

# Insuring Electric Power for Critical Services After Disasters with Building-Sited Electric Generating Technologies

Jerry Jackson, Associate Professor, Texas A&M University, College Station, TX

## Abstract

Electric power failures in the aftermath of disasters can cripple the delivery of critical services. While emergency generators are available in some facilities, these systems are designed for short-term use and support limited functions. The substantial investment required to insure emergency power for all critical services is difficult to justify because of the uncertainty associated with the likelihood and magnitude of future disasters. This calculation can change substantially by considering a different source of emergency power available with new building-sited combined heat and power (CHP) electric generation technologies. This paper evaluates the physical requirements and costs of preemptively installing these new building-sited electric generation technologies to insure reliable long-term power for critical services in hurricane-regions of the US. Analysis results indicate that costs of such a program can, in some cases, provide net energy bill savings regardless of the occurrence of a disaster.

## I. Introduction

Emergency generators in disaster-prone areas are typically designed for short-term use only for the most vital critical service functions. Evaluating future benefits of more extensive emergency power systems as part of a risk management process is difficult because of the uncertainty associated with the likelihood and magnitude of future natural disasters.

Difficulty in justifying investments required to extend critical services emergency power capabilities can potentially be overcome by considering a different source of emergency power available with new building-sited combined heat and power (CHP) electric generation technologies (see US Department of Energy, 2000 and 2002 for descriptions of these technologies). Instead of traditional emergency generator applications, these technologies are integrated in building energy systems to provide some portion of a facility's electricity and thermal energy needs including space heating and air conditioning. In the event of a power outage, these systems continue to operate providing power for critical services. Their economic benefit during normal daily operation can help offset some or all of their cost. Depending on hourly energy use characteristics of the building, CHP system characteristics and electric and natural gas costs, a preemptive strategy to provide critical services power can potentially provide net economic savings over time.

This paper evaluates the feasibility of using CHP systems to provide electric power for critical disaster management, safety, health and temporary shelter services during widespread and prolonged central electric system outages in hurricane-prone areas of the US. More generally, these analysis results are presented to suggest potential benefits of using CHP in disaster mitigation planning throughout the world.

Three geographic locations are selected for this analysis: Houston, Texas, Miami, Florida, and Charleston South Carolina. These locations are all in the "strike zone" of Caribbean-spawned hurricanes and each reflects different climate characteristics as indicated in Table 1.

Variations in hourly heating and cooling energy use help determine system configuration and energy cost savings that can occur with CHP systems. As indicated in Table 1, Miami has the warmest climate in the winter season (January) by far. All three locations are characterized by warm summer seasons requiring substantial air conditioning.

The remainder of this paper is organized as follows. The next section describes new CHP technologies and potential CHP economic advantages relative to emergency-only generators. Section three identifies required

**Table 1. Characteristics of Three Study Locations**

	Charleston	Houston	Miami
Mean January Temperature °C (°F)	8.8 (47.9)	11.0 (51.8)	20.1 (68.1)
Mean July Temperature °C (°F)	27.6 (81.7)	28.7 (83.6)	28.7 (83.7)

Source: Comparative Climatic Data, National Climatic Data Center,  
US National Oceanic and Atmospheric Administration, 2001.

critical service building facilities used in the analysis and describes the development of hourly electricity and natural gas load data required for CHP system design and economic analysis. The next section discusses CHP system design and economic analysis methodology. Analysis results are then presented with the final section providing a summary of this research.

## **II. New Building-Sited Combined Heat and Power Technologies**

Recent advances in combined heat and power (CHP) technologies provide building-sited electric generation that can serve as both an emergency source of electric power and as an integral component in meeting the daily energy needs of most commercial buildings. These CHP systems provide electricity and utilize waste heat from the generation process in existing building thermal applications such as space heating, domestic water heating. Thermal energy can also be used in an absorption refrigeration cycle to provide air conditioning and refrigeration. See Oland (2004) for a description of CHP thermal applications. CHP systems, also referred to as cogeneration and distributed generation systems (DG), have been used for decades in large industrial plants and some large commercial complexes; however, recent technology extensions provide smaller, more economical units packaged with heat exchangers, remote monitoring and control capabilities and thermal applications such as absorption air conditioning. While these systems cost more than electric-only emergency generators, they provide daily savings in energy costs that can pay for part or all of the system over time.

Modern CHP systems include: (1) a prime mover, (2) heat exchangers, (3) end-use applications and (4) controls and monitoring systems. Natural gas engines are the most common prime mover however microturbines,

fuel cells and sterling engines are also used. Heat exchangers transfer waste heat to useful thermal end-use applications. Controls and monitoring systems provide for offsite monitoring and continuous maintenance practices to limit unscheduled downtimes.

CHP systems with capacities as small as a 6 kW are available (Aisin, 2006); one larger packaged system, the United Technologies PureComfort product includes from four to six 60 kW microturbines with a double-effect absorption chiller/heaters in balanced electric-thermal designs (United Technologies, 2006). Manufacturer and installer-provided warranties along with remote sensing and control capabilities of these systems allows building owners to take advantage of CHP technology with no onsite engineering expertise or maintenance responsibilities. CHP systems are being used in offices, restaurants, grocery stores, nursing homes and other commercial and institutional buildings. Fewer than five thousand of the new smaller CHP systems have been installed in the US in the last five years (Jackson, 2005); however, a series of studies indicates that their market share could potentially reach as much as 20 percent of the US commercial, government and institutional sector (US Department of Energy, 2000).

Table 2 shows a cost comparison between an electric-only emergency generator and a CHP system for a 5,800 square meter (61,400 square foot) nursing home in Miami. Both systems provide the same generation capacity, 120kW, providing approximately 54 percent of non-emergency electricity use for the entire facility or 100 percent electricity use in a system designed to support one-half of the facility during an emergency. The CHP system costs twice as much as the electric-only system; however, it provides daily energy cost savings that are not available with the electric-only system. This example includes a natural gas engine with a

31.7 percent electric efficiency and the ability to use 48.7 percent of the natural gas input energy for thermal applications. The system has an overall efficiency of 78.3. These cost and efficiency data are taken from US Department of Energy (2002). By generating electricity on site, utility electric bills are reduced by \$79,500. Use of waste heat in the building saves an additional \$32,357 in natural gas bills. Deducting \$66,976 in natural gas costs to fuel the prime mover and operating and maintenance costs of \$12,007 and provides a net annual energy cost savings of \$32,908. These annual cost savings provide a net present value of \$170,531 and a payback of 3.5 years assuming constant costs and a discount rate of 3 percent.

As indicated in the Table 2 example, savings in avoided natural gas and electricity costs are critical components in the economic analysis that are offset, to some extent, by natural gas fuel used to run the onsite generator and other operating and maintenance costs. The onsite electric generation process can be more or less efficiency and therefore more or less costly to generate a single kWh of electricity compared to purchase from the local utility; however, the overall economic attractiveness of CHP systems depends primarily on the extent to which avoided natural gas costs resulting from the onsite use of waste heat can pay for the extra capital investment.

**Table 2. Economics of Standby Electric-Only and Combined Heat and Power Systems**

	Emergency Electric Generation Only	Combined Heat and Power
Capacity (kW)	120	120
Installed Cost (\$/kw)	450	953
Installed Cost (\$)	54,000	114,360
Avoided Costs		
Electric (\$)		79,534
Natural Gas (\$)		32,357
Operating Cost (\$)		12,007
Natural Gas Gen cost (\$)		66,976
Annual Savings (\$)		32,908
Net present value of investment (\$)	(54,000)	170,531
Simple Payback (years)		3.5

CHP waste heat utilization provides overall system efficiencies as much as 80 – 90 percent (Maine Public Utilities Commission, 2001). The extent to which onsite waste heat can offset the cost of CHP equipment is determined by the nature of hourly electric and thermal demands in the building across all hours of the year. Different building types have distinctive hourly energy use profiles reflecting building functions and weather impacts; consequently, the economics of preemptively developing emergency power capabilities with CHP systems depends on more detailed hourly building analysis of the individual building types used to provide critical services.

### III. Critical Service Facility Requirements and Hourly Energy Use Characteristics

Critical disaster mitigation functions considered in this analysis include: (1) disaster management/ municipal/public safety, (2) health, and (3) shelter services. The analysis is benchmarked to a US population unit of 100,000 people and assumes the following health care and shelter needs as a percent of pre-disaster capacity: 50 percent of hospital beds, 75 percent of nursing home beds, and shelter for 5 percent of the population (i.e., 5,000 individuals).

Table 3 shows associated facility characteristics for the various functions. These

characteristics were developed using information from the US Department of Energy's Commercial Buildings Energy Consumption Survey (CBECS) Data and the US Commerce Department's Statistical Abstract of the US (2006). For example, there are approximately 278 hospital beds per 100,000 people in the US requiring 139 hospital beds to meet the 50 percent capacity figure used in the analysis.

CBECS data indicate that approximately 93 square meters (1000 square feet) are required per bed yielding a hospital floor space requirement of 13,000 square meters or 139,931 square feet. The average US hospital has approximately 190 beds; consequently, about three-quarters of the space in an average hospital would be required to provide the required 139 hospital beds.

**Table 3. Number Of Facilities And Square Feet Required To Support 100,000 Population Center**

Building Type	Building Size		Number of Buildings
	Square Meters	Square Feet	
Disaster Management and Public Safety	5,000	53,820	1
Hospital	13,000	139,931	1
Nursing Homes	2,900	31,215	5
Shelter (schools)	4,600	49,514	10

Similar analysis was used to determine nursing home and shelter facility characteristics. The US nursing home ratio of 672 beds per 100,000 people yields a 75 percent capacity requirement of 504 beds or approximately 100 beds for each of five individual facilities. The average US nursing home facility size is 99 beds. CBECS-based floor space per bed ratio of 29 square meters per bed (311 square feet/bed) requires that the five facilities are each 2,900 square meters (31,215 square feet) in size.

The analysis assumes that schools can most easily be equipped for emergency shelter with a space requirement of 9.3 square meters (100 square feet) per person. This per-person space requirement is 63 percent of CBECS hotel/motel space requirements assuming room occupancy of four people; it is also the same as the per student space requirement in the CBECS school data. Approximately 25 percent of a 100,000 population community's educational floor space is required for emergency shelter under these assumptions.

The 5,000 square meter disaster management and public safety center space requirements reflect about 10 percent of the total municipal floor space in a typical municipality of 100,000 people; according to CBECS, approximately one-half of local government floor space is in buildings 5,000 square meters and larger.

The economics of using CHP to provide emergency power depends on electric and

thermal loads of each of these facility types in each of the three locations. Hourly energy use data for these facility types was developed by applying hourly load analysis to survey data from the US Department of Energy's Commercial Buildings Energy Consumption Surveys (CBECS) for 1992 and 1995. Data were pooled, and a proportional post stratification using US Commerce Department county-level data on establishments by employee size categories (County Business Patterns, 2000) was used to develop a national sample of nearly 15,000 commercial buildings across the US. A sample of office buildings, hospitals, nursing homes and schools were extracted from the national database for regions and climate characteristics consistent with the three locations.

CBECS data include annual electricity and natural gas use along with estimates of end-use energy including whole-building electricity use, air conditioning electricity use and natural gas use for water heating and space heating. Monthly energy use data for each of the individual establishments was used to estimate hourly electricity and natural gas use for each of the 8,760 hours of the year. Statistical estimation using local weather station hourly data was used to determine weather sensitivity of space heating, air conditioning and ventilation energy uses. Information on building shell, occupancy and equipment characteristics were used to estimate hourly energy use for each hour of the year with a heat load simulation model.

Estimation results were calibrated to billing energy and peak kW data reported for each facility. Hourly data were calibrated to typical meteorological year (TMY, National Renewable Energy Laboratory, 1995) hourly weather data to normalize the results to a typical weather year.

#### **IV. CHP System Design and Economic Analysis Methodology**

CHP system designs can be complicated. The prime mover in this study has been restricted to natural gas engines, the most frequently selected prime mover by far. Natural gas engines apply a reliable technology that has been used for decades and, more importantly for most of the facility types, has higher electric generation efficiency. That is, the ratio of generated electricity to waste heat is higher and more compatible with the end-use (space heat, water heat, etc) needs of most of the facility types considered here. Natural gas systems are also less expensive.

Limiting the prime mover choice to a natural gas engine does not resolve all system design issues, however. Larger engines cost less per kW capacity however; CHP systems must be sized in a way that maximizes cost savings from onsite use of waste heat and avoided electricity costs. These calculations depend on natural gas prices and electric rate structures. US utilities charge commercial, government and institutional facilities based on to monthly electricity use, maximum monthly 15-minute electricity use and monthly natural gas use with rate structures that include declining blocks. Waste heat can be applied to space heating and domestic water heating and to at least a portion of air conditioning loads. Other uses of waste heat such as desiccant dehumidification are not yet fully commercialized and are not included in this analysis.

The analysis in this study extracted survey records from the CBECS data to determine hourly load profiles for facilities identified in Table 3 for each of the three locations. An analysis of individually surveyed facility energy use characteristics in the database at the individual locations was conducted prior to selection of a “prototype” facility to insure selection of a “typical” facility in each location areas. Facility data included whole building hourly electric loads, air conditioning hourly electric loads and hourly thermal loads for

domestic water heating and space heating. Alternate prime mover sizes provide different ratios of electric and thermal energy; consequently, system size and end-use applications determine the appropriate electric-thermal balance. CHP designs considered (1) water heating (2) space heating and absorption (3) air conditioning thermal application separately and in combination. All data on CHP systems was taken from the US Department of Energy 2002 study.

Commercial building CHP applications are generally less attractive than industrial applications because of the smaller ratio of thermal loads to electric loads in commercial buildings. One approach to improve the economics of emergency applications given floor space requirements shown in Table 3, is to consider CHP applications in larger buildings to achieve a better electric-thermal balance but design systems to provide emergency facility support for only a portion of the building in the event of central utility system power outages. Consequently, two-facility analyses were conducted for each building type: the first with floor space indicated in table 3 and the second with twice the required floor space. The original floor space specifications in Table 3 reflect modest building sizes; consequently, doubling the building size specification is still compatible with municipal buildings found in a population center of 100,000 people.

2004 electricity and natural gas rates for local utilities are applied for the three locations. 2004 was selected rather than 2005 to avoid the energy price spikes caused by Hurricane Katrina damage to natural gas delivery systems. The analysis illustrated in Table 2 was applied to each system design. The system that provided the greatest combination of return on investment and energy cost savings was selected.

#### **V. Cost/Benefit Analysis**

Analysis of CHP applications at ten schools, five nursing homes, a hospital and a municipal “command and control” office were conducted for alternative system designs and the two facility sizes at each of the three locations to identify a “best choice” based on the combination of return on investment and energy costs savings. Results were summed across all seventeen applications for each of the three geographic locations and are shown in Table 4.

The larger facility specifications were uniformly selected as more economically attractive in all cases, reflecting better electric and thermal load balances.

Total installed capacity of the seventeen systems ranges from 2,360 kW to 2,825 kW across the three locations. Total net annual operating benefits (avoided electric and natural gas costs minus natural gas costs to run the generator minus operating and maintenance costs are slightly negative in Charleston (-\$3,961) but are sizeable and positive in both Houston and Miami. The inability of savings to help pay for the installed cost of the systems is reflected by a Charleston net present value of -\$2,133,941 which is approximately the installed cost of all of the CHP systems (\$2,099,480). Dividing the net present value by total kW capacity yields a cost of \$985/kW that is more than twice the cost of installing diesel generators of similar capacity to be used only when called on in emergencies. Clearly, electric and natural gas utility rates in Charleston do not offer an opportunity to take advantage of potential cost savings available with CHP systems. Providing Charleston with more widespread delivery of critical facilities' electric services would, under current conditions, be accomplished at less cost with emergency-only diesel generators.

The other two cities, however, provide significantly different results. In Houston, the

installation of CHP emergency capacity saves \$716,175 in annual energy operating expenses that, when used to pay the installed cost of CHP equipment yields a 3.9 year payback. The net present value of a preemptive CHP-based emergency electric capability is \$3,386,187; in other words, summing all of the discounted operating cost savings over the ten-year lifetime of the equipment and subtracting the cost of the equipment and its installation cost yields a net savings of \$3,386,187. The city of Houston can actually save money by undertaking a preemptive CHP-based emergency power system.

The Miami analysis also shows a positive economic benefit with a net present value of \$532,419. Comparing Houston and Miami annual operating benefits and costs shows smaller avoided electric savings and greater net natural gas expenditures, explaining the smaller return on CHP investment in Miami. This result reflects lower electric prices and higher natural gas prices in Miami compared to Houston. Electric and gas prices presented in the table are the marginal prices relevant for analysis of these investments. Existing rate structures in all three locations are used to calculate marginal increases or decreases in electricity and natural gas; these rates can differ significantly from average rates computed by dividing the total bill by total energy consumption because of monthly peak kW (demand) charges and block structures.

**Table 4. Analysis of Emergency Power CHP Systems in Three Locations**

	Total (Including Multiple Buildings Within Categories)		
	Charleston	Houston	Miami
Annual kWh Use Before CHP	24,377,814	28,163,992	32,649,455
Savings - kWh	13,245,669	17,296,858	19,932,919
System size (kW)	2,360	2,770	2,825
Annual Operating Benefits			
Avoided kWh Costs (\$)	961,829	1,759,704	1,651,911
Avoided Natural Gas Costs (\$)	355,055	256,728	518,398
Annual Operating Costs			
Generator Fuel Costs (\$)	1,172,444	1,094,560	1,595,261
O&M Costs (\$)	148,401	205,697	213,557
Total Net Annual Operating Benefits	-3,961	716,175	361,491
System Installation Cost	2,099,480	2,813,890	2,598,085

**Benefit/Cost Analysis**

Net Present Value	-2,133,771	3,386,187	531,419
(3% rate, 10 years, \$)			
Simple Payback (years)	N/A	3.9	7.2
Marginal energy prices			
Electricity (\$/kWh)	0.073	0.102	0.083
Natural gas (\$/MMBtu)	8.68	6.32	8.11

Results for the individual building categories are provided in Table 5. No single Charleston facility type provides operating cost savings. The spread between the price of electricity purchased from the local utility and the cost of natural gas is too small to justify running the CHP system in all but peak electric price hours. For instance, the nursing home 120 kW space heat/water heat system is run 3570 hours per year in Charleston but in Miami, CHP system economic considerations provide 5,148 annual operating hours.

Interestingly, a CHP application in Miami schools also shows a negative net present value of \$-41,210 per building; however, the positive net present value of other building types more than outweighs the negative contribution of schools. Without the school impact, the total net present value of a preemptive CHP-based emergency electric generation program would be close to \$1 million. The cost of each Miami school CHP system is approximately \$340/kW, less than the cost of installing diesel emergency backup generators to provide more extensive emergency critical services electricity.

Analysis of other building types shows that nursing homes provide the most economic application, followed by hospitals, offices and schools.

**VI. Summary**

This paper presents the results of a research study designed to assess costs and benefits of using new combined heat and power (CHP) systems to provide electricity for critical municipal services in the aftermath of hurricane damage on the US Gulf and Southeastern coasts. CHP systems generate electricity at building sites and apply waste heat for domestic water

heating, space heating, absorption air conditioning and other uses. These systems can be fully integrated with the existing power system using appropriate interconnection technologies to prevent "islanding," a situation where the CHP system can energize a portion of the distribution system, creating a hazard for line workers when the grid system is not operating. These technologies are now available in small sizes and are provided with heat exchangers and controls simplifying applications in commercial and institutional buildings such as schools, nursing homes, offices and hospitals. CHP systems are increasingly being installed because of their economic benefits in many US, European and Asian locations.

A combination of shelter, nursing home, hospital and administrative facilities types are specified to accommodate critical service needs for a population center of 100,000 people. Information on actual critical service facilities in three geographic locations were developed from a US Department of Energy database and extended to provide hourly electric and thermal loads required to analyze CHP system design and performance.

Detailed CHP design and economic analysis were conducted for typical facilities in each of the locations. Economic analysis included incorporation of utility rate structures including peak kW (demand) charges and declining block rates.

Analysis results show that CHP systems installed in all four critical service facility types can, under the right circumstances, provide a positive net present value. That is, that avoided electricity and natural gas costs associated with waste heat applications, can more than offset cost of the installed equipment and operating

**Table 5. Analysis of Emergency Power CHP Systems in Three Locations**

	Shelter - 10 Facilities			Nursing Home - 5 Facilities			Hospitals -1 Facility			Office -1 Facility		
	Charleston	Houston	Miami	Charleston	Houston	Miami	Charleston	Houston	Miami	Charleston	Houston	Miami
Annual kWh Use Before CHP	784,707	863,687	969,205	1,265,555	1,553,731	1,857,963	8,089,184	9,656,965	11,266,336	2,113,785	2,101,502	2,401,254
Savings - kWh	400,018	519,445	579,164	524,385	893,851	1,000,568	6,112,482	6,477,660	7,708,810	511,082	1,155,493	1,429,629
System size (kW)	120	120	120	60	120	120	800	800	800	60	170	225
Annual Operating Benefits												
Avoided kWh Costs (\$)	34,207	60,041	52,564	34,838	86,239	79,534	411,450	614,347	608,047	34,119	113,752	120,554
Avoided Natural Gas Costs (\$)	8,290	942	21,890	26,077	28,551	32,357	122,250	79,892	77,200	19,520	24,661	60,513
Annual Operating Costs												
Generator Fuel Costs (\$)	40,612	34,102	59,096	54,190	65,807	66,976	442,188	342,199	531,384	53,186	82,306	138,037
O&M Costs (\$)	4,800	8,638	6,950	7,866	10,726	12,007	53,405	51,821	66,866	7,666	13,866	17,156
Total Net Annual Operating Benefits	-2,915	18,243	8,408	-1,141	38,257	32,908	38,107	300,219	86,997	-7,213	42,241	25,874
System Installation Cost	114,360	150,849	114,360	61,980	114,360	114,360	584,000	584,000	684,685	61,980	149,600	198,000
Benefit/Cost Analysis												
Net Present Value	-139,596	7,084	-41,570	-71,858	216,839	170,531	-254,100	2,015,059	68,466	-124,424	216,089	25,997
(3% rate, 10 years, \$)												
Simple Payback (years)	-39.2	8.3	13.6	-54.3	3.0	3.5	15.3	1.9	7.9	N/A	3.5	7.7



costs providing a net economic benefit to municipal governments who decide to undertake a preemptive CHP-based emergency power capability initiative.

Of the three locations studied, a Houston application provided the greatest economic benefit: nearly \$3.5 million over ten years.

Analysis of a Miami initiative provided an estimated net present value of \$546,887. A Charleston analysis

showed no economic benefit from installation of CHP systems.

Differences in the economic results for the three locations are primarily a result of differences in utility electricity rates and natural gas prices.

The positive economic results in Houston and Miami suggest the possibility of a unique government initiative: that is, a government program that can potentially pay for itself.

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