electric generation. By using waste heat recovery technology to capture a significant proportion of this wasted heat, CHP systems typically achieve total system efficiencies of 60 to 80 percent, compared to only 49 percent for producing electricity and thermal energy separately (see Figure 6). In data centers where the thermal load is almost entirely cooling rather than heating, CHP can still provide an overall efficiency advantage. The waste heat from the generator is used in absorption chillers to produce cooling, which displaces electricity-powered electric chillers rather than displacing direct fuel purchases for heating. In addition to the electricity produced by the generator, the total electricity displaced by a combined cooling and power system can be up to 35 percent more than the onsite generator capacity. Therefore, the total electricity provided and displaced by a combined cooling and power system can be up to 135 percent of the onsite generator capacity.

Figure 6. Combined Heat and Power Efficiency Advantage Compared to a Central Power Plant and an Onsite Boiler



3.6 Emissions Benefits

Data centers have very low site emissions, but their high energy intensity results in a large emissions signature from a source perspective (i.e., the utility's emissions to produce electricity for the data center). CHP systems reduce emissions of criteria air pollutants—CO, NO_X, and SO_2—through increased efficiency and the use of cleaner technologies. Emission reductions can be particularly significant when state-of-the-art CHP equipment replaces outdated and inefficient existing equipment (generally used for backup power) at the site. In fact, fuel cells have such low emissions that they can emit fewer criteria pollutants in a year as the primary power source for a data center than a diesel generator will emit in 24 hours operating as a backup generator (see Tables 3 and 4). CHP also reduces emissions that contribute to global climate change; increased efficiency of fuel use allows facilities to achieve the same levels of output with lower levels of total fossil fuel combustion, reducing emissions of CO_2.

Table 3 compares annual emissions from four CHP options with central station generation:

1. 1,000-kW molten carbonate fuel cell with a double effect absorption chiller.
2. 200-kW phosphoric acid fuel cell with a single effect absorption chiller utilizing roughly half of the available thermal energy from the system.
3. 200-kW microturbine system with a double effect absorption chiller.
4. 3,400-kW gas turbine system with a double effect absorption chiller and emissions after treatment (SCR and CO reduction) with a continuous emissions monitoring system.

The CHP emissions factors are shown on a per unit of power output basis and incorporate a credit for the displaced emissions from avoided air conditioning load met by the absorption chillers. The CHP emissions are compared to the average emissions from fossil-based power generation in the United States[5], Each of the four systems show reductions in NO_X, SO_2, and CO_2, compared with the average for central fossil-based power generation.

Table 3. Emission Benefits of Combined Heat and Power

Characteristics	Combined Heat and Power				Central Power
	Molten Carbonate Fuel Cell/ Chiller	Phosphoric Acid Fuel Cell/Chiller	Microturbine/ Chiller Package	Gas Turbine/ Chiller	U.S. Fossil Power Average*
Capacity, kW	1,000	200	200	3,364	
Heat Rate, Btu/kWh	8,060	9,480	14,300	13,930	
CHP Emissions Factors (for generated electricity minus avoided air conditioning emissions)					
NO_x, lb/MWh	0.0058	0.0273	0.2583	0.0751	N/A
SO_2, lb/MWh	0.0003	0.0003	0.0003	0.0376	N/A
CO_2, lb/MWh	848	998	937	1056	N/A
Annual Emissions (based on 8,760 hours/year)					
NO_x, lb/MW-year	51	239	2,262	658	21,725
SO_2, lb/MW-year	2.36	2.77	2.60	329	44,501
CO_2, tons/MW-year	3,716	4,370	4,103	4,626	6,899

*Based on 2000 eGRID emissions data.

Table 4 shows a comparison of two backup power options—a proton exchange membrane (PEM) fuel cell and a standard diesel engine.[6] The table shows that emission reductions are significant from switching to a PEM fuel cell from a diesel engine, even if only in backup power mode. NO_X and SO_2 emissions from a fuel cell are less than 1 percent of those from a diesel engine, and CO_2 emissions are 30 percent less with a fuel cell than a diesel generator.

[5] Combustion-based power generation is power generated from fossil fuels, biomass, and waste fuels. Nuclear, hydro, solar, and wind power are not included because these sources would typically not be displaced by DG.
[6] Diesel technology emissions can be reduced through the use of low-sulfur diesel fuel and incorporation of engine modifications and exhaust after-treatment. These technologies are being developed for the transportation market, but they are not currently being used for standby engines.

Table 4. Emission Benefits of Fuel Cell Backup Power

Characteristics	PEM Fuel Cell	Diesel Generator
Capacity, kW	150	600
Heat Rate, Btu/kWh	9,750	10,000
Emission Factors (generated electricity)		
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/year)		
NO_x, lb/MW-year	2	487
SO_2, lb/MW-year	0.14	69.60
CO_2, tons/MW-year	14	20

4 Distributed Generation Applications at Data Centers[7]

DG can be applied in a variety of configurations to meet a hierarchy of facility needs, including standby/backup power, continuous prime power, and CHP. DG has been successfully employed in data centers using both fuel cells and other types of prime movers, such as reciprocating engines, gas turbines, and microturbines. Appendix 1 provides a listing of recent fuel cell installations in data centers throughout the country. It also includes three case studies of successful CHP system applications in data centers in New York and California.

4.1 Standby/Backup

The traditional emergency or backup generator is a form of DG. In standby mode, the electric utility is the primary source of power, and onsite power generation is used only as a backup during a scheduled shutdown or failure of the utility feed(s). A UPS is used to bridge the time delay while the standby system starts. This mode of operation is used in more than 99 percent of network rooms and data centers that have local power generators (see Figure 2) (APC, 2003).

The standard generation technology for this mode is a diesel generator. Emergency diesel generators are relatively inexpensive; they can pick up load rapidly on start-up, and they are reliable if properly maintained. Lack of maintenance and testing, however, can reduce system reliability and lead to the engines failing to start when needed. In addition, diesel generators for emergency use are very high emitters of pollution and can produce visible smoke, noise, and odor that can lead to local complaints when a facility tests or is forced to use its generators.

Some data centers are considering a switch to cleaner technologies for backup power, including gas- or propane-fired engines, microturbines, or fuel cells. These technologies take longer to start and pick up load than a diesel engine, so they might require additional energy storage in the form of batteries or flywheels. Fuel-cell-based backup power systems are just emerging as commercial products. Fuel cell use for backup power is being developed by a number of companies with remote telecommunications facilities as an early target market. In 2005, a fuel cell product was introduced into the market that provides backup power to data centers using bottled hydrogen as a fuel. Another fuel cell product on the market fits within a single 42U Rack and provides 30 kW of backup power. Fuel cell technology is currently aimed at data center applications where conventional backup power is impractical and where backup needs are longer than can be provided by conventional diesel generator-based UPS systems.

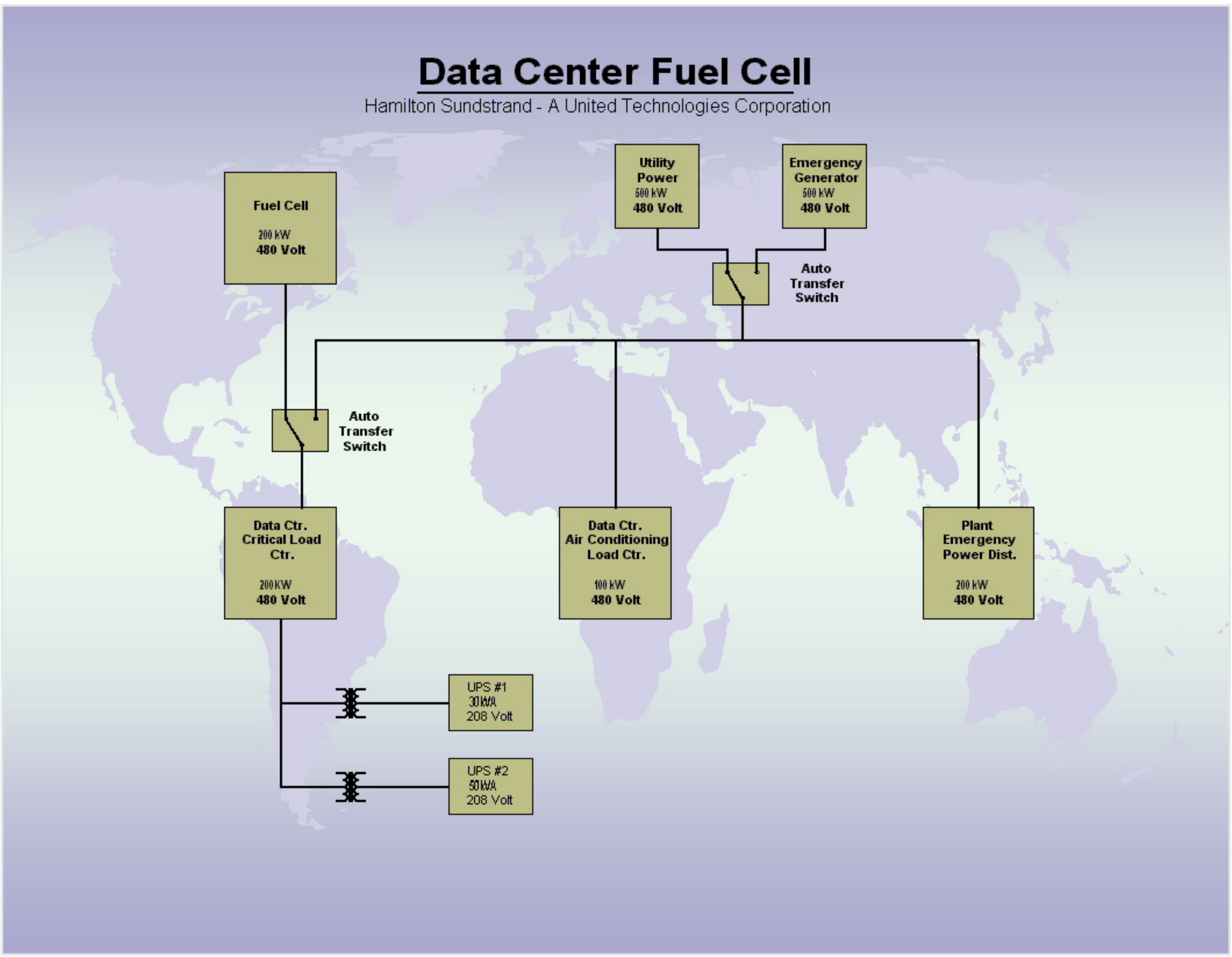
4.2 Continuous Prime Power

In continuous prime power mode, DG is the primary source of power, and utility-supplied power is used primarily as a backup during a scheduled shutdown or failure of the onsite generator. Use of the utility feed in this way is not free, but most utilities have established standard tariffs for providing standby power to a customer with its own generator. In some states, these rates are high enough to discourage customer-sited generation; in other states, standby tariffs are more

[7] Information in this section was adapted from APC, 2003.

favorable to DG/CHP.[8] UPS and battery backup are used to maintain system power during switchover from onsite to utility power and to maintain power quality. Using DG in continuous prime power mode without capture and use of waste heat can be cost-effective in areas with high overall electricity costs and/or high demand charges. One example of a prime power installation is a 200-kW fuel cell system installed at the Hamilton Sundstrand data center in Windsor Locks, Connecticut (see Figure 7).

Figure 7. Prime Power Configuration at Hamilton Sundstrand Data Center



Source: United Technologies Corporation, 2007

One efficiency measure that works particularly well for continuous prime power integrated with DG systems is the use of DC power as the underlying power backbone (Robertson, 2003). In a DC-based system, a dual DC ladder bus aggregates all of the outputs of the distributed generators and provides multiple paths for the power supply to reach the loads. The system can use any combination of generators—turbines, natural gas reciprocating engines, diesel engines, microturbines, fuel cells, or even photovoltaics, operating at any voltage or frequency.

[8] The EPA CHP Partnership tracks favorable utility rates (including standby rates) in its regularly updated funding database at: www.epa.gov/chp/funding.

Distribution feeders from the utility can be a source of generation, too. A major advantage of this architecture—demonstrated through research and development and limited commercial installation—is the elimination of all paralleling and switching required by traditional alternating current (AC)-based DG and backup power systems.

4.3 Combined Heat and Power

CHP mode can be configured in the same ways as prime power mode. The difference lies with the utilization of available heat from the onsite generator to meet facility heating and cooling loads. As previously stated, data centers require so much power—all of it converted to heat as it is used within the facility—that the most useful CHP thermal configuration is one that provides thermally activated air conditioning.

Heat recovered from the onsite power generation unit in the form of steam or hot water can be utilized in an absorption chiller. High-temperature hot water near or above the boiling point (under pressure) can power a single-effect absorption chiller. A single-effect absorption chiller needs about 17,000 Btu of high-temperature hot water or low-pressure steam to produce a ton of cooling (12,000 Btu). Double effect chillers can produce a ton of cooling with 10,000 Btu of steam. Absorption chillers would be used in a data center with computer room air handlers, or less commonly, the chilled water could be fed to water cooled racks. Absorption chillers require larger cooling tower capacity than standard electric chillers and more pumping power.

Gas turbines, reciprocating engines, high-temperature fuel cells like solid oxide and molten carbonate, and microturbines are capable of producing steam that can be used in either a single effect or a double effect chiller. The commercial phosphoric acid fuel cell has a high-temperature heat recovery option that can produce 250°F hot water for powering a single effect absorption chiller. PEM fuel cells do not produce temperatures high enough to use in an absorption cycle. While not a widespread practice at this time, Table 5 shows that there are a number of commercial CHP installations in dedicated data centers or in office buildings, banks, and communications facilities where data processing is a major activity within the building. As shown, a variety of technologies have been used successfully, including fuel cells, reciprocating engines, gas turbines, and microturbines.

Table 5. Combined Heat and Power Installations in Data Center and Communications Facilities

Facility Name	City	State	Prime Mover	Capacity (kW)	Operating Year
Telecommunications Facility	Burlingame	CA	Microturbine	120	2003
Chevron Accounting Center	Concord	CA	Recip. Engine	3,000	1988
Guaranty Savings Building	Fresno	CA	Fuel Cell	600	2004
Citibank West FSB Building	La Jolla	CA	Microturbine	60	2005
QUALCOMM, Inc.	San Diego	CA	Gas Turbine	11,450	1983/2006
WesCorp Federal Credit Union	San Dimas	CA	Microturbine	120	2003
ChevronTexaco Corporate Data Center	San Ramon	CA	Fuel Cell	200	2002
Network Appliance Data Center	Sunnyvale	CA	Recip. Engine	825	2004
Flint Energies Service Center Facility	Warner Robins	GA	Fuel Cell	5	2002
Zoot Enterprises	Bozeman	MT	Recip. Engine	500	2003
First National Bank of Omaha	Omaha	NE	Fuel Cell	800	1999
AT&T	Basking Ridge	NJ	Recip. Engine	2,400	1995
Continental Insurance Data Center	Neptune	NJ	Recip. Engine	450	1995
Verizon Communications	Garden City	NY	Fuel Cell	1,400	2005

Source: Energy and Environmental Analysis, 2006

4.3.1 Case Studies of Combined Heat and Power Applications at Data Centers

Following are three case studies of CHP systems successfully in use at data centers in New York and California.

Example Fuel Cell Application

In April 2002, Verizon Communications was awarded a U.S. Department of Energy (DOE) and New York State Energy Research and Development Authority (NYSERDA) grant through programs aimed at supporting distributed energy resources in applications for data processing and telecommunications. As part of its "Central Office of the Future" project, Verizon installed multiple fuel cells and reciprocating engine generators to power a large central communications and data facility in New York (the Garden City project). Verizon configured the fuel cells for CHP, utilizing waste heat from the fuel cells to provide thermal energy to the site as well. The company designed the project to increase understanding of controls for multiple DG units and to utilize low-grade heat for CHP benefits (CNET, 2006).

Verizon's Garden City project is unique because it uses fuel cells as its primary source of energy. Seven fuel cells generate power for the 292,000-square-foot facility that provides telephone and data services to roughly 35,000 customers on Long Island. It is connected to the commercial power grid as backup (CNET, 2006).

Verizon's benefits from the system are:

- $680,000 per year in operating cost savings.

- Higher facility reliability.
- Displacement of one-third of its electric air conditioning load to thermally activated cooling.
- Lower emissions than those produced by central station power—11 million pounds per year less CO_2 than would have been produced by a fossil-fueled central station power plant.
- Higher overall efficiency.

These benefits are mitigated somewhat by the current high cost of fuel cell power equipment. Verizon spent $13 million on the facility, making the payback about 20 years without any type of incentives. Even with the incentives that Verizon received, the overall system costs, including capital recovery, are higher than for a conventional system (CNET, 2006).

Example Reciprocating Engine Application

Network Appliance, Inc., an enterprise network storage provider, installed a state-of-the-art CHP for its facility in Sunnyvale, California (Engle, 2005). Three 275-kW internal combustion engine packages use natural gas to produce electricity, which is fed to a UPS system that uses flywheels to provide short-term energy instead of batteries.

The waste heat from the engines is used to produce air conditioning for the data center using three 120-ton adsorption chillers. The company decided to use adsorption chillers instead of the more common lithium bromide absorption chillers because the silica gel and water system that adsorption units are based on makes more effective use of the lower temperature heat available from the engine jacket water.

The $2.4-million system meets 80 percent of the facility's electricity needs. The capital cost to Network Appliance was reduced by $800,000 as a result of California's SGIP. Network Appliance estimates its $1.2-million annual electricity bill for its research and development building will be cut by two-thirds. Company management first considered developing its own DG system during the rolling blackouts of 2002, as there was a strong concern that the company's mission critical power needs could not be adequately met without onsite power generation.

Example Gas Turbine Application

Qualcomm, a manufacturer and supplier of information technology and communications equipment, has made numerous energy saving investments at its office/data center world headquarters in San Diego, California. Some of these improvements have included retrofitting lighting; upgrading HVAC; improving the building envelope; installing a 500-kW solar photovoltaic system; using hybrid vehicles for corporate shuttle service; and incorporating efficient CHP to provide power, cooling, and hot water to the facility. These measures reduced energy demand by 10 million kWh per year and reduced CO_2 emissions by 4,000 tons per year between 1993 and 2002.

Qualcomm installed a 1.6-MW gas turbine CHP system at its facility in the early 1990s. The system has saved more than $500,000 annually in cooling costs from two 500-ton absorption chillers driven by heat recovered from the gas turbines. The company saves an additional $100,000 annually through a heat recovery unit that supplies hot water to the facility. Onsite electricity generation reduces demand for utility energy by more than 14 million kWh per year, saving another $122,000. Total annual savings achieved by the CHP system is more than $775,000. Based on its positive experience with the original gas turbine system, Qualcomm is currently expanding its campus CHP system, installing two high-efficiency 4.8-MW recuperated gas turbines with heat recovery. One turbine will be dedicated to a new data center at the headquarters campus, supplying both power and cooling to the facility.

5 Issues Affecting Implementation of Distributed Generation at Data Centers

Predictions made in the late 1990s that power demand for data centers would grow rapidly to become a significant share of total U.S. electricity demand have not entirely come true. Power demand for data centers is increasing in terms of power use per square foot, but overall increases are occurring at a slower rate. Regionally, however power growth for data centers can be an important part of overall power demands and growth requirements. Reducing the power infrastructure requirements of these "data center" centers has become an important consideration particularly in areas such as the Silicon Valley in the Bay Area of California. Power demands are continuing to grow while the ability of the local grid to meet existing load plus growth is becoming increasingly tenuous. In addition, the specter of megawatts of diesel engine capacity all firing up together during capacity related outages or brownouts might prove to be unacceptable to many communities.

Fuel cells and other forms of DG power and thermally activated cooling can provide the reliability and power quality benefits that data centers require while also providing environmental benefits and energy cost savings. Widespread adoption of such systems in data center applications has been impacted by a number of issues, however:

- Power outage costs are so high that many facility operators are reluctant to deviate from the standard design of UPS, battery storage, and standby diesel generators. The failure modes of these systems are well known, and proper design to ensure reliability has become standard practice.
- Fuel cells in particular, but also other DG systems, do not have much of a track record in these high power quality, high reliability applications; therefore, not all failure modes are completely known. (Specifically, failures from the interaction of the fuel cell or microturbine system power electronics with the UPS and switching systems are relatively untested.) Demonstration systems are in place throughout the country, which are providing important opportunities to prove reliability and improve operational practices.
- Fuel cell DG systems have very high costs. Higher production levels combined with engineering and materials advances are needed to bring costs down. In addition, not enough fuel cells have run for an extended duration to provide statistically significant results to show when stack replacement is necessary, which is a major cost.
- Other types of DG systems are more cost-competitive, but these systems could also benefit from reductions in packaging, site engineering, and installation costs.
- Part of the value of CHP is the integration of thermally activated cooling from central chillers, typically used only in large facilities. Some work is needed to demonstrate the use of chillers in smaller facilities.
- Fuel-cell-based backup power systems are emerging as commercial products. These small fuel cell systems tend to compete more with battery systems than with diesel generators.

- Battery systems represent a costly component of standard systems in terms of dollars and in floor space. Integrating DG systems with other forms of energy storage, such as flywheels, could be an attractive feature for facility operators to consider as a means to reduce required battery capacity.

For these reasons, continued R&D support and incentives are needed to assist fuel cells and other forms of DG in becoming more common in data centers.

The EPA CHP Partnership can contribute to the accelerated adoption of DG/CHP in data centers as follows:

- Provide an information resource to potential users of DG/CHP equipment on available systems, cost, and performance.
- Provide an information resource to system developers and packagers on the market opportunity within the data center market.
- Coordinate with ENERGY STAR® to define data center configurations, power, and cooling requirements today and in the future.
- Support selected data center partners in doing preliminary feasibility studies of DG/CHP installations
- Quantify user and social benefits of increased reliability, environmental emissions reductions, and operating cost reductions. These analyses can stimulate the rate of adoption and also provide a basis for determining appropriate incentive payments.

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Table A-1. Fuel Cell Installations in Data Centers and Related Premium Power Applications

Site	Year	Capacity KW	Manufacturer	City	State	DG Type	Comments
NYSERDA headquarters	2006	2 x 5	Plug Power	Albany	NY	Prime Power	Two fuel cells and a photovoltaic (PV) awning system provide power to the headquarters' systems, including computer, security and phones. The solar electric awning will power one-half of NYSERDA's computer-driven power-load while inverters will convert 3.6 kW of direct current produced by the solar modules, into alternating current.
The Stella Group Ltd.	2005	1 x 5	Plug Power	Arlington	VA	Back-up	The fuel cell is dedicated to certain circuits within the office building, providing back-up power and power quality for the circuits serving the lighting, computers and office machines (telephone system, security system, fax and copier). It can also be directed to charge the battery banks in both the office building and the adjacent solar home of the Stella Group's founder.
Guaranty Savings building	2004	3 x 200	UTC Power	Fresno	CA	CHP	The building is a 12-story, 100,000-square foot, office tower, which will house the INS Division of the Homeland Security Department and the Tax Payer Advocacy Division of the IRS. The fuel cells running on natural gas operate in grid parallel configuration. The project includes a Multi Unit Load Sharing (MULS) system and static switch that enables the fuel cells to provide 24/7 power availability to the building's mission critical loads. The fuel cells include a UPS for the computer server rooms on each floor, the communications systems, building security systems, emergency lighting, elevator motors, and stairwell ventilation fans. The fuel cells provide two categories of waste heat. They provide 1,400,000 Btu/hour at 250°F high-grade heat, and 1,400,000 Btu/hour at 150°F low-grade heat. The high-grade heat is piped to a 120-ton adsorption chiller to supply a cooling load to the bottom three floors of the building. The return side of the chiller thermal supply loop supplements the building's domestic hot water supply. The low-grade heat is piped to the heating coils associated with water source heat pumps that have been installed throughout the building to provide space heating for offices, hallways, and ground-floor common areas.
Naval Oceanic Center	1990s	1 x 200	UTC Power	Stennis Space Center	MS	CHP?	The fuel cell is located at the NAVOCEANO Computer Programming Operations Center (building 1003) which houses a computer center, library, and laboratory. The fuel cell thermal output heats hot water used in the air handlers for space heating and for reheating cooled air to control humidity. (Decommissioned 2002.)
Ramapo College	2000	2 x 200	UTC Power	Mahwah	NJ	CHP	Grid parallel. Supplies power and thermal energy (hot water, space heating) to a student dormitory and a core academic building complex (housing a computer center, telephone exchange, and cable TV station).
U.S. Merchant Marine Academy	2002	3 x 5	Plug Power	Kings Point	NY	Back-up	One-year demonstration of new backup/UPS product.
Gabreski Air National Guard, base telephone exchange	2004	4 x 1	ReliOn	Westhamp-ton	NY	Back-up	The fuel cells are connected to the 48-V battery string on a new uninterruptible power supply (UPS) system installed for this project. One-year demonstration.

Site	Year	Capacity KW	Manufacturer	City	State	DG Type	Comments
Patuxent Naval Air Station office building	2004	1 x 5	Plug Power	Patuxent River	MD	CHP	Powered nine desktop computers, office lighting, oil furnace, and life support systems for animals on display in environmental / conservation building. Grid connected. Excess power transferred to the grid. Cogenerated heat used to provide heat to the building during cold months. (One-year DoD demonstration.)
Fort Gordon Army University of Technology Resource Center	2004	1 x 5	Plug Power	Fort Gordon	GA	Back-up	Provided back-up to the servers that support the online virtual training center. U.S. DoD Residential PEM Fuel Cell Demonstration Program FY 2002.
Camp Roberts Army National Guard Base	2005	1 x 200	UTC Power	Paso Robles	CA	Prime Power to CHP	The facility is the main U.S. Army communications facility on the west coast that provides worldwide communications between the U.S. National Command Authority and deployed military units. The fuel cell running on natural gas operates in grid parallel configuration to provide power stabilization and reduce the facility's electric demand from the grid. If the project receives additional funding from a submitted proposal to the California Self Generation Incentive Program (SGIP), the project will be expanded to include a grid independent back-up generation component and CHP capabilities. The CHP aspect, if implemented, will capture the thermal energy to be used in conjunction with an absorption chiller to assist with the cooling loads of the data center. The fuel cell is equipped with the high-grade heat option which will provide 400,000 Btu/hour of 250°F heat at its high-grade heat exchanger. This will allow the fuel cell to support the thermal demand of an absorption chiller having an output of approximately 20 to 25 tons of cooling.
Chevron Data Center	2002	1 x 200	UTC Power	San Ramon	CA	Prime Power	Supports critical data and retail transaction systems. During a power outage, special switching equipment ensures that the fuel cell will continue to provide electricity to these systems without interruption.
Hamilton Sunstrand Data Center	1997	1 x 200	UTC Power	Windsor Locks	CT	Prime Power	This plant serves as the primary power source for the Hamilton Sundstrand Data Center and Data Center UPSs. It is considered an ultra-high reliable power source in that if an outage occurs it is backed up by the grid via transfer switch AND if the grid is unavailable, the load is transferred to a 500-kW generator.
First National Bank	1999	4 x 200	UTC Power	Omaha	NE	Prime Power	Provides the main power for a critical data processing facility. The bank is one of the largest credit card processors in the nation. Independent verification of 99.9999% system availability using Probabilistic Risk Analysis (PRA).

Site	Year	Capacity KW	Manufacturer	City	State	DG Type	Comments
New York Power Authority, State Office of General Services - Suffolk Office	2005	1 x 200	UTC Power	Hauppage	NY	CHP	The fuel cell is to supply power to the New York State Regional Emergency Management Office, located in the facility. The Regional Emergency Management Office coordinates emergency planning and response for the New York City and Long Island metropolitan areas. The fuel cell running on natural gas is intended to operate in grid parallel and grid independent modes. In the event of a utility interruption, the fuel cell will isolate from the grid parallel circuit and automatically reconnect to a backup circuit within five seconds. Upon utility startup, the fuel cell will automatically return to the grid parallel circuit. The thermal energy from the fuel cell will be captured and used to supplement the facility's heat and domestic hot water system. The hot water loop will have a manual switch to allow for connection to either the boiler return loop or the domestic hot water loop depending on seasonal thermal demands.
Verizon	2005	7 x 200	UTC Power	Garden City	NY	CHP	Seven fuel cells generate power for a 292,000-square-foot facility that provides telephone and data services to some 35,000 customers on Long Island. The facility is connected to the commercial power grid as backup. Waste heat is used for heating and cooling the facility.

Source: Energy and Environmental Analysis, 2006