Combined Heat and Power Applications of Direct FuelCell® Powerplants

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INTRODUCTION

The annual consumption of electricity is steadily increasing. The average annual increase during the years 1990-2030 is estimated to be 1.6% for the United States and 2.7% globally [1]. This represents a significant requirement for incremental generation capacity which cannot easily be fulfilled by the addition of large central generating stations. Permitting considerations, construction costs, long schedules, and constraints in the existing transmission infrastructure all impede the deployment of new large central generation. Distributed Generation (DG) provides an alternative that avoids these limitations. Several DG technologies such as internal combustion engines, fuel cells, micro-turbines, and solar have already been commercially deployed. DG provides additional value compared to central generation: enhanced grid system reliability and power quality, reduced transmission and distribution losses, smaller environmental footprints, ability to use local renewable fuels such as biogas, and high overall efficiency due to proximity to end-user's Combined Heat and Power (CHP) applications.

The importance of CHP is growing in a world of increasing energy costs, and increased emphasis on reduction of greenhouse gases and criteria pollutants. According to the United States Clean Heat and Power Association (USCHPA), CHP systems currently produce almost 8% of US electric power, save about $5 billion annually in energy costs, reduce energy use by 1.3 trillion Btu/year, reduce NOx emissions by 0.4 million tons/year and sulfur dioxide emissions by over 0.9 million tons/year, and prevent release of over 35 million metric tons of carbon equivalent into the atmosphere [2]. In June 2009, the US Department of Energy (DOE) nominated CHP technologies as one of the target areas for funding with a solicitation of up to $60MM for eligible projects.

The necessity of implementing DG and the benefits of using CHP have brought all the different available DG technologies into the spotlight. The following sections will discuss the unique characteristics of commercially available high temperature fuel cells as a DG/CHP option.

DISTRIBUTED GENERATION WITH FUEL CELLS

Fuel cells produce power electrochemically, without combustion, and they are therefore very low in emissions. Lower temperature fuel cell types include Polymer Electrolyte Membrane (PEM) and Phosphoric Acid (PAFC) systems, which operate at ~150 °F and ~400 °F respectively. High temperature fuel cells operate at temperatures above 1,000 °F, and are of two kinds: Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC). SOFCs are in the research stage, and have the potential to eventually be a high power density, low cost technology, with electrical efficiency similar to MCFC. MCFCs have been commercially deployed since 2003, when FuelCell Energy (FCE) began shipping commercial powerplants based on the technology. FCE's version of the MCFC technology is called the Direct FuelCell® (DFC®), a reference to the fact that hydrocarbon fuel is sent directly to the fuel cell stacks, instead of being processed in an external hydrogen generation reforming system. The process of producing hydrogen from hydrocarbon fuels occurs in the electrochemical stacks of a DFC powerplant, where the hydrogen is then used to produce electricity. The heat required by the hydrogen generation reaction is supplied by waste heat from the power generation reactions, instead of by combustion of excess fuel, a key reason for the high efficiency of DFC powerplants.

FCE manufactures a line of powerplant products based on the DFC technology, ranging in output from 300kW to

2.8MW. As shown in Figure 1, the stack design is common across the product line. The stacks are configured into two types of modules: a single-stack module or a 4-stack module – depending on the product. These DFC products are quiet, virtually pollution-free, and operate at 47% LHV electrical efficiency on natural gas or biofuels.

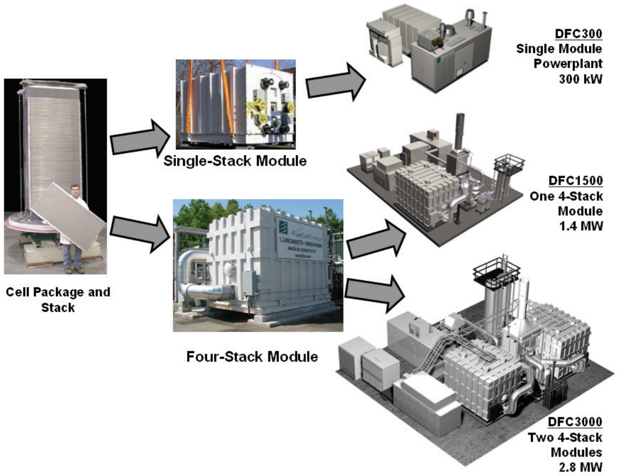

Figure 1
Direct FuelCell (DFC) Powerplants

These powerplants are characterized by a peak LHV electrical efficiency of 47% and an average LHV efficiency of 45% over the life of the cell stack. They have an availability factor exceeding 90%. These performance metrics rank among the highest for DG technologies in their size range.

Like other fuel cells, DFC powerplants use inverter-based power conditioning technology to convert the DC power from the fuel cell stacks to AC power suitable for insertion into local power grids. Inverter technology provides benefits to customer and local grid power quality. Inverters have the ability to provide or absorb reactive power (VARs), they have low frequency distortion, and they have low fault currents.

A simplified cost breakdown of retail electricity is shown in Figure 2. Transmission and distribution (T&D) cost accounts for about one-third of the total cost of retail electricity [3].

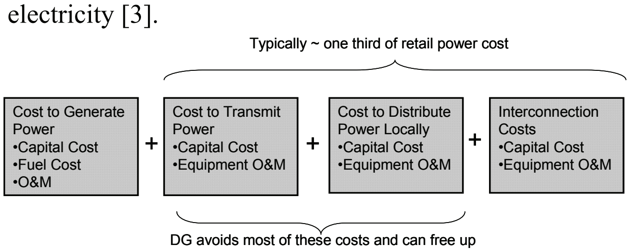

Figure 2: Cost Breakdown Of Retail Electricity

When a DFC powerplant is used in a DG setting, the savings in transmission and distribution costs are further compounded by the high electrical efficiency of the fuel cell. In 2009, the average cost of electricity to end-users in the US varied from 7 to 18.8 ¢/kWh with an average cost of 9.79 ¢/kWh [4]. The average natural gas price ranged from $9.61 to $11.99 per thousand cubic feet in 2008 for industrial and commercial users [5], which translates to an equivalent price of 4.1 to 5.1 cents per kWh of thermal energy, assuming a boiler efficiency of 80%. Since electricity is more valuable than heat, distributed generators having high electrical efficiency provide a distinct economic advantage to the end-user.

There are three energy streams in any CHP system: Fuel input, electricity output and heat output. Each of these streams has an economic value depending on the cost of power and fuel. The gross energy stream economic gain of a CHP system is the fuel cost minus the value of the heat and power streams (i.e. value of avoided grid power and boiler fuel purchases). Figure 3 shows the impact of electrical efficiency on this energy stream economic gain. A total system efficiency (electrical plus thermal) of 65% is assumed. It can be seen that there is a distinct benefit of installing a system with the highest electrical efficiency, even under unfavorable spark-spread conditions.

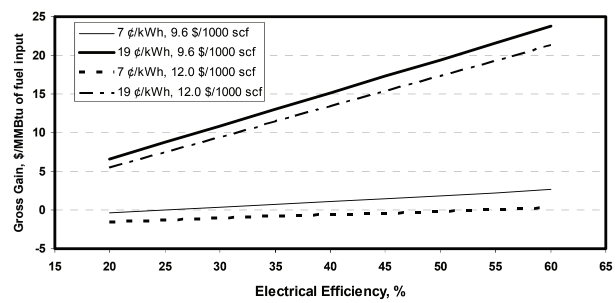

Figure 3: Gross Energy Stream Economic Gain of CHP Systems

Figure 3 does not take into account the differences in capital, operating and maintenance costs. The capital and maintenance costs of a fuel cell can be higher than alternate options; however this is often offset by the fuel savings, federal and state incentives and the sale of renewable energy credits, as discussed later in the paper.

Efficiency and Part-load Efficiency

Figure 4 shows the electrical efficiency of different generation technologies. High temperature fuel cells provide efficiencies similar to large scale combined cycle systems, but at smaller sizes appropriate for distributed generation CHP applications.

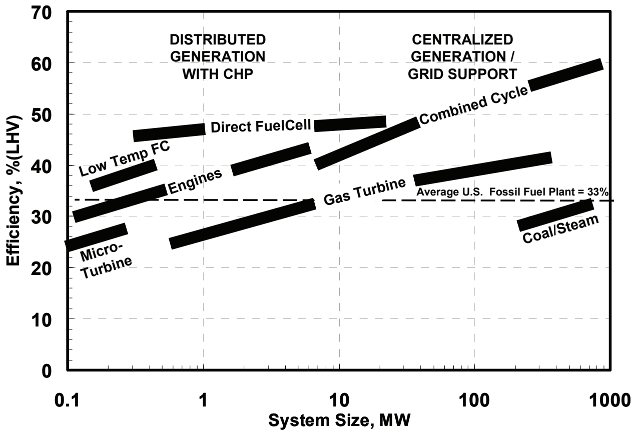

Figure 4: Electrical Efficiency of Generation Technologies

Part-load efficiency performance is an important feature of distributed generators since their electrical requirements may vary from day to night, weekdays to weekends or seasonally. Figure 5 shows the part load behavior of different distributed generation technologies [6]. High temperature fuel cells are suitable for base-load power; they not only have the highest electrical efficiency in their class, but they also have the most favorable part-load performance.

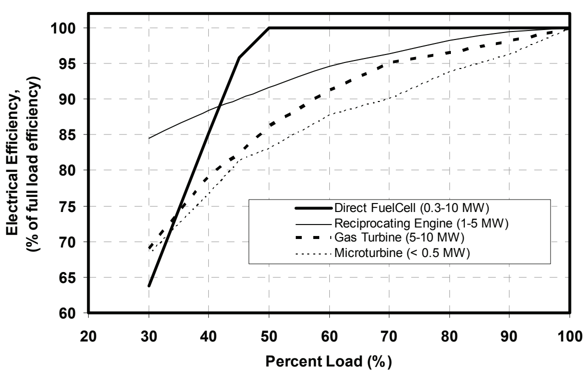

Figure 5: Part-Load Efficiency of Distributed Generators

In addition to the premium electrical efficiency, the potential to use the high temperature exhaust of the fuel cell for heat recovery is an added bonus, as discussed in the following section.

CHP OPTIONS WITH DFC POWERPLANTS

The exhaust gas from the fuel cell is at a temperature of 700°F making it a valuable source of high grade heat. Depending on the application, this heat can be used by conventional heat recovery equipment to generate steam, hot water or drive an absorption chiller. Each of these applications will be discussed below:

Hot Water Heating

Hot water is used in process heating, domestic hot water and space heating applications with varying requirements for water temperature. Figure 6 shows the amount of hot water that can be generated using a DFC powerplant. The following assumptions were made: 20 °F rise across the heat exchanger, 90% use of available heat and a 50 °F approach temperature.

Steam Generation

Steam is used as a motive fluid for rotating equipment, for process heating, space heating and sterilizing applications. Figure 7 shows the amount of steam that can be generated with the exhaust heat of a DFC powerplant. The following assumptions were made: Saturated feedwater temperature, 90% use of available heat, 50 °F approach temperature.

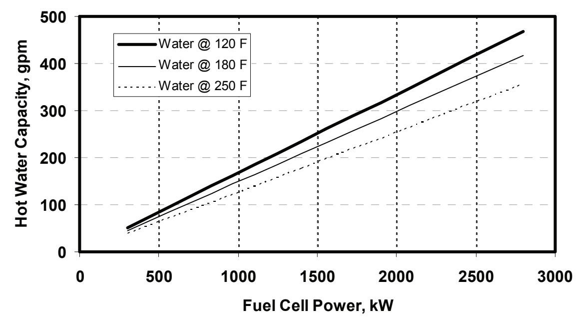

Figure 6: Hot Water Capacity

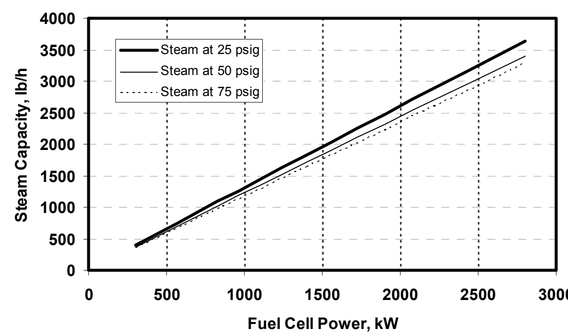

Figure 7: Steam Capacity

Absorption Cooling

Absorption cooling uses heat instead of mechanical energy to drive the refrigeration cycle with a binary mixture as a refrigerant. Chilled water supply temperature typically ranges from 40-45°F with a 10 °F drop. The rejected heat is discharged in a cooling tower. Absorption chillers are driven by:

- Hot water (typically 180°F supply, range from 160°F to 200°F)
- Steam
- Natural gas burners (direct-fired)
- Hot exhaust gas from process (indirect-fired)

When there is a source of high temperature exhaust heat, the indirect-fired absorption chiller is the most attractive option. It does not require an intermediate heat exchanger between the power plant exhaust and the chiller to produce hot water or steam. Natural gas fired burners are eliminated; fuel is not consumed and combustion products are not released to the atmosphere. Indirect-fired double-effect chillers provide the highest coefficient of performance (COP), but require an exhaust temperature of 600°F or higher, making them a good fit for DFC powerplants.

Figure 8 shows the amount of cooling that can be obtained from DFC systems driving double-effect chillers, compared to cooling provided by gas engines, microturbines, and low temperature fuel cells. Total thermal efficiency in all cases is 65%. Electrical efficiencies are 28% for the microturbine, 39% for the engine, 40% for the low temperature fuel cell, and 45% for the DFC fuel cell. The DFC powerplants and engines drive double-effect chillers, while the microturbines and low temperature fuel cells drive single-effect chillers.

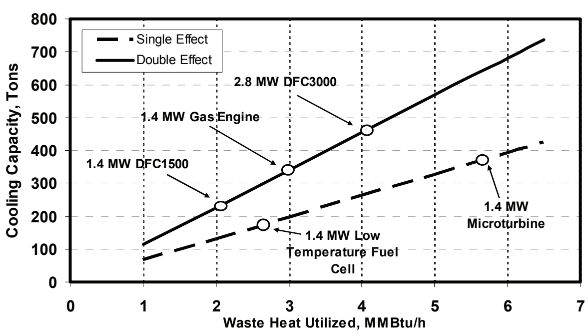

Figure 8: Absorption Cooling Capacity

Condensing Heat Recovery

The exhaust gas from a DFC powerplant typically contains 9-10% oxygen, 4-5% carbon dioxide, 18-20% water vapor and the rest is nitrogen, with a dew-point of 130-135°F. The different modes of heat recovery discussed above (hot water heating, steam generation and absorption cooling) are considered "high-grade" heat recovery where the 700°F exhaust gas is cooled to a temperature of 180-350°F. If a low-temperature heat sink is available at a customer's site (such as swimming pool heating), it is possible to cool the exhaust gas to below its dew-point and recover significantly more heat. Figure 9 shows that the overall efficiency of a DFC fuel cell CHP system can be 90% in applications requiring "low-grade" heat. For illustrative purposes, the temperature of the exhaust from the first stage of heat recovery is shown as 350°F. Depending on specific needs, it is possible to extract more heat in the first stage. This will result in a different distribution of heat recovery between the first stage and the second stage; however, the total system efficiency will still be 90%.

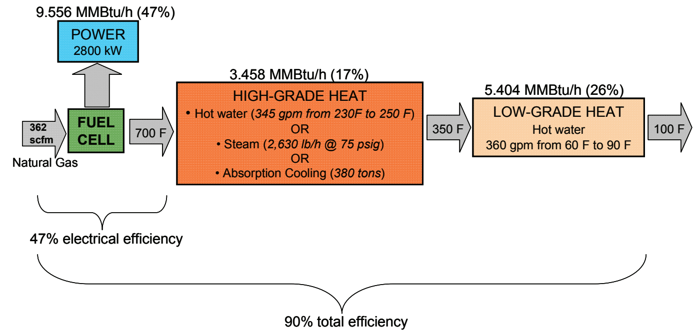

Figure 9: CHP Profile of a 2800 kW DFC Powerplant with 90% Total Efficiency

ECONOMICS OF WASTE HEAT RECOVERY

Heat recovery equipment costs are a function of the heat duty, pressure requirements, materials of construction and customer-specific features. In general, an exhaust gas heat recovery system would consist of a finned tube heat exchanger with the hot gases flowing over the fins and the heated fluid flowing inside the tubes. The temperature and composition of the exhaust from high temperature fuel cell allows the use of carbon steel fins. Stainless steel fins are more expensive and offer higher corrosion resistance (which is not required for fuel cell exhaust); however, they have a lower thermal conductivity than carbon steel and this generally results in a larger heat exchanger. Heat exchangers driven by fuel cell exhaust are therefore less expensive than those driven by exhaust gases that have corrosive components. Heat recovery systems are generally provided with an automatic bypass valve on the hot exhaust side, which is used to achieve temperature control on the cold side.

Costs for hot-water heaters, steam generators and condensing heat recovery systems are shown in Figure 10. For a given heat duty, the cost of a steam generator or a water heater varies depending on the steam pressure or the water temperature required. Installation costs are not included in Figure 10. Installation would add another 20% to 50% to the costs, depending on local construction costs.

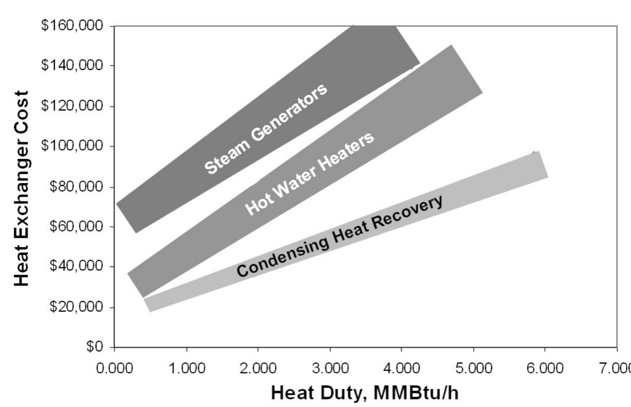

Figure 10: Cost of Heat Recovery Exchangers

Heat recovery makes economic sense. Figure 11 shows the internal rate of return (IRR) over five years for a project implementing heat recovery on an existing generator based on a natural gas cost of $10 per MMBtu. The internal rate of return (IRR) is calculated based on the installed cost of the heat recovery equipment and the revenue from avoided boiler fuel cost. As the figure shows, significant returns are possible because of the value of offset fuel purchases from a small capital investment.

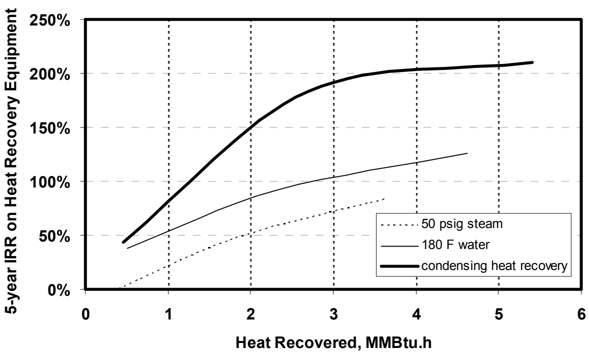

Figure 11: Internal Rate of Return (IRR) of Heat Recovery Projects

ENVIRONMENTAL IMPACT

The deployment of CHP solutions leads to a favorable impact on the environment because waste heat is used instead of fuel in the heating applications of the end user. This results in fuel savings and reduces the combustion products emitted to the atmosphere. In addition to the benefit of waste heat use, technologies that produce cleaner power reduce the overall environmental footprint of the CHP device. The emissions signature is therefore an important aspect of distributed generators. Table 1 shows the exhaust emissions levels for different distributed generators [7].

Table 1: Emissions Characteristics of Various Generation Technologies

	NOx, lb/MWh	SOx, lb/MWh	PM-10, lb/MWh	CO_2, lb/MWh
Average US Grid	1.94	5.26	0.19	1,329
Avg US Fossil Fuel Plant	5.06	11.6	0.27	2,031
Microturbine	0.44	0.008	0.09	1,596
Small Gas Turbine	1.15	0.008	0.08	1,494
Gas Engine (uncontrolled)	2.2	0.006	0.03	1,108
Gas Engine (low NOx)	0.5	0.007	0.03	1,376
DFC Fuel Cell	0.01	0.0001	0.00002	940

Fuel cells are inherently cleaner: since there is no combustion, the production of NO_x and particulates is low. Fuel cells produce less carbon dioxide per unit of electrical power due to their higher electrical efficiency. Because of their minimal impact on air pollution, DFC systems can be easily sited in areas that have stringent pollution standards such as urban areas. These areas also tend to have the greatest demand for new electricity generation and CHP.

CASE STUDIES

The advantages of the high electrical efficiency, high exhaust temperature and favorable emissions profile of a DFC powerplant are demonstrated in the following case studies. For comparison purposes, the emissions from the displaced grid power are assumed to be the US grid average: 1,329 lb/MWh of CO_2 and 1.936 lb/MWh of NO_x [8]. NOx emissions from displaced thermal loads are based on BACT boiler and flare values of 0.035 and 0.015 lb/MMBtu respectively. The case studies evaluate the impact of CHP using a DFC and a typical conventional CHP system, based on a natural gas engine.

Wastewater Treatment

Wastewater treatment facilities present a good opportunity for deployment of CHP. According to a 2007 EPA report, there are more than 16,000 municipal wastewater treatment facilities (WWTFs) in the US and they represent a significant source of biogas, which is produced as a byproduct of the anaerobic digestion process used to treat solid waste [9]. Currently, approximately one third of municipal WWTFs use their biogas for heat, power, or CHP applications leaving a vast reserve of untapped biogas. The typical CHP application at a WWTF involves on-site power generation to offset site electrical load, and heat supply to the digesters, which require heat to operate properly. At facilities which currently use biogas in fired applications (engines or boilers), increasing emissions constraints are forcing evaluation of cleaner technologies. Table 2 shows the energy and emissions profile in a WWTF without CHP and with two options for CHP.

Table 2: Wastewater Treatment Facility Energy Profile

	No CHP System	Gas Engine	Direct FuelCell
WWTP flow, MGD	42.7	42.7	42.7
Population served	425,000	425,000	425,000
Digester heat load, MMBtu/h	1.274	1.274	1.274
Boiler heat load @ 80% efficiency, MMBtu/h	1.593		
Heat content in digester gas, MMBtu/h	10.618	10.618	10.618
Gas flared, MMBtu/h	9.025	0.000	0.000
LHV Electrical efficiency of CHP system		39%	45%
Total efficiency of CHP system		65%	65%
Electricity produced, kW		1213	1400
Heat available from CHP device, MMBtu/h		2.761	2.124
Heat Used in Digesters (90% Heat Transfer Eff.)		1.416	1.416
Unused heat, MMBtu/h		1.345	0.708
NO_x, lb/MWh from generator		2.20	0.01
CO_2, lb/MWh (biogas considered CO_2 neutral)		0	0
NO_x reduction from power production, tons/year		-1.26	10.63
CO_2 reduction from power production, tons/year		6,357	7,334
NO_x reduction from heat production, tons/year		0.8	1.5
CO_2 reduction from heat production, tons/year		0	0
Total NO_x reduction, tons/year		-0.5	12.1
Total CO_2 reduction, tons/year		6,357	7,334

As the table shows, the fuel cell provides 15% more CO_2 reduction (in the form of grid power offset) compared to the lower-efficiency engine. The fuel cell reduces NOx (relative to the grid) while the engine produces more NOx than if the power had been provided by the grid (shown as a negative reduction in the table). The NOx values used for the engine assume no NOx control equipment is used. NOx levels could be reduced with control equipment, but this adds substantially to the capital cost and reduces efficiency, increasing the CO_2 impact.

Hospitals

According to the US Department of Energy, hospitals consume 836 trillion Btu of energy annually. They produce more than 30 pounds of CO_2 emissions per square foot. Hospitals spend over $5 billion annually on energy, which equates to around 1 to 3% of a typical hospital's operating budget or an estimated 15% of profits [10]. The average hospital annually consumes approximately 0.084 kW of energy per square meter, or 20.94 kW per bed [11]. Approximately 40-50% of the energy is consumed in the form of heat for space heating, domestic hot water heating and cooking, while the rest is consumed as electricity. Table 3 shows the energy profile in a typical hospital without CHP, and with two options for CHP.

Table 3: Hospital Energy Profile

	No CHP System	Gas Engine	Direct FuelCell
Number of beds	400	400	400
Hospital electrical load, kW	3,349	3,349	3,349
Hospital heat load, MMBtu/h	17.153	17.153	17.153
Boiler heat load @ 80% efficiency, MMBtu/h	21.441		
On-Site Genration Capacity, kW		2,800	2,800
LHV Electrical efficiency of CHP system		39%	45%
Total efficiency of CHP system		65%	65%
Natural gas for power production, MMBtu/h		24.50	21.24
Heat available from CHP device, MMBtu/h		6.371	4.247
Boiler offset at 90% Heat Transfer Eff		5.734	3.823
Boiler natural gas used, MMBtu/h	21.441	14.273	16.663
Total natural gas used, MMBtu/h	21.441	38.777	37.899
NO_x, lb/MWh from generator		2.20	0.01
CO_2, lb/MWh from generator		1,131	980
NO_x reduction from power production, tons/year		-2.91	21.26
CO_2 reduction from power production, tons/year		2,188	3,852
NO_x reduction from heat production, tons/year		0.9	0.6
CO_2 reduction from heat production, tons/year		3,095	2,064
Total NO_x reduction, tons/year		-2.0	21.8
Total CO_2 reduction, tons/year		5,283	5,916

The high thermal efficiency of both options provides substantial reductions in CO_2 emissions, by avoiding the CO_2 associated with grid power and boiler fuel. As with the WWTF case, the fuel cell results in reduced NOx emissions, while the engine produces more NOx than the case with no on-site generator.

Data Centers

Data centers are a growing energy consumer. Power consumption for data centers in the US doubled between the years 2000 and 2005, and constitutes approximately 1.2% of the total power consumption in the US [12]. Data center power consumption is a function of the number of servers in the center (often expressed as square feet of server room space) and the level of reliability of the center. The Uptime Institute has developed a tier classification system which rates centers from Tier I (28.8 hours annual downtime) to Tier IV (0.8 hours annual downtime) [13]. Higher Tier centers have more equipment redundancy and therefore more power use per unit of server area. A Tier I center will have a server power load of 20 to 30 watts per square foot of server room area while a Tier IV center will use 150 watts or more per unit of server area. Auxiliary non-cooling loads typically add another third to the CPU load, all of which results in heat generation that needs to be removed from the center. This adds an additional load for air conditioning. Data centers are one of the most effective CHP applications because the waste heat can be used in absorption chillers to offset some of the cooling electrical load.

Table 4 shows the energy profile of a Tier II data center with 5.4 MW of combined server, auxiliary, and cooling power demand. The table shows the impact of adding 2.8 MW of on-site CHP generation. In this case, waste heat from the electric generator is used to drive absorption chillers to offset electrical cooling load.

Table 4: Data Center Energy Profile

	No CHP System	Gas Engine	Direct FuelCell
Server Area, ft2	60,000	60,000	60,000
Cooling load, Tons	1,024	1,024	1,024
Electrical Load, kW			
IT and Auxiliary Equipment	3,600	3,600	3,600
Cooling	900	900	900
Total Electrical Load, kW	4,500	4,500	4,500
On-Site Genration Capacity, kW		2,800	2,800
LHV Electrical efficiency of CHP system		39%	45%
Total efficiency of CHP system		65%	65%
Natural gas for power production, MMBtu/h		24.50	21.24
Heat available from CHP device, MMBtu/h		6.371	4.247
Double Effect Chilling, Tons		690	460
Cooling Power Offset, kW		607	404
Net Facility Load Reduction, kW		3,407	3,204
Utility Electrical Purchases, kW	4,500	1,093	1,296
NO_x, lb/MWh from generator		2.20	0.01
CO_2, lb/MWh from generator		1,131	980
NO_x reduction from power production, tons/year		-2.91	21.26
CO_2 reduction from power production, tons/year		2,188	3,852
NO_x reduction from heat production, tons/year		4.6	3.1
CO_2 reduction from heat production, tons/year		3,178	2,119
Total NO_x reduction, tons/year		1.7	24.3
Total CO_2 reduction, tons/year		5,366	5,971

As Table 4 shows, the power displaced by each generator's electrical output and cooling load offset results in significant CO_2 reduction for both generators: 5,366 tons per year for the engine and 5,971 tons per year for the fuel cell. NOx is reduced by 24 tons per year for the DFC, and in this case the engine provides a slight NOx reduction (1.7 ton per year) by offsetting NOx associated with grid power for electric air conditioners.

A summary of these three example applications is shown in Table 5. It can be seen that in all three cases the high temperature fuel cell offers reductions in CO_2 and NOx emissions beyond the capabilities of conventional technology.

Table 5: Emission Reductions Achieved By Conventional Generator and DFC in CHP Applications

Application:	Wastewater Treatment Facility		Hospital		Data Center	
	Gas Engine	DFC	Gas Engine	DFC	Gas Engine	DFC
CO_2 Reduction, tons/year	6,357	7,334	5,283	5,916	5,366	5,971
NO_x Reduction (Increase), tons/year	(0.5)	12.1	(2.0)	21.8	1.7	24.3

FUEL CELL ECONOMICS

As a relatively new technology produced in lower volumes, fuel cell capital costs tend to be higher than conventional distributed generation options. Lower fuel consumption helps make up for this difference, and another significant impact is provided by subsidy programs. The Federal Investment Tax Credit (ITC) provides a tax credit or grant of up to $3,000/kW for fuel cell powerplants, and the Energy Policy Act of 2005 provides for accelerated depreciation of fuel cell assets for tax purposes. California's Self Generation Incentive Program (SGIP) provides capital cost rebates of $2,500/kW for natural gas fuel cells and $4,500/kW for fuel cells operating on biogas.

The state of Connecticut has a similar capital cost rebate program as well as a premium power price program for distributed generation sales directly into the grid. South Korea has a grid sales feed-in tariff program. These programs are effective in offsetting the higher initial costs for this new technology. There are currently more than 90MW of FuelCell Energy's DFC powerplants installed or in backlog, for commercial customers around the world. These projects generate real economic benefits for customers based on local power and fuel costs and local incentive programs. The cost of high temperature fuel cell powerplants is significantly reduced every year as a result of cost reduction activities and expanding volume [14], so fewer incentive dollars are needed each year. In addition, emissions credit markets are emerging in the US and around the world that provide benefits based on the NOx and CO_2 reductions that DFC powerplants provide.

Table 6 shows a summary of an economic comparison done by a California wastewater treatment facility, which had solicited proposals for fuel cells, microturbines, and engines to operate on their digester fuel, at the 750kW power level [15].

Table 6: Economic Comparison for California WWT Facility

	750kW DFC	750 kW Natural Gas IC Engine	750 kW Microturbine
Installed Cost, $	5,182,545	4,147,000	5,043,768
Installed Cost, $/kW	6,910	5,529	6,725
State Incentive Grant, $	3,375,000	848,000	975,000
California Incentive Grant, $/kW	4,500	1,131	1,300
Net Installed Cost, $	1,807,545	3,299,000	4,068,768
Net Installed Cost, $/kW	2,410	4,399	5,425
Emission Compliance Payments, $		71,943	12,000
Five-year generator O&M, $	1,092,848	458,114	408,924
Five-year gas cleanup O&M, $	500,500	500,500	500,500
Total Cost over 5 Years	3,400,893	4,329,557	4,990,192
5 year kWh Generation, kWh	29,565,000	29,565,000	29,565,000
Average Power Cost over 5 Years, ¢/kWh	11.5	14.6	16.9

While fuel cells are generally more expensive than conventional generation technologies, the addition of construction costs and costs for heat recovery equipment tends to bring total installed costs closer together, within 25% in this case. At the time this project was done, California offered a variety of capital cost rebate programs as incentives for on-site generation with biofuels. As shown in the table, the fuel cell qualified for a higher level of incentive due to its clean emissions. The fuel cell also avoids the need to make emissions compliance payments, which the conventional generators would incur. Fuel cell operating and maintenance (O&M) is higher than the other generators because it includes the cost of a new set of fuel cell stacks, which would continue plant operation beyond the five-year period. The higher O&M cost is offset by the difference in state incentive programs, making the fuel cell system the most economical choice. The municipality will also be able to sell Renewable Energy Credits (RECs) associated with the power generation from the system, further reducing the cost of energy.

CONCLUSIONS

DFC powerplants are an extremely attractive option for distributed generation in CHP applications. They are commercially deployed and have a history of producing clean, baseload power with high electrical efficiency and availability. Due to their favorable emissions profile and low noise levels, they make good neighbors and are easy to site in populated areas that generally have a large power demand and congested grids. Their high exhaust temperature enables access to a variety of heat recovery technologies, and this flexibility enhances the deployment of the technology in many different applications.

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