Combined Heat & Power: A Federal Manager's Resource Guide

Final Report

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Combined Heat and Power: A Federal Manager's Resource Guide

Abstract

Executive Order 13123 *Greening the Government Through Efficient Energy Management*, identifies in Section 403(g) that Federal facilities shall use combined cooling, heat and power systems when life-cycle cost effective to achieve their energy reduction goals. This is a renewed emphasis placed by the Federal government on implementation of technologies that achieve overall system energy efficiency, reduce greenhouse gas emissions, and trim operating expenses. FEMP created *Combined Heat and Power: A Federal Manager's Resource Guide* to assist in this endeavor.

Combined Heat and Power (CHP) is a master term for onsite power generation technologies that simultaneously produce electrical or mechanical energy and useful thermal energy. Cogeneration has existed for more than 100 years and is now achieving a greater level of acceptance due to increased reliability *and* overall cost efficiency. Capturing and using the thermal energy produced as a byproduct from fuel sources such as oil, coal, or natural gas, increases the power gained from the original fuel source. CHP technologies have the potential to reduce energy consumption—decreasing energy bills, as well as pollution.

Internal combustion engines and combustion turbines are two CHP technologies currently used in industrial, commercial, and government facilities across the nation. Two exciting new CHP technologies are fuel cells and micro-turbines. Fuel cells produce power electrochemically (like a battery) except that they consume fuel (hydrogen) to maintain the chemical reaction. Fuel cells have no moving parts and provide a quiet, clean, and a highly efficient source of onsite generation with thermal outputs. Fuel cells produce low levels of pollutants and, although still too expensive for many applications, are slowly becoming economically viable. Micro-turbines are scaled down versions of combustion turbines that provide reasonable efficiency, require minimal maintenance, allow fuel flexibility, and have low emissions. Hybrid systems that utilize the best features of both fuel cells and micro-turbines are also being tested.

Combined Heat and Power: A Federal Manager's Resource Guide identifies the short-, medium-, and long-term potential of internal combustion engines, combustion turbines, fuel cells, and micro-turbines for Federal facilities. It outlines successful application procedures for these CHP technologies and provides case studies of successful implementations. Sources for additional information on CHP technologies are listed at the end of this Guide.

2.0 The Technologies of Combined Heat and Power

Combined Heat and Power (CHP), also known as cogeneration, is a system that efficiently generates electricity (or shaft power) and takes advantage of the heat that is normally not used, to produce steam, hot water, and/or chilled water. DOE has estimated that about seven percent of the total electrical power generation in this country is produced by CHP equipment. The Department of Energy (DOE) has recently introduced a new initiative that includes space cooling to the useful energy outputs of these combined energy systems, and has designated this as Buildings Cooling, Heating and Power "BCHP." The specific cooling technologies and details of its application will be included in future editions of this guide.

Figure 2–1 visually depicts the concept of CHP because the energy input to the system is used to generate both electrical power and useful thermal energy.

Long before the energy crisis of the 1970s, waste heat from power plants was used for thermal applications. Thomas Edison's first power plant utilized waste heat for steam that he sold to help pay generating expenses. Unfortunately, because of central station utilities, the practice of CHP decreased for many generations, even though when applied well, it significantly improved the efficiency of a power plant.

In this new era of electric utility restructuring, there is a renewed enthusiasm for CHP, stemming from the promise of lower total life cycle operating costs, environmental compliance, and system reliability. CHP is not limited to one technology, but rather is applicable to a growing array of products designed to help Federal facilities meet their onsite generation needs. These proven technologies (internal combustion engines, steam turbines, combustion {gas} turbines, fuel cells, micro-turbines) can provide useful thermal energy for a variety of building applications (see table 2–1) as well as electricity for base load, peak shaving, or backup situations.

Figure 2–1. Combined Heat and Power System

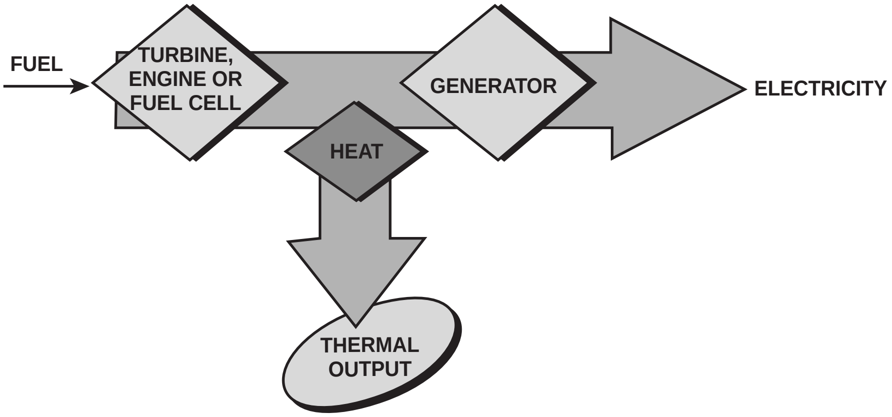


Table 2–1. Waste Heat Applications

Space heating
Domestic hot water heating
Boiler feed-water preheating
Steam generation to supply turbines (Combined Cycle)
Pool water heating
Steam/hot water for absorption chiller
Process hot water/steam

Cogeneration is defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), as the simultaneous production of electrical or mechanical energy (power) and useful thermal energy from a single energy stream, such as oil, coal, or natural gas. In certain locations, the energy source can be provided from solar, geothermal or biomass. Several technologies produce both electrical energy and thermal energy. This chapter provides an overview of the following:

2.1 Internal Combustion Engines
2.2 Steam Turbines
2.3 Combustion (Gas) Turbines
2.4 Fuel Cells
2.5 Micro-turbines
2.6 Hybrid fuel cell/micro-turbine systems

2.1 Internal Combustion Engine

One of the original cogeneration technologies is the reciprocating internal combustion (IC) engine. Engine generator sets produce electricity along with waste heat that can be captured for a variety of building thermal needs.

IC engines are the fastest growing segment of the small size (1 to 10 MW) CHP market for systems that use heat diverted to a boiler. IC engines have outsold turbines 18-to-1 in the 1 to 5 megawatt range largely because they have higher electric generating efficiencies than gas turbines in this size range. (Based on DOE studies.)

A large majority of the smaller IC engines use diesel or gasoline to provide backup power to facilities during emergency situations or power outages. Traditionally, these generators were noisy, dirty suppliers of electricity without employing the benefits of heat recovery—exhausting heat directly into the atmosphere instead of capturing it for useful building purposes.

Today, manufacturers are producing variously sized (down to 25 kW) natural gas-powered, high-output, and highly efficient packaged cogenerators that are used in a variety of small- to medium-sized building applications. These modular, quiet, and clean engines are used not only in backup or peak shaving situations, but also to supply base load electricity to a growing number of facilities. Packaged IC engines can provide Federal facilities with the following (relative to other CHP technologies):

- Low start-up costs
- Reliable onsite energy
- Low operating costs
- Clean energy
- Ease of maintenance
- Wide service infrastructure

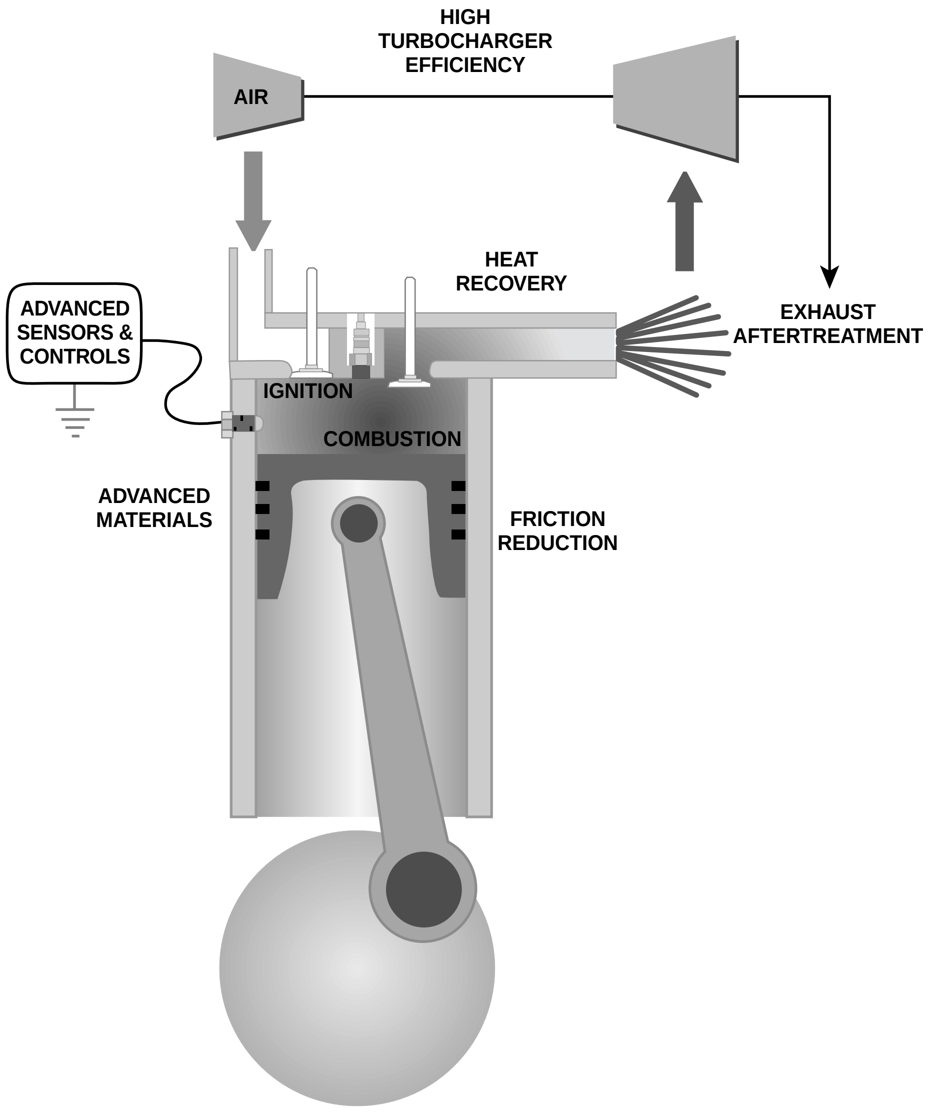
DOE currently sponsors the Advanced Turbines and Engine Program (ATEP) to assist industry in developing cleaner, more efficient heat engines through funding for R&D and prototype testing. Figure 2–2 represents a heat engine and the possible efficiency opportunities that can lead to lower operating costs.

Heat Recovery

Waste heat has never been captured to its potential from smaller IC engines because IC engines were traditionally used in backup or peak shaving situations. Today, packaged natural-gas IC engine cogenerators can be made to fit the specific electric and thermal load profile of the end user, allowing for optimal overall plant efficiency.

Of course, not all heat produced during onsite electric generation can be captured. Small IC cogenerators can retain about one-half of the heat produced—Table 2–2 illustrates this fact.

Figure 2–2. Natural Gas Engine



Source: FETC

Table 2–2. IC Engine Generation Process

(Values are approximated. Figures total 100%. Values in bold represent useful energy.)

	Without Heat Recovery	With Heat Recovery
Engine output at flywheel ~	**35%**	**35%**
Un-Recoverable heat	65%	21%
Recoverable heat ~	0%	**44%**
Total useful energy	**35%**	**79%**

When all recoverable heat is used at a facility, the process can achieve overall efficiencies approaching 80 percent. Exhaust heat can be utilized in thermal applications with hot water needs reaching 250 F.

Today's natural gas IC engines are a proven technology that offer low first costs (as a CHP project installed for $800-$1500/kW), uncomplicated start-up, and good reliability. Emissions have been reduced significantly in the past couple of years thanks to exhaust catalysts and advancements in the combustion process. IC engines are well suited for CHP projects in Federal applications requiring less than 10 megawatts.

2.2 Steam Turbines

In the United States today, most electricity is generated by conventional steam turbine power plants. Unlike other CHP technologies discussed in this chapter, a steam turbine does not directly convert a fuel source to electric energy but requires a source of high-pressure steam delivered by either a boiler or a heat recovery steam generator (HRSG).

Steam turbines used in CHP system are usually in the form of either an extraction-condensing type system or as a back-pressure system. Extraction-condensing turbines have higher electrical efficiencies than back-pressure systems but are more complex in nature. The heat extracted from the steam in extraction-condensing systems is optimized by exhausting the steam from the turbine at less than atmospheric pressures. Back-pressure turbines (non-condensing) exhaust steam at or above atmospheric pressure and use hot water as the primary heat distribution medium to give a good balance between power and heat output. The complexity of individual CHP projects will dictate the type of steam turbine to employ to ensure optimal performance.

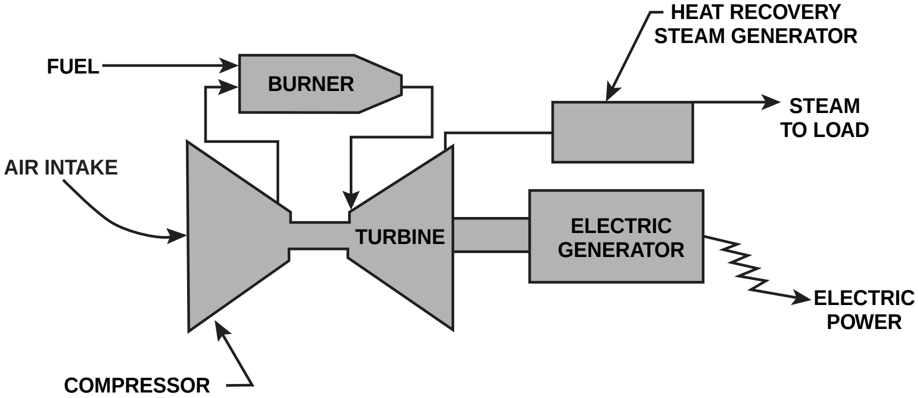
Steam turbines can vary in electric generating efficiency but usually falls in the range of 20% - 40%, with a boiler/ steam turbine installation cost ranging from $800-$1000/kW. The incremental cost of adding a steam turbine to an existing boiler system or to a combined cycle plant is approximately $400-$800/kW.

2.3 Combustion Turbines

Combustion turbines (also referred to as gas turbines) are used throughout the world as an effective way to simultaneously produce useful power and heat from a single fuel source. Combustion turbines, ranging in size from 500 kilowatts to hundreds of megawatts, produce electricity through their generators while providing useful heat captured from the turbine exhaust flow. The Department of Energy (DOE) and their industry partners (under the Advanced Turbines and Engine Program {ATEP}) are developing high-efficiency, low-emission natural-gas-fired turbines to provide an environmentally superior technology solution for CHP applications.

Gas turbines operate in different cycle configurations. Simple-cycle gas turbines (figure 2–3) are the concept of a single shaft machine (with compressor and turbine on the same shaft) that includes an air compressor, a burner, and a power turbine driving an electric generator. Simple-cycle gas turbines are generally used in small generation capacities less than 25 megawatts.

Figure 2–3. Simple-Cycle Gas Turbine

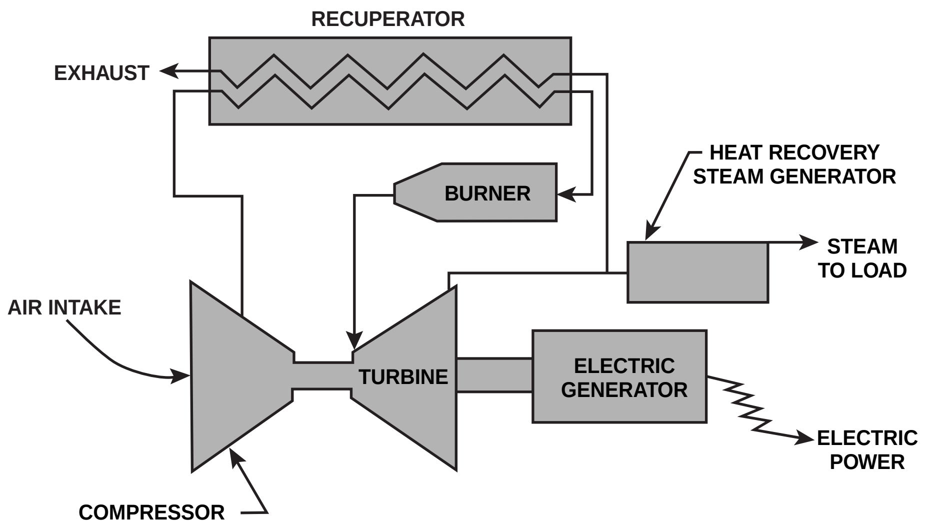


A recuperated gas turbine, shown in figure 2–4, is the same as a simple-cycle turbine, except for the addition of a recuperating heat exchanger that captures exhaust energy to preheat the compressed air before it enters the burner. Recuperative gas turbines are also primarily used in small generation applications less than 25 megawatts.

Buildings that have stable and predictable electrical and thermal loads can use turbine exhaust flow to fuel a heat recovery steam generator (HRSG), which provides steam for heating, cooling, and other thermal applications. Such buildings can maximize efficiency by using both the electrical and thermal capacity of the turbine.

The demand for electric and thermal energy, however, varies depending on the time of day, month, or year. As illustrated in figure 2–5, the thermal load of Building A decreases in the summer with the absence of space heating while its electric load increases due to summer cooling needs. This kind of variable load is not unusual and may result in the turbines' available electric and or thermal outputs to go underutilized.

Figure 2–4. Recuperated Gas Turbine

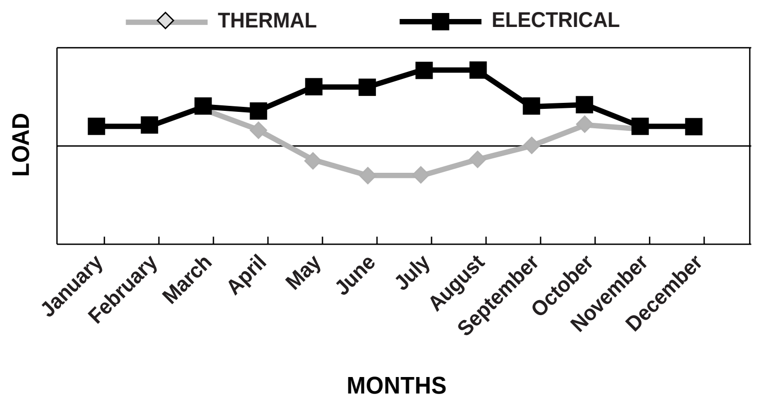


Building A might be forced to run its combustion turbine at partial load and buy electricity from a local utility—or run its turbine at full load and bypass (that is, waste) a large amount of heat from its physical plant. Since both of those options are undesirable, one possible solution may be a CHP system that can vary the flow of the steam and vary the electrical output.

Load fluctuations exhibited by Building A may be resolved by a combined cycle system. A combined cycle consists of a combustion turbine with an HRSG in series with an electric generating steam turbine (Figure 2–6). The waste heat from the combustion turbine produces steam at the HRSG that fuels the steam turbine to produce electricity. Combined cycle systems have improved greatly over the years, and today advanced systems (such as the Steam Turbine Assisted Cogeneration {STAC} System developed by Solar Turbines) are specifically designed to optimize the variance between electrical and thermal load requirements. During periods of higher electrical demand, all or a majority of the steam output from the HRSG can be sent through the steam turbine to create additional electrical output. In contrast, during periods of higher thermal demand, all or part of the steam from the HRSG can be used for process needs at the facility.

Low maintenance, high quality waste heat, and electric efficiencies varying between 25% - 40% make combustion turbines an excellent choice for CHP applications larger then 5 megawatts. Capital costs

Figure 2–5. Load Profile of Building A



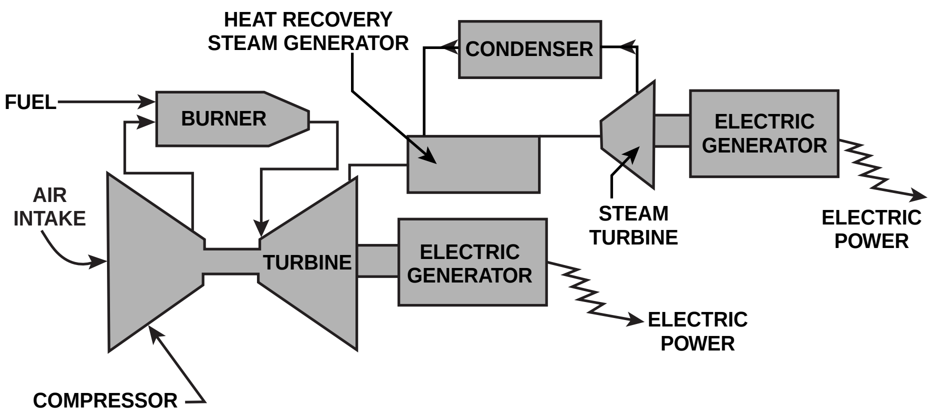


Figure 2–6. Combined Cycle System

for gas turbines vary between $300-$900/kW.

2.4 Fuel Cells

Fuel cells are an exciting technology that convert hydrogen-rich fuels, such as natural gas, into electricity and heat through an extremely quiet and environmentally clean process. Fuel cells generate electricity through an electrochemical process in which the energy stored in the fuel is converted directly to electricity (catalytic reaction). There are three main components that govern the operation of a fuel cell.

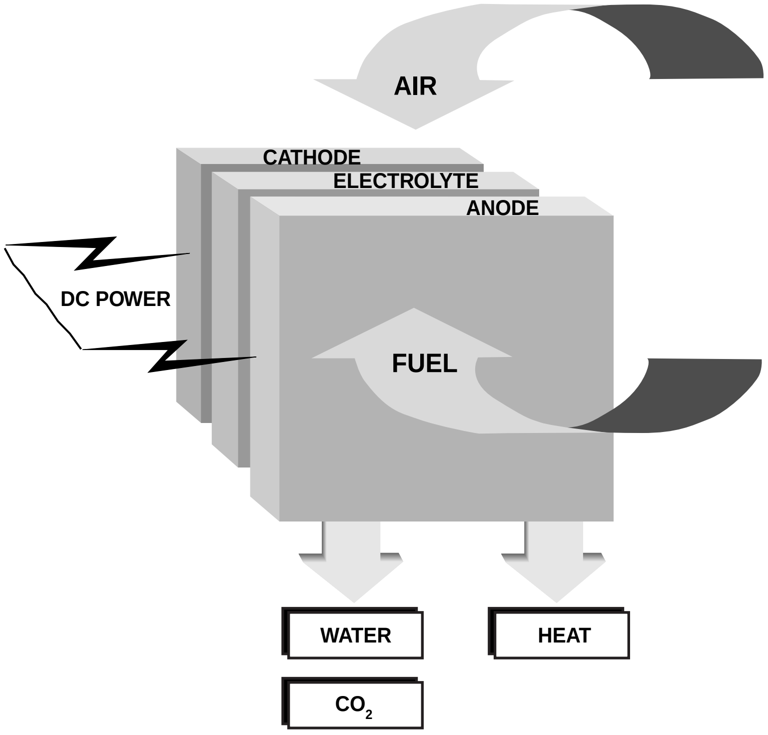
1. **Hydrogen Reformer,** fuel processor that extracts hydrogen from a fuel source (such as natural gas, biomass, or propane)
2. **Fuel Cell Stacks,** electrolyte materials situated between oppositely charged electrodes, where the hydrogen fuel generates DC power in an electrochemical reaction
3. **Inverter,** converts DC outputs to AC power

Figure 2–7 provides a visual example of the energy flows.

The operating conditions of a fuel cell are determined by the electrolyte; therefore, fuel cells are identified by the electrolyte employed in the process. Several fuel cell technologies are operating and under development today:

- **Phosphoric acid** fuel cells (PAFCs) are most common because they were the first fuel cell types to become commercially available. They have an acid electrolyte and operate at relatively low-temperatures, about 400°F. ONSI, the only commercial manufacturer of fuel cells using this technology, produces units sized at 200 kW with 700,000 Btuh of thermal heat recoverable in the form of hot water.
- **Molten carbonate** fuel cells (MCFCs) are relatively high-temperature units, operating in excess of 1100°F. MCFCs are designed for large-scale applications on the order of 50 to 100 MW. The high-temperature exhaust gases can be used in a combined cycle system, creating an overall efficiency of about 80 percent.
- **Solid oxide** fuel cells (SOFCs) also operate at high-temperatures, 1100 to 1800°F. At these

Figure 2–7. Fuel Cell Schematic



Source: DOD

temperatures, a natural gas-powered fuel cell does not require a reformer. A variety of 20 to 25 kW SOFC units have been tested, and units up to 150 kW are planned.

- **Proton exchange membrane** fuel cells (PEMs) operate at low temperatures, about 175°F. Manufacturers are targeting units in the range of 7 kW to 250 kW. Their very low thermal and noise signatures might make them especially useful for replacing military generator sets.

Efficient and Clean

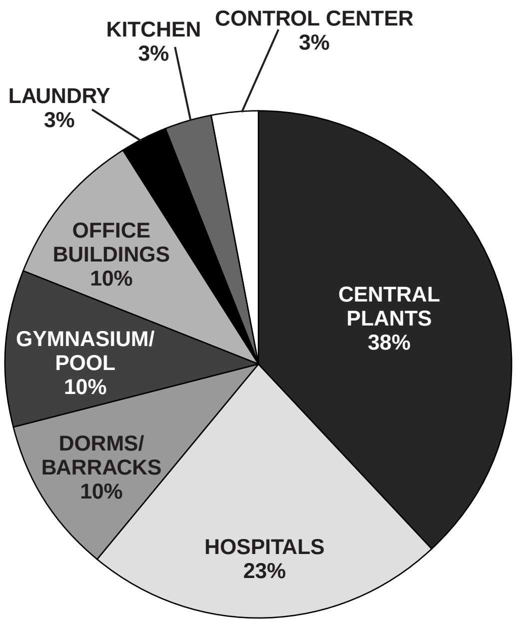
Pollution from fuel cells is so low that several Air Quality Management Districts in the United States have exempted fuel cells from requiring a permit to operate. Today’s natural gas-fired fuel cells operate with an electrical conversion efficiency of 35 to 40 percent and are predicted to climb to the 50 to 60 percent range in the near future. When recovered heat from the fuel cell process is used to capacity by a facility, efficiencies can exceed 85 percent. And as with microturbines, multiple fuel cells can be synchronized to meet changing demand needs.

DOD FUEL CELL Demonstration Project

The Department of Defense (DOD) and The U.S. Army Construction Engineering Research Laboratory (USACERL) have engaged in a demonstration program to stimulate growth and economies of scale in the fuel cell industry and to determine the role of fuel cells in DOD’s long-term energy strategy. In this demonstration program, a total of 30 PAFCs, manufactured by the ONSI Corporation, were installed and are being operated at DOD sites across the United States.

This demonstration project has been used in a range of thermal applications shown in figure 2–8.

Figure 2–8. DOD Thermal Applications



The DOD fuel cells are used in a variety of diverse military building applications. The DOD demonstration program yielded significant results that can be viewed in entirety at www.dodfuelcell.com. Table 2–3 provides a snapshot of results at three DOD demonstration facilities.

As of October 1998, the DOD Fuel Cell Fleet Summary showed the following:

• Total Run Time	328,725 hours
• Unadjusted Availability	71%
• Energy $ Saved (estimated)	$2,331,958
• NOx Abated	113 Tons
• SOx Abated	249 Tons
• CO_2 Abated	13,924 Tons

The DOD Fuel Cell Demonstration Program obtained a great deal of information about the selection and installation of fuel cells for onsite cogeneration. Using this information, USACERL created an application guide to provide a framework for other Federal facilities evaluating the potential for fuel cell cogeneration. This interactive guide can be found on the DOD Fuel Cell Demonstration Web site previously listed.

The major barrier to fuel cell market acceptance is their high first cost: $3,000 to $3,500 per

Table 2–3. DOD Facility Results

Site Name	Building Application	Thermal Application	Estimated Savings
Edwards Air Force Base	Hospital	DHW/ Space Heat	$96,000
Fort Richardson (Army)	Armory Building	Space Heat/ DHW	$67,000
United States Naval Academy	Academy Dormitory	Kitchen DHW	$38,000

kilowatt installed. Experts predict that fuel cell costs will have to come down below $1,000 per kilowatt before any significant non-government subsidized market transformation takes place. Growing public interest and increased manufacturer competition will play a major role in driving down the price over the next few years.

2.5 Micro-Turbines

Micro-turbine generators are small, single-staged combustion turbines with outputs ranging in size from 30 to 100 kilowatts. Micro-turbines used in CHP applications can vary in cost between $500 to $1500 per kilowatt installed. They are reasonably efficient (30 percent), have low maintenance costs, offer fuel flexibility, allow recovery of thermal heat, and have low emissions. When more power is required, multiple units can be synchronized to meet the changing demand.

Honeywell Power Systems has developed a micro-turbine labeled the Parallon 75 TurboGenerator Power System. The Parallon 75, with its 75 kilowatt rating, can act as a sole source of power—parallel to the grid, but not actually connected to it—or as a second source of power—connected to the grid to provide lower cost electricity and reliable backup. *Parallel power* is a self-contained system that monitors the grid around the clock; whenever the system can generate electricity for less than the utility company, it kicks on automatically, supplying onsite micro-turbine power in lieu of costly utility power.

The Capstone Micro-Turbine™ was the first technology of its kind to be commercially available to the power industry and energy customers. The Capstone 30 kW MicroTurbine (Figure 2–9) is a UL listed, low-emissions power generation system with unusually low maintenance needs. A gas turbine-driven high-speed generator is coupled with power electronics that allow the system to operate similar to the Parallon 75, either connected to the grid or in stand-alone modes. Both manufacturers offer quality onsite CHP solutions.

Figure 2–9. Capstone 30kW MicroTurbine

Reprinted with Permission: Capstone Turbine Corp

2.6 Hybrid Fuel Cell/ Micro-Turbine Systems

Edison Technology Solutions, in cooperation with DOE, the California Energy Commission, and Siemens Westinghouse, have developed the world’s first “hybrid” generating plant, integrating a fuel cell with a micro-turbine generator. This hybrid power plant has a lower capital cost than a stand-alone fuel cell with approximately twice the efficiency of a micro-turbine. The technology is expected to operate at an electric efficiency of 60 percent with an average cost of $1,000 per kilowatt.

This hybrid technology uses the micro-turbine’s compressor to deliver high-pressure air to the fuel cell where it reacts with natural gas to produce electricity and heat through an electrochemical process. Exhaust gas from the fuel cell then feeds the micro-turbine to produce even more electricity. Edison Technology Solutions chose the National Fuel Cell Research Center at UC Irvine in Irvine, California, to test this new and exciting technology. The test project is currently integrating a 60 kilowatt micro-turbine with a 200 kilowatt solid oxide fuel cell.

Technology Summary

Chapter 2 examined different cogeneration technologies, some emerging and some established. Table 2–4 offers a comparison of the technical and economical parameters distinguishing CHP technologies.

Table 2–4. Technical and Economical Parameters Distinguishing CHP Technologies

Parameter (approximations)	**Natural Gas Engine**	**Steam Turbine**	**Gas Turbine**	**Fuel Cell**	**Micro-Turbine**	**“Hybrid”**
Capacity	25 kW-5 MW	Any	500 kW-25 MW	200 kW-2 MW (testing down to 1kW)	25 kW-100 kW	250 kW
Electric Efficiency	25-45%	30-42%	25-40%(simple) 40-60% (combined)	35-55%	25-30%	60%
Footprint (sqft/kW)	0.22-0.31	<0.1	0.02-0.61	0.6-4.0	0.15-1.5	–
CHP installed Cost $/kW (typical)	800-1500	800-1000	700-900	>3,000	700-1300	1000-1500
O&M Cost ($/kWh) (typical)	0.007-0.015	0.004	0.002-0.008	0.003-0.015	0.002-0.01	–
Availability	92%-97%	Near 100%	90%-98%	>95%	90%-98%	–
NOx Emissions (lbs/MWh)	2.2-28	1.8	0.4-4.0	<0.02	0.4-2.2	–
Uses for Heat Recovery	Hot water, LP steam, district heating	LP-HP steam, district heating	Heat, hot water, LP-HP steam, district heating	Hot water, LP-HP steam	Heat, hot water, LP steam	–
CHP Output (Btu/kWh)	3,400	N/A	3,400-12,000	500-3,700	4,000-15,000	–
Usable Temp For CHP (F)	180-900	N/A	500-1,100	140-700	400-650	–

Source: ONSITE SYCOM Energy Corporation, 1999 (except for Hybrid data)

3.0 Federal Sector Potential

The feasibility of applying combined heat and power (CHP) technologies within Federal government facilities is dependent upon identifying the best uses of CHP and assuming an appropriate investment time frame. Undertaking a CHP project should be viewed as a long-term investment, in terms of planning, implementation, and operation. The proper planning of all key aspects of a medium- to large-scale successful CHP project—including legal, financial, regulatory, environmental, engineering, and training issues—requires that the project schedule match the expected benefits from full CHP implementation.

The financial benefits from a CHP project will depend upon the amount of the purchased thermal and electric power that the CHP system is replacing. Larger Federal building sites, including military bases, multi-building medical centers, national laboratory complexes, and training/research centers, have the largest purchased fuel and electric power requirements. Therefore, these larger Federal facilities will reap the greatest financial benefit from applying existing CHP technology.

Federal energy-using facilities fall into one of three time horizons in which installation of a CHP system will achieve its greatest potential:

A. Short-term (0 to 3 years)

- Off-shore military bases (for reasons of security, power quality, and power stability)
- Federal correctional facilities in heating dominated climates (because these buildings have a need for the thermal output from a CHP system for both space heating and domestic hot water heating)
- Department of Veterans Affairs and DOD medical centers (because these multi-building centers have a fairly constant need for the thermal output from a CHP system for such things as heating domestic hot water, heating service water for reheat coils, and sterilizing medical equipment)

- Federal office building complexes (such as multiple-building Federal facilities that could use the thermal output from a centralized CHP system as the input to absorption cooling equipment to achieve higher overall efficiency)
- Government Owned/Contractor Operated (GOCO) manufacturing and research facilities (because many manufacturing and research processes require steam or other thermal power for the production of industrial or research products)

B. Mid-term (more than 3, but less than 5 years)

- Larger (500,000 sf and larger) stand-alone Federal buildings located in areas not served by district steam or district chilled water systems. These larger Federal office buildings can use the thermal output from a CHP system to provide the needed heat-source for absorption cooling equipment. For example, the 2.3 million square foot immigration facility located next to the Canadian border in Ambrose, North Dakota
- Military base-wide steam heating systems that have large central plant boilers during the summer or other off-peak periods

C. Long-term (5 or more years)

- Medium-sized Federal buildings that can use the thermal output as the source for operating absorption cooling equipment in summer.
- Military base light industrial facilities (such as welding, vehicle engine repair shops, machine shops) that need peak power use and can use the thermal output for process steam.

Five years from now, CHP technologies will likely be less expensive to install and will have greater output per unit of input fuel. Increases in the cost of fuel oils and natural gas can result from international events beyond the control of fuel suppliers, but this will result in a lower life cycle cost for all CHP technologies. Thus, as the range of applications for CHP grows—installing separate fuel cells in individual military base housing units, for example—the economics of CHP will become more attractive.

4.0 Applications

Chapter 4 discusses seven significant parameters when considering combined heat and power (CHP) implementation in Federal facilities. These parameters include screening methodology, economic analysis, utility interconnections, environmental compliance, preliminary dos and don’ts, operating concerns, and maintenance issues.

Screening Methodology

Chapter 3 describes optimal conditions for implementing CHP technologies in Federal facilities. If your facility does not meet the conditions, implementing CHP technologies might not be ideal. Conversely, meeting those conditions indicates a strong technical case for further (economical) consideration of CHP technologies. Generally, plants having a very low percentage of electrical to total energy conversion are not considered economical for conversion to CHP. However, if these electricity generation costs per kilowatt-hour (for capital plus production) are less than the cost of electricity purchased from the local utility, then your facility has met the first screening test.

Because the main incentive of CHP is to generate electricity at a lower cost than it can be purchased from the utility, the economics of CHP are sharply influenced by the marginal cost of generating electricity. There are two kinds of primary plant costs: capital costs and production costs. *Capital costs* (in $/kWh) determine whether a given plant is sound enough to obtain financing, and thus able to pay the fixed charges against these costs. *Production costs* are the true measure of the cost of power generated. Production costs are composed of the following:

a.) Fixed charges.
b.) Fuel costs.
c.) Operation and maintenance costs.

It is important to calculate the production costs of electricity as an excess over the generating costs of thermal energy alone, and to compare these production costs with the cost of electricity purchased from a utility.

Economic Analysis (Life-Cycle Costing)

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). (Source: FEMP). Life-cycle costing is an effective method for calculating the economic feasibility of CHP projects. Life-cycle costs account for the collective total of implementation, operating, and maintenance costs over the life of an upgrade. Appendix B outlines the Federal life-cycle costing procedures and information on the Building Life-Cycle Costing (BLCC) software developed by the National Institute of Standards and Technology (NIST).

Utility Interconnections

Requirements for interconnection with public utilities' grids vary from cogenerator to cogenerator and from one electric utility to another, depending upon generation equipment, size, and host utility systems. Interconnection equipment requirements increase with generator size and voltage level. Generally, complexity of the utility interface depends on the mode of transition between paralleling and stand-alone operation.

The plant connection to the electric grid must have an automatic utility tie-breaker and associated protective relays. When utility power is lost, this tie-breaker opens and isolates the generator and its loads from the utility. The protective relays at the entrance and at the generator must be coordinated so that the utility tie-breaker opens before the generator's breaker. An automatic load control system is needed to shed non-critical loads to match generator's capacity. When utility power returns, the generator must be synchronized with the utility across the utility tie-breaker, whereas under normal start-up conditions the generator is synchronized across the generator circuit breaker. The synchronizing equipment must accommodate both situations.

When a cogeneration system is integrated into the utility system, the following issues must be met:

(a) Control and monitoring
(b) Metering
(c) Protection
(d) Stability
(e) Voltage, frequency, synchronization, and reactive compensation for power factors
(f) Safety
(g) Power system imbalance
(h) Voltage flicker
(i) Harmonics

Utility interconnection with onsite CHP technologies is currently a burdensome and lengthy process. This laborious process causes a certain degree of apprehension and disincentive for Federal facilities considering CHP projects. The Barriers and Solutions section of Chapter 5 describes this grid connection problem and outlines DOE initiatives to alleviate the situation.

Environmental Compliance

Advantages of Outdoor Air Compliance

CHP technologies are frequently fueled by natural gas, which is inherently clean compared with other fossil fuels. Combining a relatively clean fuel with state-of-the-art combustion controls found in newer technologies results in an extremely clean CHP process. And thanks to an electrochemical process, fuel cell air pollution is almost negligible.

As a result, CHP technology has the potential to reduce overall emissions of both criteria pollutants (NOx, SO_2) and greenhouse gases (CO_2). The use of CHP systems by customers to supply some or all of their electricity will displace the need for power purchases and offset central station plant and line loss emissions. CHP technology also displaces emissions from the existing boiler or furnace at the site.

The Outdoor Environmental Barrier Confronting CHP:

In the past, pollution from electricity generation was always the utilities' problem; now, with the emergence of onsite generation, accountability for emissions (when in excess) shifts to the facility. The Clean Air Act requires costly and time-consuming New Source Review (NSR) procedures when emissions significantly increase at a site. Also, current air pollution regulations in the United States are based on limiting the amount of emission per unit of fuel input. This approach does not credit CHP with emission reductions associated with grid reductions or from displaced emissions from onsite fossil fuel combustion sources.

Possible Solutions:

CHP advocates, both private and institutional, acknowledge that environmental permitting is a major obstacle to the proliferation of new onsite CHP projects. Advocates of CHP are encouraging the EPA to adopt output-based standards that set pollution allowances per unit of heat and electricity, accounting for overall emission reductions resulting from displaced central station and existing boiler emissions. Paul Stolpman, Director of EPA's Office of Atmospheric Programs remarked at last year's CHP Summit in Washington, D.C.: "EPA recognizes CHP as a key component of climate policy and is committed to pursuing regulatory actions to level the playing field for CHP."

Preliminary Do's and Don'ts

Do's

1. Select components that are designed for industrial applications and that include no design life compromises inherited from vehicle or aerospace ancestries. Prime movers, in particular, must be designed to achieve 80,000 hours of useful life.
2. Consider prime movers that have at least 8,000 hours mean time between forced outages.
3. Take into account only systems that comply with following specifications: Electrical efficiency for the gas-turbine-based systems that include recuperators or heat recovery units (or both) must be greater than 35% based on HHV of a fuel (or greater than 38% LHV) regardless of their cogeneration efficiency. For cogeneration systems larger than 50 kW, part load (~50%) electrical efficiencies should be no less than 30%.
4. For systems burning natural gas as a fuel, ensure that emissions do not exceed the following values: NOx < 10 ppmv, CO < 25 ppmv.
5. If the plant utilizes Rankine cycle, (i.e., a steam turbine) use the topping cycle for power generation.
6. When using a gas-turbine engine in a simple-cycle configuration, consider a counterflow recuperator to increase thermal efficiency.
7. Use steam turbine in lieu of pressure reducing stations.

Don'ts

1. Do not use a bottoming cycle.
2. Do not match the electrical output of the CHP generator to the peak electrical demand.
3. Do not use expensive post-processing of the exhaust to compensate for elevated emissions of inadequate combustion equipment.
4. Do not design and construct complex thermodynamic or exotic hybrid cycles—the technology is not perfected yet.

Operating Concerns

Natural Gas Engines and Turbines

Years of reliance on grid-connected central station electricity have created apprehension about the reliability of new onsite CHP technologies. Fortunately, extensive research (see table 4–1) has shown that gas engines and gas turbines are just as reliable as central station utility plants, if not more so.

Natural gas power generation systems exceed the reliability of most central station power generation units, according to a study conducted by ARINC Corporation for the Gas Research Institute (GRI). The study consisted of 122 natural-gas-powered generating units with nearly 2 million hours of operating time. Units were grouped into categories reflecting size (from 60 kW to 100 MW), type of system (engine or turbine),

Table 4–1. Reliability of Natural-Gas-Powered Cogeneration Systems

	Reciprocating Engines			Gas Turbine Engines			Electric Utility
Operational Reliability Measure	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	1986-1990
Power	60 kW	80-800 kW	>800 kW	1-5 MW	5-25 MW	>25 MW	–
Availability Factor (%)	95.8	94.5	91.2	92.7	90.0	93.3	85.9
Forced Outage Rate (%)	5.9	4.7	6.1	4.8	6.5	2.1	24.7
Scheduled Outage Factor (%)	0.2	2.0	3.5	3.0	4.8	4.8	9.9

use of emission controls, and type of thermal application; all of these units included cogeneration heat recovery. Table 4–1 displays the results of this analysis, comparing cogeneration and central station reliability.

Table 4–1 demonstrates the impressive reliability of CHP technologies—natural gas engines and turbines—when compared with traditional central station utility generation.

Fuel Cells

Fuel cell technology has been around for a long time, but its use as a stationary electric generating source is quite recent. Most applications are in the prototype or demonstration phase, but the Department of Defense (DOD) and USACERL have completed a reliability study of the fuel cell demonstration project at various military installations across the United States. The results of the demonstration project are summarized in table 4–2 to reflect the many operating parameters involved in fuel cell cogeneration. Beyond energy, costs, and pollution, the demonstration project analyzed the reliability of fuel cells. Note that Table 4–2 displays only the average findings for the 30 Phosphoric Acid (PAFC) ONSI fuel cells.

Table 4–2. DOD Fuel Cell Demonstration Project—Reliability Results

Availability	**71.0%**
Forced Outage Rate	**7.7%**
Cell Voltage Degradation	**8.0%**

Hybrid Micro-Turbine/Fuel Cell

As stated earlier in this report, the hybrid micro-turbine/fuel cell is so new that it is only now being installed at the National Fuel Cell Research Center for testing and evaluation. Until further studies are conducted, it would not be prudent to make reliability predictions.

Maintenance Issues

Natural Gas Engines

Natural gas-engine-packaged cogenerators (as described in section 2.1) are being developed for onsite CHP applications with ease of maintenance in mind. A recent study indicates that operations and maintenance (O&M) costs for gas engines are in the range of $0.0075-$0.01/kWh.

Steam Turbines

Proper maintenance is important because the power output of steam turbines (as described in section 2–2) can degrade if contaminants from the boiler carry over and deposit on turbine nozzles. Maintenance is also crucial to auxiliary components, such as lubricating-oil pumps, coolers and oil strainers. Steam turbine (O&M) costs are typically less than $0.004 per kWh.

Gas Turbines

Gas turbines being developed out of DOE's Advanced Turbine Systems program (as described in section 2.3) are designed with modular assembly and maintenance components. The major subsystems—including the burner, turbine, compressor, recuperator, gearbox, and generator—can be changed independently in the field without replacing the entire gas turbine. O&M costs vary among dealers, but can be expected in the $0.002-$0.008/kWh range.

Fuel Cells

To properly maintain fuel cells (as described in section 2.4), it is important to set up a schedule of routine maintenance cycles. Fuel cell O&M costs to the end user are usually in the $0.003 to $0.015/kWh range. This ensures reliability and peak performance over the life of the product. Maintenance usually covers components such as the fuel cell stack, air filters, water treatment beds, pressure vessels, motors, valve actuators, and pressure piping systems.

Micro-Turbines

Micro-turbines (as described in section 2.5) are a relatively new CHP technology slowly entering the market as a viable option for small-scale CHP generation. Micro-turbines are designed to be as maintenance-free as possible. They are developed with quiet air-bearings that need no oil, water, or other maintenance. Of course, routine maintenance of air/fuel filters, ignitors, thermocouples, and fuel injectors, is important for warranties that guarantee specific efficiencies and equipment life spans. Maintenance is highly recommended by the manufacturer to ensure peak performance. O&M costs are estimated at $0.002-$0.01/kWh.

5.0 Technology Performance

Field Experience

As discussed in Chapters 2 and 4, field experience reveals that on-site CHP gas engines and gas turbines not only operate with lower energy costs and cleaner emissions, but are just as reliable as central station utility plants, if not more so. The real question about CHP technology today is how will all CHP technologies perform as a stationary electric power source at Federal facilities?

One path to answer that question can be found in the Department of Defense (DOD) Fuel Cell Demonstration project. The project included the installation and monitored operation of 30 ONSI PAFCs under the direction of CERL. As of September 1999, these fuel cells have generated 82,504 megawatt-hours of electricity, 157,808 mega-Btus of thermal energy, and saved $3,368,307 in displaced electrical and thermal energy costs. High initial costs are the main barrier to non-subsidized fuel cell implementation in the Federal sector; however, the DOD Demonstration project revealed that the technology clearly works and that with further government research and development with industry partnerships, economical installed costs are within reach.

While CHP technologies other than fuel cells have been installed, there is no similar compilation of statistics of these non-fuel cell applications showing energy saved and costs displaced.

Equipment Changes

Because of market-driven competition and DOE research support, CHP equipment has undergone more improvements and subsequent changes than other types of traditional thermal and power generation equipment. Key to improvements in CHP technology is that major manufacturers have quickly accepted DOE-sponsored research and have incorporated the results into their products.

As an example of this partnership, DOE's Office of Industrial Technologies has an Industrial Power Generation program to produce 21st century gas turbines and systems. Partners in this study include gas turbine manufacturers, universities, natural gas companies, electric power producers, National Laboratories, and end users. Solar Turbines, a major turbine manufacturer of CHP systems, was selected by DOE to test the use of advanced ceramics (nozzles and blades with enhanced strength and durability) to increase the performance of its gas turbines. The benefit to the CHP industry of these innovative ceramic components is the increase in turbine inlet temperature and reduction in cooling air requirements. An environmental benefit is that the "hot wall" ceramic lines also enabled a reduction in gas turbine emissions of NOx and carbon monoxide.

Barriers and Solutions

CHP systems are efficient. They reduce total utility expenses, decrease central power plant air pollution, and are reliable. So why isn't this technology catching on? Unfortunately, many institutional and regulatory barriers—interconnection with the grid, pricing practices, utility tariffs, and environmental permitting, to name a few hinder implementation.

Barrier

The Clean Air Act requires costly and time-consuming New Source Review (NSR) procedures. As well, compliance requirements do not credit CHP projects with emission reductions associated with grid reductions *or* from displaced emissions from on-site fossil fuel combustion sources.

Solution

DOE is currently working with EPA and individual states to assist efficient onsite CHP technologies within the framework of the Clean Air Act. This approach is to increase the use of performance and output-based environmental standards and streamline the permitting processes for onsite CHP generation.

Barrier

Implementation of CHP is not the primary mission for any federal agency. Most agencies are required to address the programs funded by Congress, and excluding DOE, this does not include CHP. Therefore, this is little incentive to "try something new" as CHP is often perceived.

Solution

DOE needs to take the leadership position and demonstrate the energy expense savings success that CHP can achieve. As more agencies realize that OMB will issue a "scorecard" for their energy performance, CHP should be positioned as a ready means to improve their score.

Barrier

Interconnectivity

Utility requirements for interconnecting non-utility–owned onsite CHP generation with the utility's electric distribution grid can severely delay a new CHP project, increase its cost, or even terminate the project altogether. Utility interconnection requirements can be burdensome, particularly for smaller CHP projects. A utility's requirements describing its mandated procedures can be laborious, and each utility typically has a different set of requirements. Meeting those requirements can cost thousands of dollars.

Back Up Charges

On occasion, CHP technologies will require down time for maintenance. During this time the facility will have to purchase its electricity (under a "back up" rate schedule) from its local utility. These "backup" charges are in many cases excessive and make onsite generation economically unfeasible.

Solution

Excerpts from Dan Reichers (Assistant Secretary for Energy Efficiency and Renewable Energy) Testimony to the United States Senate – June 1999

What is needed is a non-discriminatory national standard that applies to all distributed power technologies that also assures that these systems are properly integrated into the grid in a manner that addresses critical safety, reliability, and power quality issues. DOE has begun several activities to address interconnection and is working with the Institute of Electrical and Electronics Engineers (IEEE) to develop a uniform national interconnection standard. DOE's support will enable what is typically a 5- to 8-year process to be accomplished in about 2 years. An important piece of DOE policy strategy is to knock down onsite generation barriers, which is included in the Administration's Comprehensive Electricity Competition Act submitted to Congress on April 15, 1999. The bill also includes a number of tax provisions that are needed to update Internal Revenue Code to provide fair treatment to onsite power. The bill would set tax depreciation schedule lifetimes for onsite power equipment at 15 years, not 39 years. Addressing this current ambiguity in the Internal Revenue Code is critical to the economic future of onsite generation technologies that potentially are disadvantaged by inequitable depreciation schedules. In addition, the bill also includes an 8-percent tax credit for certain combined heat and power systems due to the substantial economic and environmental benefits these systems can provide.

Also, the Gas Research Institute (GRI) recently started a program called Switch-gear and Interconnection Systems (ISIS), designed to accomplish the following:

- Create a reduction in capital costs (25–50%).
- Advance the concept of "Plug and Play" (50% reduction in installation time and labor).
- Integrate with leading natural gas engine and turbine generator set manufacturers.
- Conform to basic electric utility interconnection requirements and incorporate advanced interconnect/ generator set protective functions.
- Conform to existing or projected industry standards.
- Advanced remote monitoring, communications, and control functions.

Conclusion

Barriers to CHP implementation are real and, in some cases, daunting. Fortunately, DOE and other Federal agencies are acknowledging these barriers and expending resources to streamline the laborious processes and procedures of grid connection and environmental permitting.

6.0 Combined Heat and Power Case Studies

This chapter presents case studies of CHP technologies. Due to the changes in the operational requirements mandated by increased security regulations on different Department of Defense locations, and the increase in privatization of distribution systems, there is limited information available about DOD CHP installations. Many DOD facilities that either have or had CHP installations were contacted, but most did not provide complete system characteristics. Nevertheless, these DOD sites are listed in Appendix A for informational purposes only.

Traditional CHP

The Marine Corps Recruit Depot at Parris Island, South Carolina

South Carolina Electric & Gas Company (SCE&G) currently supplies base load electricity services to the Marine Corps Recruit Depot (MCRD) at Parris Island, South Carolina (PISC). Historically, an onsite Central Power Plant (CPP) was used to supply all the electric power needs for the Depot. Today, however, the three 1,000-Kilowatt (KW) extraction steam turbo-generators that make up the CPP are providing peak shaving, power factor correction, and combined heat and power (CHP) for the 12.47 KV system. Distribution from the power plant is via 4. 16 KV underground system, which serves 43 mission-essential buildings in the core area.

During the last couple of years, MCRD has worked with the Department of Energy (DOE) and Pacific Northwest National Laboratories (PNNL) in the study, design and installation of the Decision System for Operations and Maintenance (DSOM) Project. The DSOM system is an innovative approach to the operation and maintenance at the CPP at MCRD. DSOM is an integrated hardware/software platform for improving energy efficiency, and reducing operating and maintenance costs. The system also reviews purchased electricity costs and fuel costs to ensure that the Depot is operating the turbine generators in the most economical manner (i.e. to generate electrical power versus purchasing from the local power company). The projected economics savings for CHP/peak shavings for this project are $100K per year.

The Naval Medical Center, San Diego, California

The Naval Medical Center, San Diego (NMCSD) delivers quality health services in support of the US Armed Forces and maintains medical readiness while advancing military medicine through education, training, and research. Energy Management is another strong attribute of the medical center. Currently, three 800 kW gas turbines, operating parallel to the grid, supply high quality power to supplement and reduce NMCSD's dependence on central utility power. The exhaust heat from each gas turbine produces 6,100 pounds-per-hour of high-pressure steam via a heat recovery steam generator (HRSG). The HRSG provides useful thermal energy for a variety of heating and cooling needs, including an 800-ton absorption chiller, domestic hot water, sterilization and kitchen support systems. NMCSD's CHP plant has proven a successful and viable option for onsite support of hospital electrical, heating and cooling needs.

Fuel Cells

Fuel cells are poised to be a major player in future cogeneration efforts. They offer the promise of exceptionally clean onsite power generation. For many projects, the cost of fuel cells—about $3,000 per kilowatt for the primary equipment, and approximately $1,000 per kilowatt for installation—is no longer prohibitive, thanks in part by efforts of the Federal government to provide leadership in promoting fuel cell research to determine their potential and to lower their cost. In the past few years, the cost of fuel cells per kilowatt has already dropped some 66 percent. Like all co-generation technologies, fuel cells produce both electricity and useful thermal energy. Capturing and using the heat produced by the chemical reaction that produces electricity is key to making fuel cell technology economically viable.

For the DOD Fuel Cell Demonstration program, 30 fuel cells manufactured by ONSI Corporation of South Windsor, Connecticut were installed on different DOD sites. All of these fuel cells use phosphoric acid as an electrolyte and, and like most fuel cells, it uses natural gas as its source of hydrogen. Additional information on each of the 30 fuel cell demonstrations can be found on the DOD Fuel Cell Demonstration web site located at www.dodfuelcell.com

The U.S. Military Academy at West Point

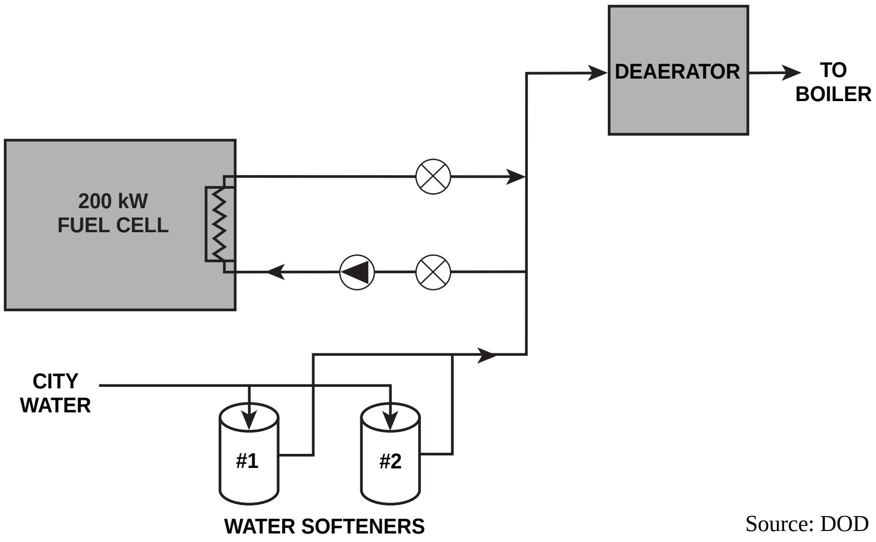
The U.S. Military Academy in West Point, New York, has used a fuel cell to supply some of its electricity and thermal energy needs since November 1995. The Academy, selected by the DOD Fuel Cell Demonstration Project to help test the viability and potential of fuel cells, has an annual enrollment of more than 4,000 cadets. ASHRAE design temperatures for the site are 4ºF in the winter and 88ºF in the summer. The fuel cell is located at the central boiler plant in the parking area on the south side of the main building.

The fuel cell is a Model PC25B rated at 200 kilowatts. Its electrical interface is at the existing 480-volt panels in the electrical room of the central boiler plant. It uses natural gas as its fuel source. The heat produced by the fuel cell is used to preheat boiler make-up water.

Length of piping/wiring runs	
Electrical (to panel)	~150 feet
Thermal (to mechanical room)	~90 feet
Natural Gas	~150 feet
Cooling Module	~20 feet

The energy efficiency of this installation is approximately 68.2 percent. Electric efficiency is 31.9 percent, and thermal efficiency is 36.3 percent (HHV). (See figure 6–1.)

Figure 6–1. Thermal Use Schematic, U.S. Military Academy



Source: DOD

The U.S. Military Academy purchases its electricity from Orange and Rockland Utilities and its natural gas from Central Hudson Gas & Electric Company. The fuel cell has allowed the Academy to achieve the following annual savings.

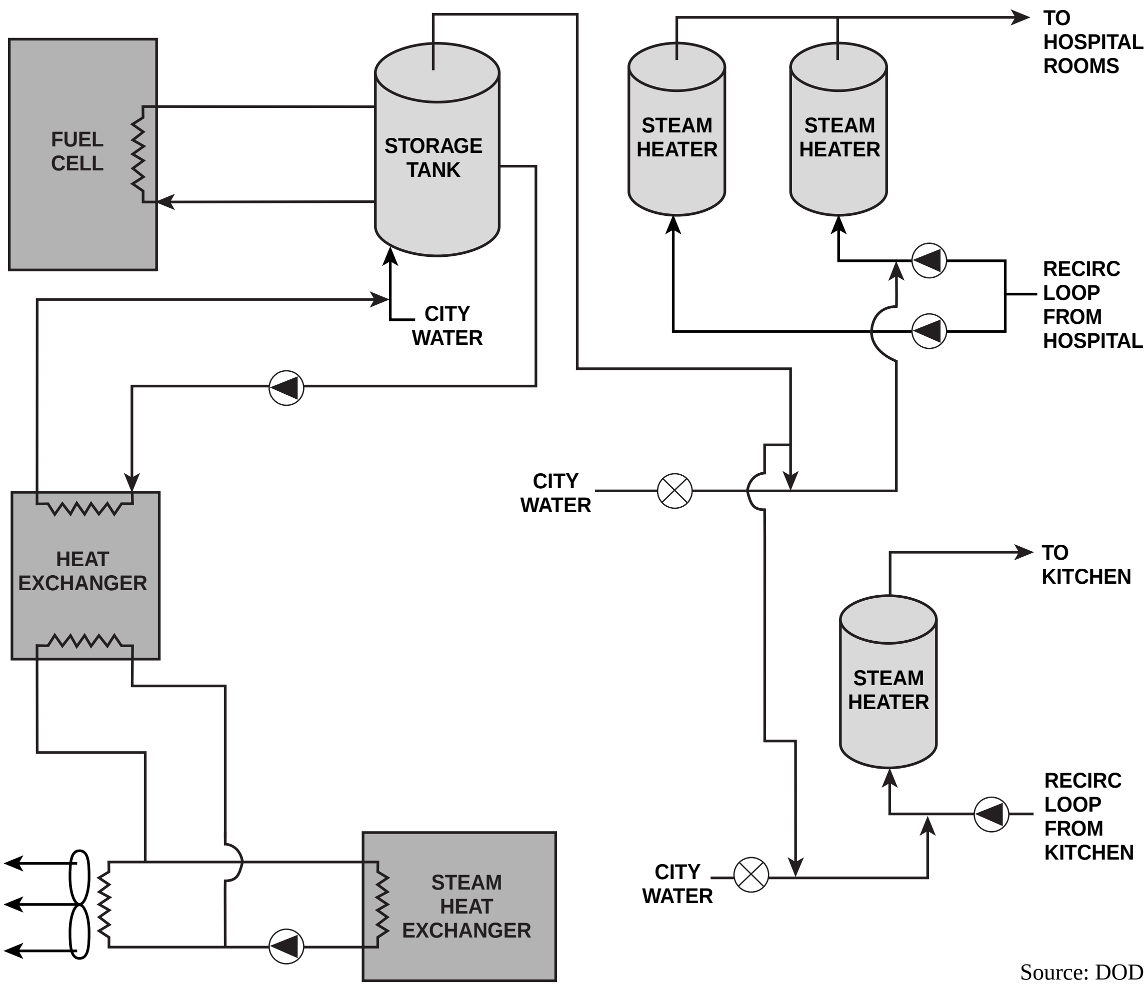
Electrical Savings	$79,000
Thermal Savings	$26,000
TOTAL SAVINGS	**$105,000**
Minus Natural Gas Cost	($75,000)
NET SAVINGS	**$30,000**

Even without including installation costs, the simple payback is high, however, there are several efforts both public and private aimed at bringing fuel cell prices down to more competitive levels.

The U.S. Naval Hospital in Jacksonville, Florida

The U.S. Naval Hospital at Naval Air Station (NAS) Jacksonville is a nine building complex that serves base personnel as well as other service personnel in the region. The main building has eight stories and originally contained 400 beds. Most of the area has been converted to support outpatients. The hospital currently handles around 40 to 50 overnight patients. The other buildings in the complex include a new 90,000-sf outpatient facility, laboratories, office buildings, and training facilities. The ASHRAE design temperatures for the site are 32ºF in the winter and

Figure 6–2. Thermal Use Schematic, U.S. Naval Hospital, Jacksonville



Source: DOD

94ºF in the summer. A fuel cell was installed in 1997 in a chiller room adjacent to the main mechanical room.

The fuel cell is a Model PC25C rated at 200 kilowatts. Its electrical interface is an electrical panel located in the chiller room. It is fueled by natural gas. Thermal energy from the fuel cell is directed toward a refurbished 1,500-gallon thermal tank that feeds two instantaneous water heaters.

Length of piping/wiring runs	
Electrical (to panel)	~60 feet
Thermal (to storage tank)	~65 feet
Natural Gas	~30 feet
Cooling Module	~20 feet

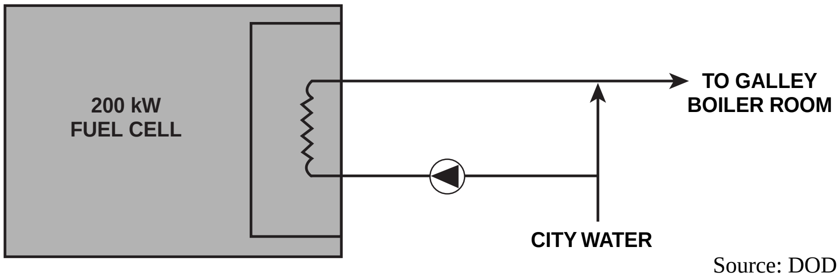
The hospital complex purchases electricity from the NAS Public Works Center at a flat rate of 6.8 cents per kilowatt-hour. The fuel cell has allowed the hospital to achieve the following annual savings:

Electric Savings	$107,000
Thermal Savings	$45,000
TOTAL SAVINGS	**$152,000**
Minus Natural Gas Cost	($62,000)
NET SAVINGS	**$90,000**

The U.S. Naval Academy at Annapolis

The U.S. Naval Academy in Annapolis, Maryland, established in 1845, is an undergraduate college that prepares young men and women to become officers in the

Figure 6–3. Thermal Use Schematic, U.S. Naval Academy



Source: DOD

U.S. Navy and the U.S. Marine Corps. It is also an energy showcase site for the U.S. Navy, where advanced energy technologies are demonstrated. The fuel cell, which was installed at the Academy in 1997, is housed in the galley at which more than 12,000 meals are served each day.

The fuel cell is a Model PC25C rated at 200 kilowatts. Its electrical output is a fuse box inside a nearby electrical room. Like most fuel cells, it is fueled by natural gas. Thermal energy from the fuel cell is used to preheat the cold water make-up for domestic hot water purposes.

Length of piping wiring runs	
Electrical (to panel)	~70 feet
Thermal (to make-up line)	~400 feet
Natural Gas	~100 feet
Cooling Module	~20 feet

Thermal utilization is estimated at 78 percent.

Savings on energy bills achieved by using the fuel cell are approximately $40,000 annually.

Electric Savings	$75,000
Thermal Savings	$21,000
TOTAL SAVINGS	**$96,000**
Minus Natural Gas as fuel	($56,000)
NET SAVINGS	**$40,000**

7.0. Outlook for CHP Technology: Strategies for Success

For some 50 years, centralized power generation has been used almost exclusively. Small-scale CHP technology depended on the use of reciprocating engines. Most electrical generators were for emergency purposes and not connected to the public utility grid. Now, with the advent of fuel cells and hybrid technologies, there is an increasing demand for smaller scale distributed generation equipment. The restructuring of the electric utility industry has created the need for Federal energy consumers to realize that there are now and will be more choices for energy supply. The need for reliable electric power on-site, and the increasing strains on an aging electric power grid both mean that the trend is toward CHP. Used wisely, CHP can be the key technology to improve power quality, boost system reliability, reduce energy costs, and help delay utility capital investments.

Traditional CHP markets are those with high heat demand, such as industrial sites with process heating requirements (especially the petroleum, chemical, brewing, and paper industries), hospitals, leisure centers, sewage treatment plants, and district heating/cooling plants. Today, new engine and turbine technologies have a significant potential for small-scale CHP in multi-residential and commercial applications.

Improvements in combustion turbine performance, decline in equipment and construction prices, and apparent ease of project permitting, have resulted in gas-fired combined-cycle combustion turbines and simple-cycle micro turbines emerging as the least-cost alternative for bulk power generation.

CHP economics are sensitive to site- and plant configuration and are governed by the site's energy demand profile as well as the plant's capital and maintenance costs, rating hours, and energy prices. Many times, inadequate attention to even one of these factors has led to failure of the plant to fulfill its promise. Thus, despite strong Federal support of the principle of CHP, this sensible energy generation technology has not been fully embraced by the Federal or private sectors.

On the other hand, a properly implemented CHP plant rewards its owner with strong reliability and profitability. Successful CHP installations are based on the realization of the following basic requirements:

1) The system is sized to not exceed the thermal needs of the process.
2) Natural gas is used as the preferred fuel for commercial CHP.
3) To enable efficient power generation, thermal energy is generated at substantially higher pressure and temperature than that which needed for its final use. For example, the outlet temperature and pressure of steam from a heat recovery steam generator is significantly higher than the conditions needed to heat service hot water for perimeter heating, preheat domestic hot water, preheat boiler feedwater, preheat ventilation air, or other typical building thermal loads. Electric power is first generated and then thermal energy is recovered for use in a process that is applicable for the site.
4) Heat load and power demand are simultaneous at the plant.
5) Simultaneous demands for heat and power must be present for at least 4,500 hours a year. The most cost effective applications are those that have 8,760 hours per year.
6) Heat-to-Power ratio for the plant must not fluctuate more than 10 percent.
7) Technology for implementing a CHP must be commensurate with plant's required Heat-to-Power ratio.
8) The viability of CHP depends on energy prices. The highest potential for CHP occurs when the utilities' electricity prices are high (and rising) while prices for natural gas are low (and falling).
9) The economic feasibility of CHP is inversely related to the plant's capital and maintenance cost. In other words, the higher the capital costs or the higher the maintenance costs, the less likely the CHP facility will be economically feasible.
10) The CHP plant must ensure highest availability.

The Big Picture

The correct application of CHP represents a great opportunity to reduce greenhouse gas emissions in the United States. CHP also presents an opportunity to not only improve the bottom line for Federal facilities, but also to provide a mechanism for improving air quality.

The United States is taking steps toward creating policies to promote CHP by establishing a national target. DOE and EPA have begun to review the means for achieving this target. The target now needs to be translated into concrete policies and programs at both the Federal and state levels for overcoming the significant hurdles to greater use of CHP.

At the 1998 CHP Summit in Washington, D.C., Dan Reicher, Assistant Secretary, DOE's Office of Energy Efficiency and Renewable Energy, challenged government and industry alike to move forward with CHP initiatives and proliferate the implementation of CHP projects across America. Reicher's challenge included the following:

- Develop a CHP vision to double the amount of energy supplied by 2010.
- Quantify the benefits of CHP.
- Share the benefits of CHP with people throughout the country.
- Develop a roadmap outlining action to take, analysis to perform, public outreach to execute, and niche markets to explore.
- Measurement of CHP progress.

DOE and industry partners are well on their way to educating, testing, and implementing CHP strategies and will continue to do so until national CHP goals are achieved.

8.0 Federal Program Contacts

The importance by the Federal government on CHP has been entrusted to several offices within DOE. This section provides the name of the primary person to contact to obtain specific program information on CHP:

Federal Energy Management Program
Contact: Arun Jhaveri
Seattle Regional Office
800 Fifth Ave., Suite 3950
Seattle, WA 98104
Phone: (206) 553-2152
Fax: (206) 553-2200

Office of Industrial Technologies
Contact: Thomas King
1000 Independence Ave., SW
Washington, DC 20585
Phone: (202) 586-2387
Fax: (202) 586-3237

Office of Buildings Technology, State & Community Programs
Contact: Ron Fiskum
1000 Independence Ave., SW, EE-42
Washington, DC 20585
Phone: (202) 586-9154
Fax: (202) 586-5557

Office of Power Technologies
Contact: Bill Parks
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Washington, DC 20585
Phone: (202) 586-2093
Fax: (202) 586-3237

Pacific Northwest National Laboratory
MS K5-08
P. O. Box 999
Richland, WA 99352-0999
Contact: Steven Parker
Phone: (509) 375-6366
Fax: (509) 375-3614

Oak Ridge National Laboratory
P. O. Box 2008
Oak Ridge TN 37831-6070
Contact: Robert C. DeVault
Phone: (423) 574-0738
Fax: (423) 574-9329

U. S. Department of Energy
Energy Efficiency and Renewable
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P. O. Box 3048
Merrifield, VA 22116
Phone: (800) 363-3732
Web site: www.erec.doe.gov

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david.waldrop@hq.doe.gov

9.0 Manufacturers and Additional Sources of Information

Note: The firms listed below were identified as manufacturers of the technology at the time of this report's publication. This listing does not purport to be complete, to indicate the right to practice the technology, or to reflect future market conditions.

CHP Technology	Manufacturer
Natural Gas Engines	**Admic Controls** (80 Kw – 130 Kw),
	Alston Energy Inc (750 Kw – 1.3 Mw),
	Alturdyne (25 Kw – 2 Mw),
	Caterpillar, (55 Kw – 3.4 Mw)
	Cooper Cameron Corp, (350 Kw – 6.5 Mw)
	Enerflex Power Systems, (50 Kw – 2.5 Mw)
	Katolight Corp, (up to 2 Mw)
	Lister-Petter Inc, (5 Kw to 400 Kw)
	Rolls-Royce Energy Systems, (3 Mw – 51 Mw)
	Synergy International, (up to 2 Mw)
	Tecogen, (60 Kw – 75 Kw)
	Wartsila NSD, (1 Mw – 16 Mw)
	Waukesha Engine Div, (6.5 kW – 3.3 Mw)
Fuel Cells	**Allied Signal,** (Solid Oxide Fuel Cells)
	Analytic Power Corporation, (Ammonia Cracker Hydrogen Source Fuel Cell - 2 Kw)
	Avista Corp., (2 Kw Polymer Electrolyte Membrane Fuel Cell)
	Ballard Power Systems, (Proton Exchange Membrane (PEM) Fuel Cell – 250 Kw)
	Energy Partners, (PEM up to 10 Kw)
	Energy Research Corporation, (Direct Fuel Cell – 2.5 Mw)
	H Power Corporation, (Proton Exchange Membrane Fuel Cells – up to 1 Kw)
	ONSI Corporation, (PC25™ Fuel Cell – 200 Kw)
	Plug Power, LLC, (Proton Exchange Membrane (PEM) Fuel Cell 7 Kw)
Turbines	**Solar Turbines**
	Siemens
	GE
	Westinghouse
Micro Turbines	**Capstone Turbine Corporation,** (28 Kw)
	Honeywell Power Systems, (75 kW)
	Elliott/Bowman, (45 Kw and 65 Kw)
	Northern Research, (30 – 250 Kw)

Advocates

National Fuel Cell Research Center
http://www.nfcrc.uci.edu/

Northeast-Midwest Institute
http://www.nemw.org

American Council for Energy-Efficient Economy
http://aceee.org/chp/

DOE CHP Challenge:
http://www.oit.doe.gov/chpchallenge

U.S. Combined Heat & Power Association
http://www.nemw.org/uschpa

International Cogeneration Alliance (ICA)
http://www.localpower.org/

Distributed Power Coalition of America
http://www.dpc.org/

Gas Research Institute
http://www.gri.org

Software

DG Pro™—Economic screening tool
http://www.archenergy.com/dgpro/

Ergon—feasibility assessmentswww.ies4d.com/products/4DperformanceAssessmentTools/ergon/ergon.htm

energyPRO—optimization program
http://www.emd.dk/energyPRO/default.htm

Publications

The following 3 papers can be found at:
http://www.nemw.org/uschpa/papers.htm

Combined Heat and Power: Saving Energy and the Environment

Federal Strategies to Increase the Implementation of Combined Heat and Power Technologies in the United States

An Integrated Assessment of the Energy Savings and Emissions-Reduction Potential of Combined Heat and Power

Combined Heat and Power (CHP), A Vision for the Future of CHP in the US in 2020
http://www.nemw.org/uschpa/vision2020.pdf

The Role of Distributed Generation in Competitive Energy Markets
www.gri.org/pub/solutions/dg/distgen.pdf

Federal Technology Alert: Natural Gas Fuel Cells
http://www.eren.doe.gov/femp/prodtech/pdfs/FTA_natgas_fuelcell.pdf

Guide to Community Heating and CHP
www.energy-efficiency.gov.uk
publication # GPG234

Note: This guide does not constitute an endorsement by FEMP or the Department of Energy of any of the sources listed below, as FEMP has not independently verified the information provided by the following advocates, software, or publications.

Appendix A—Former Federal Combined Heat and Power Sites

Facility	Location	Federal Agency	Technology	Capacity
Brooklyn Naval	Kings County, NY	Navy/Marines	Gas Turbines	315 MW
Argonne National Laboratory	Idaho Falls, Idaho	DOE	NA	19.5 MW
Naval Medical Center	San Diego, CA	Navy/Marines	Gas Turbine	2.3 MW
VA Medical Center	San Diego, CA	Dept. of Veterans Affairs	Gas Turbine	880 KW
Naval Air Station, Point Mugu	Port Hueneme, CA	Navy	Gas Turbine	1.6 MW
Naval Air Station, Point Mugu	Port Hueneme, CA	Navy	Steam Turbine	775 KW
Naval Station	San Diego, CA	Navy/Marines	Steam Turbines	2.54 MW
Fort Dix, NJ	Burlington County, NJ	Army	Spark Ignition	30 KW
Naval Submarine Base	New London, CT	Navy/Marines	Combined Cycle	20 MW
Naval Surface Warfare Center	Indian Head, MD	Navy/Marines	Steam Turbine	10 MW
Naval Shipyard	Norfolk, VA	Navy/Marines	Steam Turbines	60 MW
Naval Training Center	Great Lakes IL	Navy/Marines	Steam Turbines	3 MW
Marine Corps Base	Parris Island, CA	Navy/Marines	Steam Turbine	3 MW
North Island Naval Air Station	San Diego, CA	Navy/Marines	Combined Cycle	36 MW
Naval Station	San Diego, CA	Navy/Marines	Combined Cycle	36 MW
Naval & Marine Corps Recruit Training Center	San Diego, CA	Navy/Marines	Combined Cycle	30 MW

Note: It is recognized that there are other DOD CHP facilities that are contractor owned and operated. As private corporations, the operators of these CHP facilities are not always willing to provide technical details.

Appendix B—Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). Energy Cost includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable). Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

Where PV(x) denotes “present value of cost stream x,”
IC is the installed cost,
EC is the annual energy cost,
OM is the annual non-energy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative’s LCC is less than the baseline’s LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

Or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

Where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project’s LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

Appendix C—Acronym Glossary

Acronym	**Full Title**
ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc.
ATEP	Advanced Turbine and Engine Program
BCHP	Buildings Cooling Heating and Power
BLCC	Building Life-Cycle Costing
CHP	Combined Heat and Power
CO	Carbon Monoxide
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
FETC	Federal Energy Technology Center
GOCO	Government Owned/Contractor Operated
GRI	Gas Research Institute
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
IC Engine	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
MCFC	Molten Carbonate Fuel Cell
NOx	Oxides of Nitrogen
NSR	New Source Review
PAFC	Phosphoric Acid Fuel Cell
PEM	Proton Exchange Membrane
SOFC	Solid Oxide Fuel Cell
STAC	Steam Turbine Assisted Cogeneration
USACERL	U.S. Army Construction Engineering Research Laboratory
USCHPA	U.S. Combined Heat and Power Association