Analysis of CHP Potential at Federal Sites

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ACKNOWLEDGMENTS

FOREWORD

This document was prepared at the request of the U.S. Department of Energy's (DOE's) Federal Energy Management Program (FEMP) under its Technical Guidance and Assistance and Project Financing Programs. The purpose was to provide an estimate of the national potential for combined heat and power (also known as CHP; cogeneration; or cooling, heating, and power) applications at federal facilities and the associated costs and benefits including energy and emission savings. The report provides a broad overview for the U.S. Department of Energy (DOE) and other agencies on when and where CHP systems are most likely to serve the government's best interest.

FEMP's mission is to reduce the cost to and environmental impact of the federal government by advancing energy efficiency and water conservation, promoting the use of renewable energy, and improving utility management decisions at federal sites. FEMP programs are driven by its customers: federal agency sites. FEMP monitors energy efficiency and renewable energy technology developments and mounts "technology-specific" programs to make technologies that are in strong demand by agencies more accessible. FEMP's role is often one of helping the federal government "lead by example" through the use of advanced energy efficiency/renewable energy (EERE) technologies in its own buildings and facilities.

CHP was highlighted in the Bush Administration's National Energy Policy Report as a commercially available technology offering extraordinary benefits in terms of energy efficiencies and emission reductions. FEMP's criteria for emphasizing a technology are that it must be commercially available; be proven but underutilized; have a strong constituency and momentum; offer large energy savings and other benefits of interest to federal sites and FEMP mission; be in demand; and carry sufficient federal market potential. As discussed in the report, CHP meets all of these criteria. Executive Order 13123 directs federal facilities to use CHP when life-cycle costs indicate energy reduction goals will be met. FEMP can assist facilities to conduct this analysis.

The model developed for this report estimates the magnitude of CHP that could be implemented under various performance and economic assumptions associated with different applications. This model may be useful for other energy technologies. It can be adapted to estimate the market potential in federal buildings for any energy system based on the cost and performance parameters that a user desires to assess. The model already incorporates a standard set of parameters based on available data for federal buildings including total building space, building type, energy use intensity, fuel costs, and the performance of many prime movers commonly used in CHP applications. These and other variables can be adjusted to meet user needs or updated in the future as new data become available.

EXECUTIVE SUMMARY

Combined heat and power (also known as CHP; cogeneration; or cooling, heating, and power) can be used to provide thermal energy for buildings or processes while at the same time generating a portion of electricity needs. A CHP system recovers the heat from electricity generation for productive uses such as heating, cooling, dehumidification, or other processes. This heat is normally wasted by conventional power plants. And because a CHP system generates electricity near the point of use, CHP also avoids transmission and distribution losses from distant central stations. For these reasons, properly designed CHP systems can be much more efficient than the average U.S. fossil fuel power plant, as shown in Fig. S-1.

Fig. S-1. CHP systems recover usable heat and avoid transmission and distribution losses to potentially deliver total efficiencies of 70–85%.
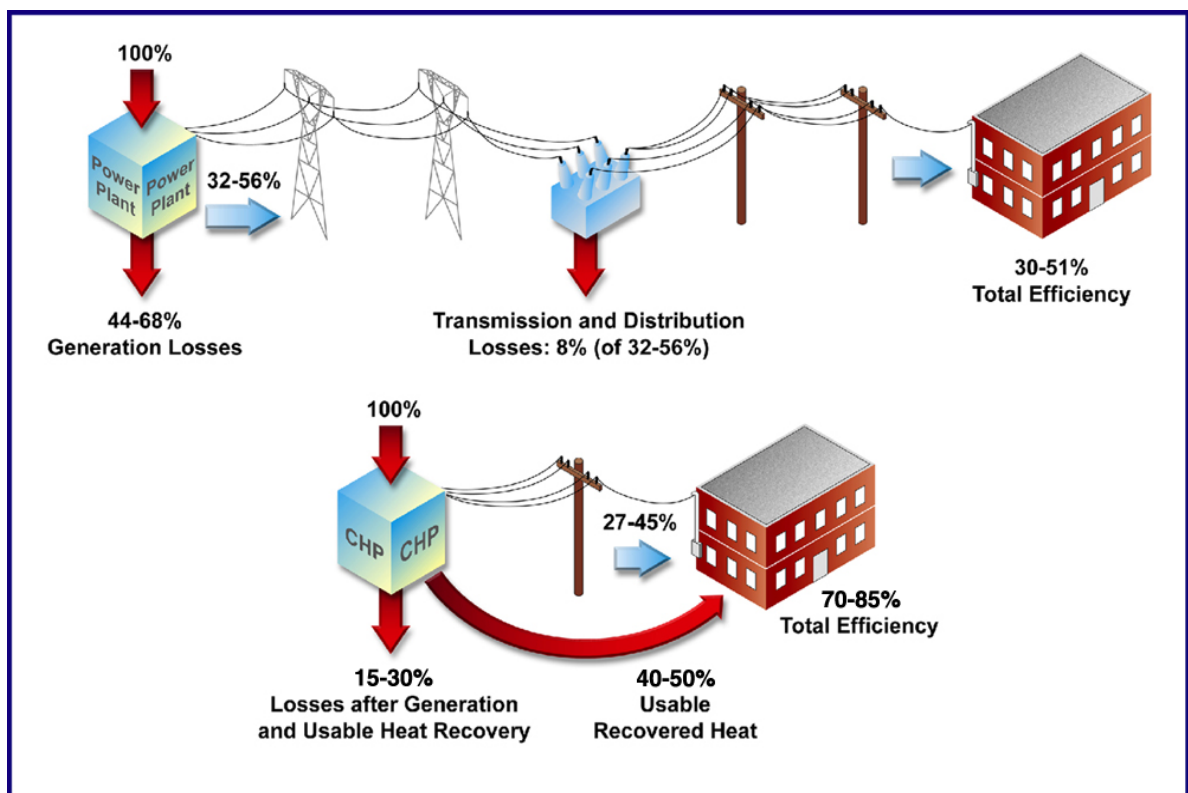
There has been a recent upsurge in interest in fuel-efficient distributed energy resources (DER) such as CHP among project developers, federal facility managers, and policy makers because these systems have the potential to significantly reduce key power sector constraints. They offer an opportunity to meet increased energy needs, reduce transmission congestion, cut emissions, increase power quality and reliability, and increase a facility's overall energy security. In sufficient numbers, interconnected CHP systems can offer increased power security for the grid as well (Casten and Casten 2001). CHP was highlighted in the Bush Administration's National Energy Policy Report as being commercially available and offering extraordinary benefits in terms of energy efficiencies and emission reductions. CHP in

buildings facilitates a transition to cleaner fuels and technologies of the future (such as hydrogen and fuel cells) that would rely upon the same infrastructure as CHP.

Many questions arise regarding CHP in federal facilities: How much capacity is potentially available nationwide? Is it significant? Where and in which agencies is it concentrated? What are the economics involved? What difference does technology make? What types of buildings are the best candidates for CHP? To help answer these questions, staff at Oak Ridge National Laboratory (ORNL) created a model that calculates the energy use and costs in different types of federal buildings across the country. This model allows the user to select various parameters regarding the CHP technology, energy prices, and energy use for various building types. It then calculates the financial payback of CHP to determine the amount that could be implemented economically. The base case included only those buildings with simple paybacks of less than ten years.

Table S-1: National CHP potential at federal facilities larger than 25,000 ft² using base case assumptions

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
Total Mft², all buildings[a]	141	115	514	41	144	136	463	2757[b]
Buildings with CHP payback <10 years, Mft²	113	80	146	16	100	42	82	579
Estimated number of sites with CHP potential	235	75	167	38	70	42	74	700
Percent of sites with CHP potential	71%	42%	7%	38%	17%	5%	7%	9%
Potential TWh of electricity from CHP	2.93	2.25	0.76	0.24	0.81	0.06	0.65	7.69
Energy savings, TBtu	19.3	14.8	5.0	1.5	5.4	0.4	4.3	50.7
Potential CHP capacity, MW	446	342	248	36	265	18	211	1567

[a] Includes buildings in General Services Administration (GSA) database >25,000 ft², even those without CHP potential
[b] Total includes other building types not shown
Mft² = million square feet   TBtu = trillion Btu   TWh = terawatt hours

Total potential CHP capacity was estimated to be 1500–1600 MW under the assumptions and parameters used for this analysis, using gas reciprocating engine or gas combustion turbine technologies in federal facilities across the country. Electricity potentially produced with this capacity represents approximately 13% of all electric use in the federal sector (FEMP 2002). The federal building types with CHP potential were primarily hospitals, industrial and R&D facilities. Table S-1 summarizes analysis results including the amount of capacity and savings for each building category studied. The assessment considered 7 building types for 28 different federal agencies. Figure S-2 shows the calculated amount of CHP capacity for the 9 major agencies; the others each had capacities of less than 10 MW. Not surprisingly, the military branches had highest overall CHP potential in most building categories. Concentrations of potential CHP capacity at the various federal agencies examined were as follows: the VA—hospitals; NASA and DOE—R&D and industrial; General Services Administration (GSA) and Postal Service—offices; and the Justice Department—prisons.

Fig. S-2: Potential CHP capacity for major federal agencies (MW).
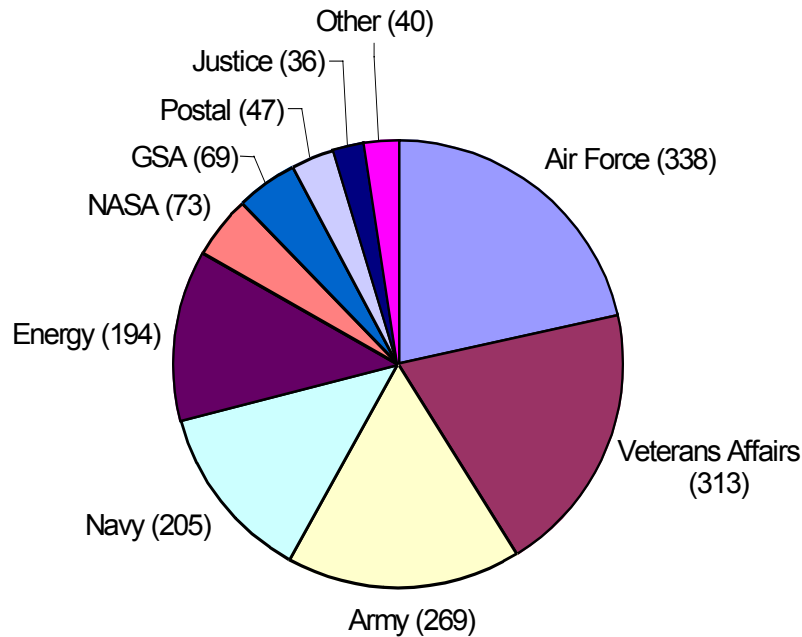
Sensitivity analysis of base case variables created widely varying estimates of potential capacity. Changing the performance and cost assumptions for CHP technology gave a range from 390 (doubling installed cost) to 2800 MW using typical commercial power and gas rates instead of industrial rates. Using turbines with today's costs and efficiencies instead of the base case gas reciprocating engines gave similar results (1670 MW), although future turbine efficiencies are expected to improve such that capacity with a less-than-10-year simple payback increases to 2400 MW, as shown in Fig. S-3. Fuel cells were assessed in the model but do not appear to be economical under present cost and performance parameters.

The authors acknowledge that the assessment methodology developed and utilized here is limited by the databases available to support it. For example, GSA's federal facility database does not always reflect recent changes in building ownership and use. It contains building-level data but no information on whether these buildings are served by district energy systems. District energy systems are a key indicator of CHP potential because they already have the infrastructure in place to supply thermal energy to multiple buildings. Where these systems exist, the significance of building types, which this study is based on, becomes secondary.

Do you have CHP potential?

Ideal sites will fit the following profile, but sites meeting only a few of these characteristics may also have a cost-effective CHP opportunity:

- ✓ high electric prices (more than 5 cents/kWh);
- ✓ average electric load greater than 1 MW;
- ✓ ratio of average electric load to peak load > 0.7
- ✓ a central or district heating and/or cooling system in place (or a need for process heat)
- ✓ "spark spread" (difference in price per million site Btu between gas and electricity) >$12
- ✓ high annual operating hours (> 6000)
- ✓ thermal demand closely matches electric load

Fig. S-3: Potential CHP capacity in federal sites under different technologies and performance parameters.
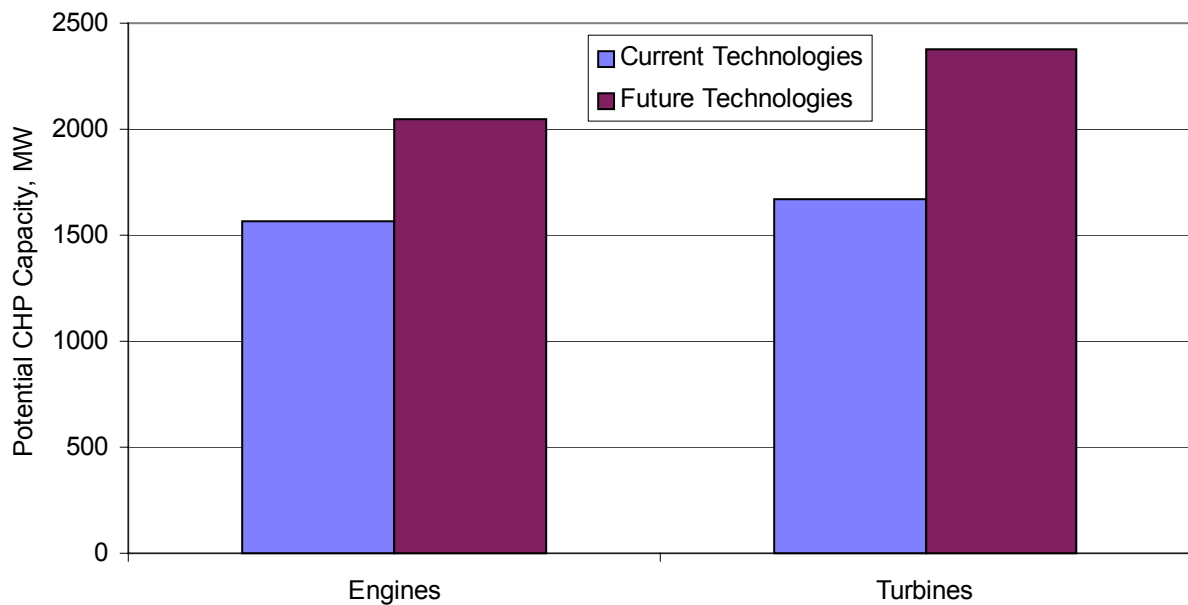
This study cannot attempt to identify which specific sites have CHP potential. Site-specific information is needed to identify the actual best candidates for federal CHP. This analysis used state and regional averages for many of the key parameters defining the amount of energy needed and price paid. The economics and feasibility of CHP are very site-specific because the condition of existing equipment, energy use at a facility, prices paid for electricity and gas, and local regulations related to emissions, interconnection, and siting can vary widely by site. However, this study does indicate the expected amounts of CHP and the most likely states, agencies, and building types for applications. And the model used for analysis of potential can easily generate results adjusted according to changing assumptions about energy prices and other variables. As energy prices increase and CHP system costs decrease, the amount of cost-effective CHP potential will rise. The actual numbers could be significantly higher or lower depending on the specific characteristics of any given site.

Our assessment reveals significant potential for CHP in the federal sector. The 1.5 GW of estimated potential in the base-case scenario has an average simple payback of 6 years and could save the federal government $170M per year in energy costs. Given the large amount of potential for CHP at federal sites, why haven't more facilities installed this technology? Preliminary discussions with federal facility managers suggest the following primary reasons:

- historically low tariffs for electricity;
- high initial cost of CHP systems;
- limited budgets for capital improvement (agencies rarely have sufficient appropriations for even much smaller energy conservation investments);
- complexity of CHP systems due in part to the need for custom engineering and design of different components for each site;
- a lack of time and capability for facility managers to evaluate potential applications and benefits to their site;
- obstacles related to local regulations and policies for interconnection, standby/backup charges, siting, and emissions; and
- a lack of trusted sources of information about the costs, operation, and performance of CHP systems.

The Federal Energy Management Program (FEMP) is collaborating to address many of these obstacles by offering unbiased information and technical and project financing assistance to any federal agency interested in developing a CHP project. FEMP CHP services, resources permitting, include:

- CHP quick technical screening for interested federal sites;
- site survey and feasibility verification;
- partnership building between federal sites and project developers that bring financing if needed;
- baseline data collection;
- link appropriate federal sites with industry teams developing "packaged" CHP systems;
- design and technical assistance to projects selected under FEMP calls for projects;
- support for addressing policy and regulatory constraints — siting and permitting, grid interconnection requirements, exit fees, standby/backup charges;
- verify designs, component matching, and system sizing to thermal and power profiles; and
- technical/price proposal evaluation

Under present assumptions, the regions with the greatest CHP potential are the Southwest (CA to TX), Northeastern metropolitan areas (NY to DC), and the Southeast (FL, GA, AL). Figure S-4 maps the potential capacity for each state. FEMP recognizes the potential for CHP to reduce the costs of government, increase energy security, and improve air quality, and is actively working to make advanced CHP technologies more easily accessible to federal agencies.

Fig. S-4: Distribution of potential CHP capacity in federal sites under base case, MW.
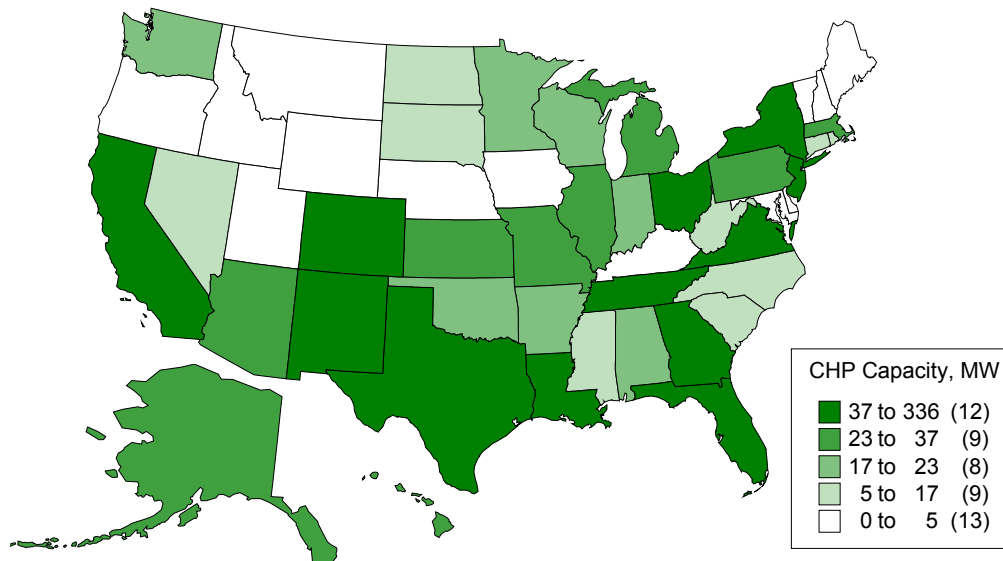
1 Introduction

CHP systems play an essential role in our nation's present energy supply and future plans. The United States has over 50 gigawatts (GW) of installed CHP capacity producing about 7% of the nation's electricity (USCHPA 2001). The Department of Energy (DOE) and the Environmental Protection Agency (EPA) have partnered with the private sector in an effort to double CHP capacity by 2010 because of the environmental and economic benefits offered (Fig. 1). The National Energy Policy Report focuses on the importance of CHP to help meet critical goals related to emissions reductions, energy security, reliability, and new energy production in a cost effective manner (NEPDG 2001). Federal agencies have a mandate to lead by example in meeting national energy and environmental goals, and an Executive Order specifies that agencies "shall use combined cooling, heat and power systems when life-cycle cost-effective" (FEMP 1999).

It is not surprising that there has been a recent upsurge in interest in CHP in federal facilities across the country. There is ample rationale to look carefully at the potential for CHP applications in the federal sector.

Agencies to Assess and Implement CHP: Executive Order 13123, "Greening the Government Through Efficient Energy Management" (6/99) states that the federal government, as the nation's largest energy user, shall lead the nation in energy-efficient building design and operation. Section 206 notes that "The Federal Government shall strive to reduce total energy use and other air emissions at the source. To that end, agencies shall undertake life-cycle cost-effective projects in which source energy decreases, even if site energy use increases." The order also states that agencies must implement district energy systems and other highly efficient systems in new construction or retrofit projects when cost-effective and must consider CHP when upgrading and assessing facility power needs. The full text of the Executive Order, related guidelines and additional information on CHP and other FEMP programs are available on the FEMP website, http://www.eren.doe.gov/femp. FEMP can assist federal agencies to assess the life-cycle costs of their potential CHP projects.

Fig. 1. National CHP roadmap—objectives for 2000–2010.
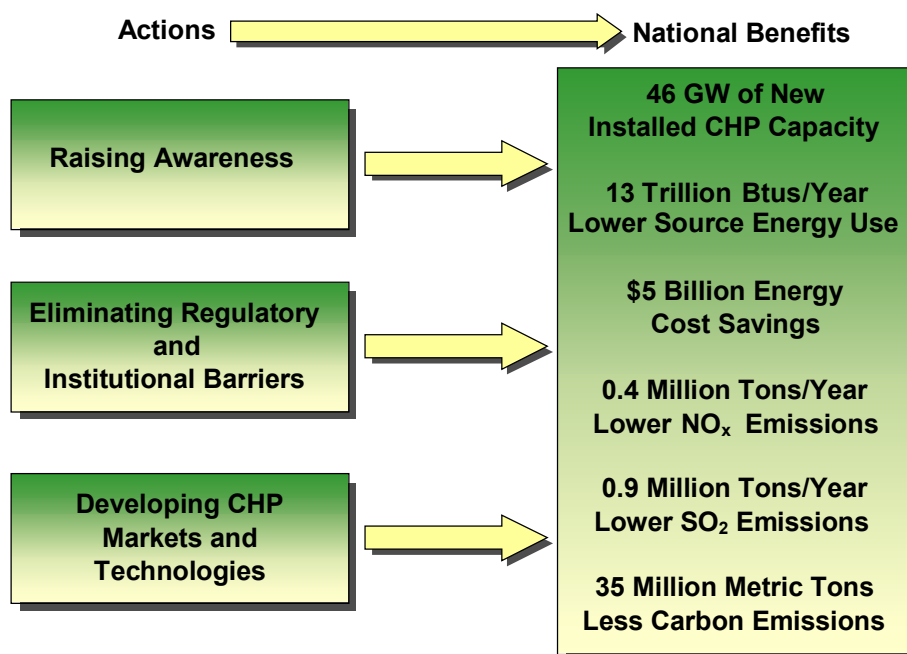
Source: USCHPA 2001

1.1 Background

What is CHP? Combined cooling, heat, and power, also known as cogeneration or building cooling, heat and power (BCHP) is a system that efficiently generates electricity (or shaft power) and uses the heat generated in that process to produce steam, hot water, and/or hot air for other purposes. The most common building applications use a prime mover (turbine or engine) coupled with a generator to produce electricity and capture the waste heat for process steam and space heating and, when coupled to a chiller, to assist with space cooling or refrigeration.

CHP is based on **system integration**. A well-designed CHP plant integrates proven technologies for power generation (such as gas turbines or reciprocating engines) and thermal load management (chillers, dehumidifiers, boilers, other HVAC or process heat equipment) to maximize overall efficiency. Usually this involves sizing a system carefully to meet site-specific needs, taking into consideration existing equipment, fuel costs, electric and thermal load duration curves and other factors. CHP systems can be designed to make a site totally independent from the grid or, more commonly, to maximize savings and provide increased reliability for a strategic portion of the load at a site.

Reciprocating engine and generator sets have been supplying dependable power for over 50 years, so the technology is well known. Steam turbines that produce electricity from existing boiler capacity are also a thoroughly proven and highly reliable technology. Combustion gas turbines (over 500 kW in size), while more recent, have successfully penetrated the market over the past 20 years based on proven reliability, reduced emissions and competitive operation and maintenance costs. Smaller gas turbines and fuel cells are being demonstrated at many federal sites. Their present costs per installed kW of capacity are often higher than other options and their performance records are still being established.

The heat recovery systems are also well known and can be based on heat transfers from combustion exhaust, engine jackets, or other elements to either air or fluids. If exhaust heat can be transferred directly to an auxiliary unit (such as an absorption chiller or desiccant dehumidifier) it is called a "direct fired" application. More common are applications using steam or hot water. These systems normally use a heat recovery steam generator (HRSG) (see Fig. 2). There is substantial information available from manufacturers' and DOE websites regarding sizes, specifications, costs and performance of this equipment (such as that summarized later in Table 10 of this report).

Fig. 2. Components of typical gas-fired turbine CHP unit.
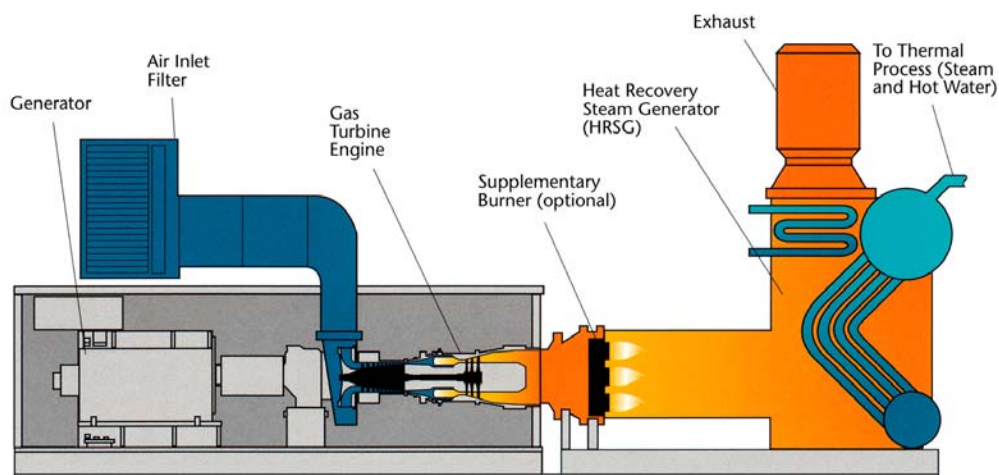
Graphic (adapted) courtesy of Solar Turbines Corp.

In a typical federal installation such as those modeled for the market assessment, CHP is assumed to provide thermal energy for heating and cooling a building while at the same time generating a portion of its electricity needs. Because it uses the waste heat from electricity generation for the other functions, it is much more efficient at generating power than distant central stations. Figure 3 compares equivalent electric and heat using CHP or conventional technologies.

While other applications (process steam for industry, laboratories, laundry, hot water, dehumidification) and more complicated systems (thermal storage, multiple units of variable sizes and types, multiple thermal applications) are possible and often result as site specific conditions are analyzed, these alternatives were not considered in the assessment.
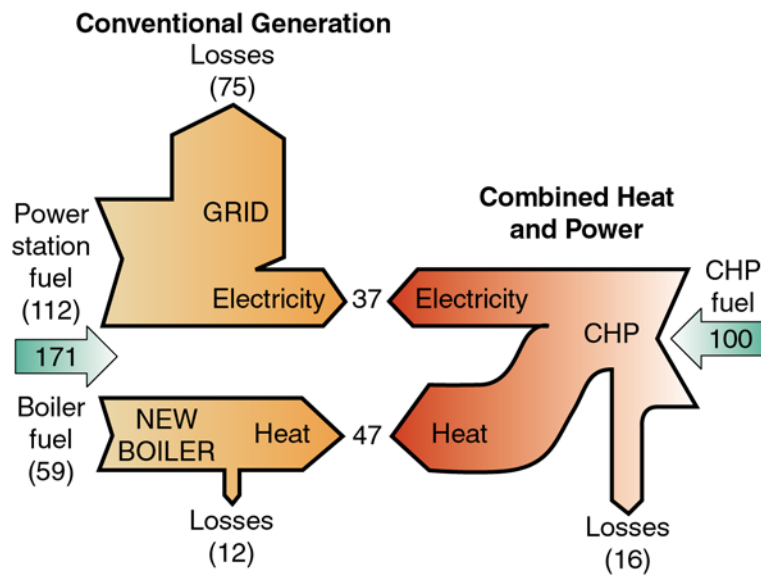
Fig. 3. A comparison of providing equivalent electric and heat using CHP or conventional technologies. Source (adapted): http://www.eren.doe.gov/der/combined_heat_power.html

Many questions arise regarding CHP in federal facilities. How much capacity is potentially available nationwide, and is it significant? Where and in which agencies is it concentrated? What are the economics involved? What difference does technology make? What types of buildings are most favorable? To help answer these questions, staff at Oak Ridge National Laboratory (ORNL) created a model that calculates the energy use and costs in different types of federal buildings across the country. The user can select various parameters regarding CHP and energy use for the various building types. Then the financial benefits can be calculated to determine the capacity of CHP that could be implemented within a defined payback period.

1.2 Summary of Methodology

We started with the General Services Administration (GSA 2001) database of all federal facilities, grouping the buildings by type and state. Separately, we calculated energy intensities from the Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) (EIA

1998) database for each building type, building size, and region of the country. Analyzing data from these two sources allowed us to estimate the gas and electricity use for each federal building across the country.

The EIA releases retail energy prices for each state in several publications (EIA 2001). Resource Data International compiles the electric sector data into a convenient database known as PowerDat (RDI 2001). Selecting either the commercial or industrial rates for a given year, we calculated the cost of energy for each building. Using the size and energy use of the building, along with input parameters for the CHP technology, we calculated the amount and cost of energy use with CHP. Comparing the difference in cost with and without the CHP revealed the annual savings. Based on the type of CHP, the capital and installation cost can also be calculated. Dividing the annual savings by the cost gives the simple payback, while a more detailed payback that uses inflation and the cost of capital was also revealed. Those buildings with no cost savings or with simple paybacks longer than ten years were rejected, and the remaining potential CHP projects were summed for each state.

2 Data Sources for Analysis

2.1 GSA Database of Federal Facilities

There are two datasets of federal facilities available. The Federal Energy Management Program (FEMP) maintains a data set called FEMPTracks. This dataset lists sites with number of buildings and square feet by type of building. It also has site-specific data on energy use and prices, but only for some sites. The data set includes 5800 records (with multiple buildings per record) and has a structure and content based on a dataset maintained by the GSA.

This GSA dataset provides a more comprehensive list of sites, containing 37,000 records, but does not include energy data. For this study, we used the GSA dataset. While the FEMPTracks data include more information on energy, the amount and quality of information was uncertain. It appears that both data sets have limitations in terms of timely updates to reflect new construction and decommissioning or change in facility use.

The GSA dataset was reorganized to sum all of the square feet and number of buildings by building type for each site. This reduced the number of records to 21,000 separate sites across the country. Appendix A contains GSA definitions for the 11 building categories.

Building categories in GSA database

- Hospital
- Office
- R&D
- Storage
- Housing
- Prison
- School
- Services
- Industrial
- Other institution
- All other

Besides square feet and number of buildings for each type, the dataset included site-specific information such as location and owner. The location information was used to assign the energy intensity and power prices from other datasets.

2.2 Energy Intensities

Every five years the EIA conducts a survey of commercial buildings across the U.S. The most recent surveyed 5766 buildings in 1995 (EIA 1998). This dataset contains a large amount of information on the buildings, including energy use by type of fuel, equipment installed, main end-uses for energy, and envelope characteristics. It includes the square feet for each building, as well as a weighting factor to indicate what percentage of all buildings each record represents.

The CBECS dataset includes 29 different building types as opposed to the 11 in the GSA dataset. Those that most closely matched the GSA types were used as shown in Table 1. CBECS does not include industrial facilities. Given the high energy intensity of industrial facilities, for this analysis, we assumed that they and GSA R&D facilities were similar to the "laboratory" category of CBECS. The "Other" category in CBECS may not necessarily match the "Other" and "Other Institution" categories in the GSA dataset. There are also obvious differences between "Federal Prisons" in the GSA data set (which tend to be large, "24/7" facilities) versus the "Public Order and Safety" category in CBECS, which includes many smaller buildings. Because of the way the data were analyzed, this difference will result in a more conservative estimate of the amount of CHP potential. Also, "housing" in GSA refers primarily to military housing, versus "lodging" (hotel/motel/dorm) in CBECS.

Table 1: Building types from CBECS with associated GSA types

GSA Category	CBECS Category
Hospital	Health care (inpatient)
Housing	Lodging (hotel/motel/dorm)
Industrial	Laboratory
Office	Office/professional
Prison	Public order and safety
Other institution	Other
RD&D	Laboratory
School	Education
Services	Service (excludes food)
Storage	Warehouse (non-refrigerated)
All other	Other

Electric and gas intensities were calculated for each of the building types for each region of the country and for two different sizes (25,000 to 100,000 ft^2 and greater than 100,000 ft^2). Despite the large initial survey size, segregating the data by region, type, and size left some data categories with no samples. In those cases, we used the value from the other building sizes but the same type and region. If other sizes for that region were unavailable, we used the national average of the energy intensity for that building type. Tables 2 through 5 show the gas and electric energy intensities used (thousands of Btu per square foot).

Table 2: Electric site energy intensities (kBtu/ft^2) for buildings greater than 100,000 ft^2

Electric	Hospital	Housing	Industrial	Office	Prison	Other	R&D	School	Service	Storage
All	107	49	117	78	45	59	117	28	82	21
Northeast	71	254	84	48	47	59	84	20	28	22
Mid-Atlantic	85	53	94	56	37	113	94	23	49	24
E-N-Central	118	40	99	70	52	71	99	22	21	14
W-N-Central	96	57	110	73	12	40	110	29	251	27
South Atlantic	125	51	179	82	58	56	179	38	65	15
E-S-Central	137	17	104	85	45	81	104	52	8	34
W-S-Central	112	70	117	84	78	59	117	47	85	20
Mountain	92	41	117	102	45	59	117	41	62	16
Pacific	101	48	111	104	71	19	111	32	59	26

Source: EIA 1998, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*

Table 3: Gas site energy intensities (kBtu/ft^2) for buildings greater than 100,000 ft^2

Gas	Hospital	Housing	Industrial	Office	Prison	Other	R&D	School	Service	Storage
All	162	67	134	30	36	60	134	36	75	18
Northeast	176	63	41	32	96	60	41	34	98	27
Mid-Atlantic	159	69	104	22	28	35	104	29	13	18
E-N-Central	237	104	168	38	59	91	168	48	76	24
W-N-Central	174	84	132	66	52	109	132	47	104	29
South Atlantic	125	37	179	28	4	5	179	30	36	12
E-S-Central	135	61	122	35	36	18	122	26	22	18
W-S-Central	107	90	134	20	34	60	134	20	161	7
Mountain	182	36	134	32	36	60	134	50	169	18
Pacific	158	60	35	19	6	60	35	30	25	14

Source: EIA 1998, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*

Table 4: Electric site energy intensities (kBtu/ft^2) for buildings between 25,000 and 100,000 ft^2

Electric	Hospital	Housing	Industrial	Office	Prison	Other	R&D	School	Service	Storage
All	93	50	138	63	62	37	138	27	41	20
Northeast	87	50	138	32	24	37	138	18	29	19
Mid-Atlantic	241	46	77	62	50	25	77	26	14	34
E-N-Central	54	33	134	51	41	24	134	20	39	20
W-N-Central	61	36	79	70	53	48	79	24	50	62
South Atlantic	54	53	298	58	61	45	298	28	65	17
E-S-Central	93	62	90	68	62	37	90	36	44	12
W-S-Central	114	91	138	59	42	37	138	32	39	19
Mountain	109	51	138	79	62	37	138	30	62	11
Pacific	136	46	130	72	18	37	130	32	7	16

Source: EIA 1998, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*

Table 5: Gas site energy intensities (kBtu/ft^2) for buildings between 25,000 and 100,000 ft^2

Gas	Hospital	Housing	Industrial	Office	Prison	Other	R&D	School	Service	Storage
All	162	66	81	40	34	58	81	46	86	25
Northeast	151	63	81	30	14	58	81	46	98	33
Mid-Atlantic	368	60	9	39	1	38	9	37	39	24
E-N-Central	162	80	80	65	64	19	80	72	51	44
W-N-Central	22	80	3	46	97	159	3	39	87	39
South Atlantic	99	60	224	12	27	31	224	21	36	21
E-S-Central	162	63	21	17	34	58	21	42	92	20
W-S-Central	64	34	81	24	13	58	81	30	161	9
Mountain	669	51	81	58	34	58	81	58	169	19
Pacific	36	76	128	27	52	58	128	55	86	6

Source: EIA 1998, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*

A second set of factors from the CBECS data set was also important. Not all commercial buildings have gas service and the configuration of HVAC equipment and distribution systems necessary to easily adopt a CHP system. We calculated what percentage of each building type used natural gas and had central heating (either district hot water or steam) (Table 6). We separately calculated the percentage with central cooling or forced air systems, but decided that the most likely candidates would have a central heating system that could use the exhaust heat from a CHP unit. (Appendix B describes the calculations in more detail.) We then assumed that those percentages also applied to the federal buildings under analysis. This allowed us to estimate the percentage of each building category that was expected to be compatible with CHP. As with the energy intensities, the values for laboratories were used for industrial buildings.

The housing, storage, and "other" building types in CBECS did not necessarily reflect the categories in the GSA database, nor were they expected to offer significant CHP potential at this time, so they were excluded from this study. The study methodology also excludes from assessment a percent of floor space in each building category that is not likely to have infrastructure compatible with CHP. Note that in all categories except hospitals, a relatively small percentage of buildings under 100,000 ft^2 are expected to have infrastructure that facilitates CHP. While the lack of infrastructure does not necessarily preclude a cost-effective CHP project, it certainly reduces the probability. And since the costs to retrofit for thermal applications are so highly site-specific and variable, we decided it would be more realistic to limit CHP analysis to the percent of building stock for each category listed in Table 6.

Table 6: Percentage of building type using natural gas and central heating (district hot water or steam)—assumed "CHP compatible" for this study (%)

	Hospital	Housing	Industrial	Office	Prison	Other	R&D	School	Service	Storage
>100,000 ft^2	88		78	48	56		78	71	24	
<100,000 ft^2	66		7	11	16		7	30	3	

Source: EIA 1998, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures.*

2.3 Retail Gas and Electric Prices

The EIA releases the retail prices for natural gas and electricity through several publications. We used the Natural Gas Monthly data set (EIA 2001) that contains monthly residential, commercial, and industrial natural gas prices for each state for recent years (Table 7). In addition to EIA data, we used the PowerDat dataset from Resource Data International (RDI 2001) to find the commercial and industrial electric prices for each state for 1999 and 2000. Our base case analysis assumed that federal facilities' prices were closest to the industrial rates, but for a sensitivity test we also used the commercial rates. We also included the capability to use 1999 or 2000 prices, because gas prices were unusually high in the latter part of the 2000. Actual rates at a given federal facility are often negotiated on a site-specific basis and can vary widely from commercial or industrial tariffs.

Table 7: Electric and gas commercial and industrial prices for 1999 and 2000

State	1999 Gas Price $/MBtu		2000 Gas Price $/Mbtu		1999 Electric Price $/MWh		2000 Electric Price $/MWh	
	Comm.	Industrial	Comm.	Industrial	Comm.	Industrial	Comm.	Industrial
AK	2.19	1.25	2.06	1.57	81.25	66.78	81.35	70.34
AL	6.73	3.43	7.79	4.41	65.64	39.89	66.17	40.92
AR	5.40	3.44	5.40	3.87	56.55	43.51	57.60	44.44
AZ	6.17	3.43	6.72	4.43	74.00	55.39	73.54	54.90
CA	6.18	3.42	7.56	5.76	93.73	60.46	91.67	53.91
CO	4.55	2.83	5.24	3.33	53.96	42.04	54.94	43.06
CT	6.49	4.16	6.59	5.74	96.88	74.29	92.13	73.75
DC	7.38	5.73	8.96	7.23	74.74	45.90	78.28	48.53
DE	7.00	4.15	6.94	5.20	71.47	43.67	58.91	37.65
FL	6.51	3.64	7.83	5.21	61.64	46.56	61.30	47.92
GA	5.09	3.39	6.19	4.37	64.89	41.99	63.92	42.32
HI	14.32	8.21	17.29	10.18	124.32	93.50	142.28	110.82
IA	4.82	4.01	6.73	5.22	66.33	38.55	68.60	39.05
ID	4.78	3.30	5.69	3.91	41.49	27.11	41.77	30.30
IL	5.36	4.12	7.14	5.77	75.54	50.79	73.68	44.66
IN	5.20	4.27	5.99	4.55	61.52	41.36	59.84	39.98
KS	5.06	3.03	5.02	4.01	59.28	44.52	59.78	44.51
KY	5.14	3.31	6.78	5.00	50.19	28.88	48.81	30.04
LA	5.73	2.51	7.02	4.09	67.44	42.22	71.14	46.35
MA	7.60	5.19	9.47	7.00	86.68	72.26	90.71	78.29
MD	7.07	5.73	7.98	7.23	68.35	41.98	68.94	41.62
ME	6.65	4.92	6.78	5.24	105.22	64.84	91.43	48.64
MI	4.94	3.82	4.91	4.30	78.87	52.15	79.41	52.43
MN	4.44	2.97	6.29	4.46	63.55	45.70	64.20	45.71
MO	5.47	4.23	6.93	5.82	59.30	45.44	60.05	48.29
MS	4.88	3.24	6.07	4.31	59.28	37.01	62.45	39.31
MT	5.15	3.65	5.23	4.91	64.98	52.66	58.66	31.95
NC	6.22	3.73	7.51	5.53	60.15	44.81	60.71	45.35
ND	4.52	2.81	5.96	4.96	58.21	45.78	58.53	45.50
NE	4.13	3.39	5.51	4.67	53.01	32.96	54.40	33.58
NH	6.86	4.53	7.36	6.69	115.32	93.58	114.91	94.22
NJ	3.98	3.10	5.31	4.18	98.00	77.70	87.05	67.76
NM	3.83	2.41	4.68	3.88	76.26	43.12	69.20	47.19
NV	6.05	4.78	5.56	5.35	67.43	48.08	67.18	49.69
NY	5.10	3.68	5.24	5.10	115.63	47.32	129.50	48.30
OH	5.63	4.00	7.03	6.03	75.68	42.33	74.49	44.17
OK	5.16	3.50	6.40	5.15	53.16	35.06	58.62	39.54
OR	5.66	4.02	6.42	4.54	50.21	33.85	51.21	35.89
PA	7.32	3.97	7.38	4.82	66.96	42.76	63.85	40.95
RI	8.19	4.53	8.32	5.45	82.76	66.56	94.20	82.83
SC	6.54	3.39	7.92	4.88	61.11	36.67	60.29	36.27
SD	4.56	3.41	5.93	4.35	67.67	45.96	66.92	46.40
TN	5.73	3.76	6.73	5.39	62.86	43.76	62.70	44.54
TX	4.44	2.49	5.48	3.99	64.74	40.61	66.72	43.96
UT	4.11	2.97	4.89	3.69	51.68	33.02	50.56	33.02
VA	5.99	3.78	5.80	4.72	54.57	37.47	55.78	37.92
VT	5.69	3.06	6.49	4.64	107.00	71.72	104.52	70.74
WA	4.90	2.68	5.72	3.36	51.51	26.77	52.08	32.11
WI	4.84	3.97	6.30	5.40	59.42	39.58	60.75	40.72
WV	6.31	3.09	6.68	4.83	55.08	37.95	55.18	37.59
WY	4.38	3.30	5.03	3.76	51.43	32.65	51.70	33.11

2.4 CHP Parameters

There are a number of available prime movers for CHP systems, ranging from internal combustion engines to microturbines to industrial turbines to fuel cells. Each comes in a variety of sizes, with associated costs and efficiencies. Figure 4 shows an example of energy flows of a combined cooling, heat, and power system. Even for a single size and technology, there are a range of costs and efficiencies. Actual costs are very site-specific; a broad analysis such as this cannot capture the intricacies of installation and operation at any given site. To compensate, we used a range of estimates for each parameter and conducted sensitivity analyses using the minimums and maximums of each parameter.
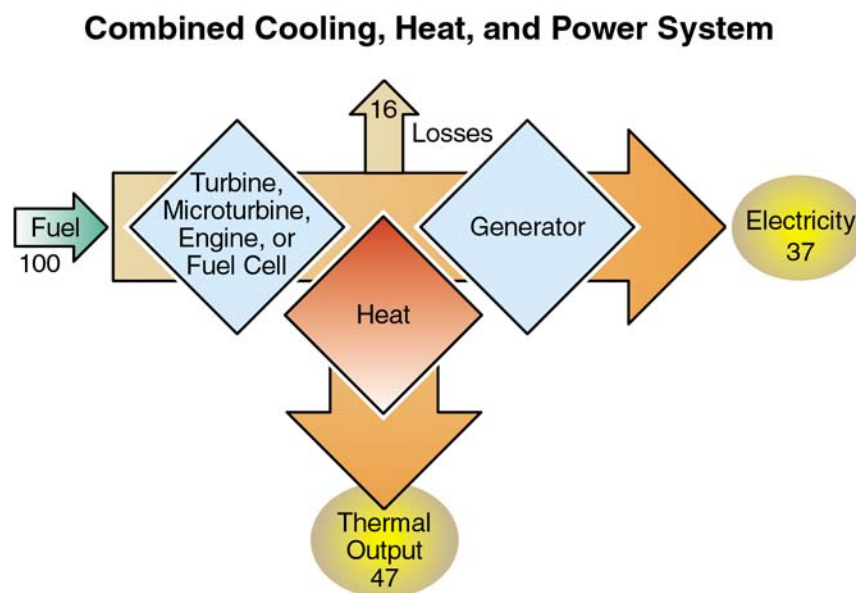
Fig. 4. Energy flows of a combined cooling, heat, and power system.

Resource Dynamics Corporation has conducted a market assessment for CHP (RDC 2001). In the document, they provide estimates of the current and future cost and performance of several technologies and sizes (Table 8). We used the current cost and performance values for reciprocating engines as the base case for this assessment. Engines are the most widely used technology currently; they are low cost and have good load-following capabilities and electrical efficiencies. However, they may have more problems with emissions than the other technologies (turbines and fuel cells). For sensitivity analysis, we used these other technologies and the cost factors that RDC projects for the future. In addition, we ran a sensitivity case with installation costs double that of the current costs in the table. Our experience with installations at federal sites indicates that total project costs can be two to three times those shown in the table. However, those costs include other aspects of the installation not considered in these values, such as refurbished piping, chillers, or other modifications to a site's HVAC system and infrastructure.

Table 8: CHP cost and operations parameters

CHP Design	Size KW	Installed Cost $/kW		O&M Cost $/MWh		Electrical Efficiency	
		Current	Future	Current	Future	Current	Future
Engine[a]	45–75	1033	815	15	10	31%	42%
Engine[a]	75–150	953	730	12	9	32%	42%
Engine[a]	150–300	880	640	12	8.5	34%	43%
Engine[a]	300–600	800	605	10	8	35%	43%
Engine[a]	600–1,000	730	570	8	8	37%	44%
Engine[a]	1,000–2,500	704	550	7.5	7.5	38%	45%
Engine[a]	2,500–5,000	622	465	7.5	7.50	39%	45%
Engine[a]	5,000–10,000	575	450	7	7.00	42%	45%
Engine[a]	10,000–20,000	563	435	7	7	42%	45%
Turbine	45–75	1383	965	10	10	27%	40%
Turbine	75–150	1231	860	10	10	27%	40%
Turbine	150–300	1074	720	9	9	27%	40%
Turbine	300–600	1015	675	9	9	27%	40%
Turbine	600–1,000	757	670	6	6	25%	40%
Turbine	1,000–2,500	704	525	5.5	5.5	28%	40%
Turbine	2,500–5,000	592	420	4.5	4.5	29%	40%
Turbine	5,000–10,000	550	400	4	4	31%	42%
Turbine	10,000–20,000	488	395	4	4	33%	42%
Fuel cell	150–300	5003	1555	15	15	39.6%	50%
Fuel cell	300–600	4812	1520	15	15	39.6%	50%

[a] The base case used reciprocating engines sized to the average site for the state, with costs and efficiency based on the "current" values above.
Source: RDC 2001, *Building Cooling, Heating, and Power (BCHP): A Market Assessment*

2.5 Summary of Parameters

The key assumptions used to define the base case are summarized in Table 9.

Table 9: Summary of key parameters for base case.

❑ Federal sites used are from GSA database, focusing on 7 categories with greatest CHP potential and larger facilities. Excluded were housing, storage, "other institutional," or "other" building federal building categories and any buildings where square footage for a category at that site was <25,000 ft^2.
❑ CHP potential was further adjusted to reflect infrastructure compatibility for each type and size of building based on CBECS data (e.g., 88% of hospital facilities over 100k ft^2 were assumed to have gas available and compatible heat distribution systems, while only 48% of office facilities in that size range were considered compatible).
❑ Energy intensities for each category and geographic area are from CBECS database, with industrial building types using laboratory intensities.
❑ Energy prices were based on 2000 Industrial energy tariffs for each state from EIA.
❑ CHP is assumed to provide 75% of electrical needs of hospitals, prisons, and industrial facilities. It provides 50% of electrical needs of offices, schools, R&D and service facilities.
❑ Hospitals, prisons, and industrial facilities are assumed to have load factors (average to peak production) of 85%; load factors for offices, schools, R&D and service facilities are 35%.
❑ CHP uses reciprocating engine technologies using industry citations to estimate current costs and efficiency, with electrical efficiencies based on the unit's size and a recoverable waste heat efficiency of 75%; steam boilers replaced by CHP are assumed to have 80% efficiency.
❑ Hospitals, prisons, and industrial facilities install two CHP units to provide increased reliability while others only install one.
❑ All recoverable waste heat is assumed utilized by the facility to offset thermal energy purchases (this assumption is examined in sensitivity analyses).
❑ Only sites where the simple payback period was 10 years or less were counted in base case.

3 CHP Calculation

Based on the data discussed in Sect. 2, we could calculate the amount of CHP that could be installed. For each state, we summed the amount of federal floor space of each building type. Table 10 shows the methodology used to calculate the CHP potential capacity for each state, using California as an example. The following sections walk the reader through the calculations in Table 10 row by row, referencing data sources as appropriate.

We summed the space of those sites that had more than 100,000 ft^2 of any given building type (row a); in California there were 19 sites with hospitals (row b). The electric intensity for hospitals in the Pacific region was 101 kBtu/ft^2 (row c) (Table 2). Based on the CBECS analysis, 88% of hospital facilities over 100,000 ft^2 in size are estimated to have infrastructure compatible with CHP (row d) (Table 6).

Table 10: CHP capacity calculation, example for California buildings >100,000 ft^2

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
(a)Total area, kft^{2a}	11,917	6,290	50,371	3,609	23,931	11,814	72,547	365,154[b]
(b)Total no. of sites[a]	19	9	133	10	28	39	90	551[b]
(c)Intensity kBtu/ft^2	101	111	104	71	111	32	59	
(d) % bldgs. w/piping	88%	78%	48%	56%	78%	71%	24%	
(e) % electric provided	85%	85%	50%	85%	50%	50%	50%	
(f) GBtu of electricity	901	462	1,254	121	1,033	134	514	4,421
(g) GWh of electricity	264	135	368	36	303	39	151	1,296
(h) Load factor	75%	75%	35%	75%	35%	35%	35%	
(i) Capacity, MW	40.2	20.6	119.9	5.4	98.8	12.8	49.1	346.9
(j) CHP units per facility	2	2	1	2	1	1	1	
(k) Avg. capacity, MW	1.20	1.48	1.89	0.49	4.55	0.47	2.27	
(l) CHP elec. efficiency[c]	38%	38%	38%	35%	39%	35%	38%	
(m) Equipment cost, k$	28,311	14,503	84,399	4,327	61,447	10,272	34,599	237,859
(n) Operating cost, k$	1,982	1,015	2,757	355	2,272	394	1,130	9,904
(o) Gas costs, k$	5,727	2,934	7,967	780	6,540	864	3,266	28,078
(p) Electric savings, k$	14,242	7,296	19,814	1,916	16,327	2,122	8,123	69,840
(q) Net savings, k$	6,534	3,347	9,090	780	7,516	864	3,726	31,858
(r) Payback, years	4.3	4.3	9.3	5.5	8.2	11.9	9.3	
(s) Energy saving, Gbtu	1,740	891	2,421	232	1,999	257	992	8,534

[a] Includes all buildings in GSA database >100,000 ft^2, including those without CHP potential
[b] Total includes other building categories not shown
[c] CHP system efficiency for converting fuel to electricity (from Table 8). This does not reflect overall system efficiency that would include use of waste heat for thermal applications.

The amount of energy provided by CHP (row e) and the load factor of the CHP units (row h) are dependent on the profile of energy used by the building being modeled. Two basic load curves for implementation of CHP were developed: one for a system used during typical 5-day-per-week office building occupation, and one for a more continuously run, load-following system.

The first diagram (Fig. 5) shows the electric load profile of a typical, large office building (ORNL 1994). While power demands peak at 1.7 MW, during nights and weekends they drop to around 0.2 MW, giving an average load of around 0.6 MW. In this system, a 0.8 MW CHP unit would operate during the hours of 7 a.m. to 7 p.m. on weekdays (with some adjustment for start-up). This would replace power purchases during the most expensive peak times of the day, and would present a relatively flat load to the utility, further improving the likelihood of low power rates. In this example, CHP provides 50% of the electric energy needs of the building and has a capacity factor of 35%.

Fig. 5: Load curve template for office building and CHP unit used during occupation.
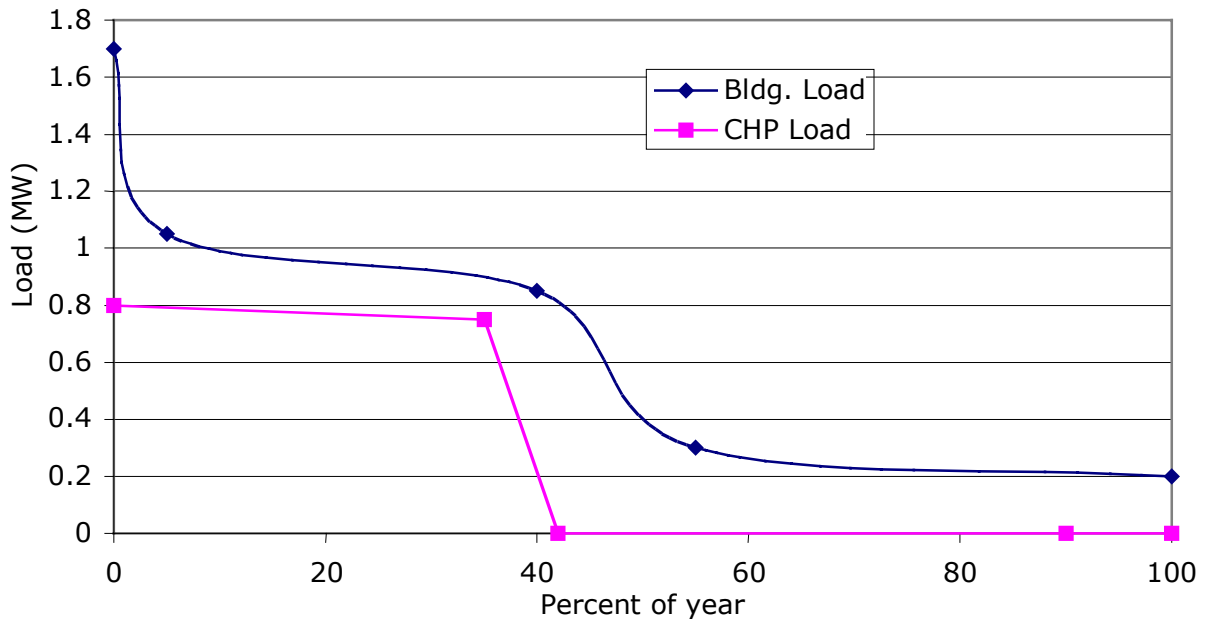
An alternative system would be for a building that operates relatively constantly (has a high load factor) and uses CHP to provide a large share of its steam and electricity needs. The example is from a system installed at the Iowa Methodist Medical Center. This hospital's power usage peaks at around 3.6 MW, with a minimum of 1.8 MW. They chose to install two 1.5-MW dual-fuel diesel generators with heat recovery.

Figure 6 shows the average power levels for the hospital for each of three shifts for each month of the year. Ordering them from highest to lowest shows the load curve, the fraction of year when demand is at or above a certain load. If two CHP units are installed, each capable of providing 1.5 MW, they could provide the amounts of energy shown by operating at an average capacity factor of 77%. Combined, they provide 87% of the hospital's electricity needs. At low power levels, one unit would operate at full power. Either could be operating, with the other one down for maintenance. At times of highest demand, both would operate, providing 3 MW of power. In between, they could either both be partly loaded, or one could operate at full load while the other operates at partial load.

Fig. 6: Load curve template for hospital with two load-following CHP units.
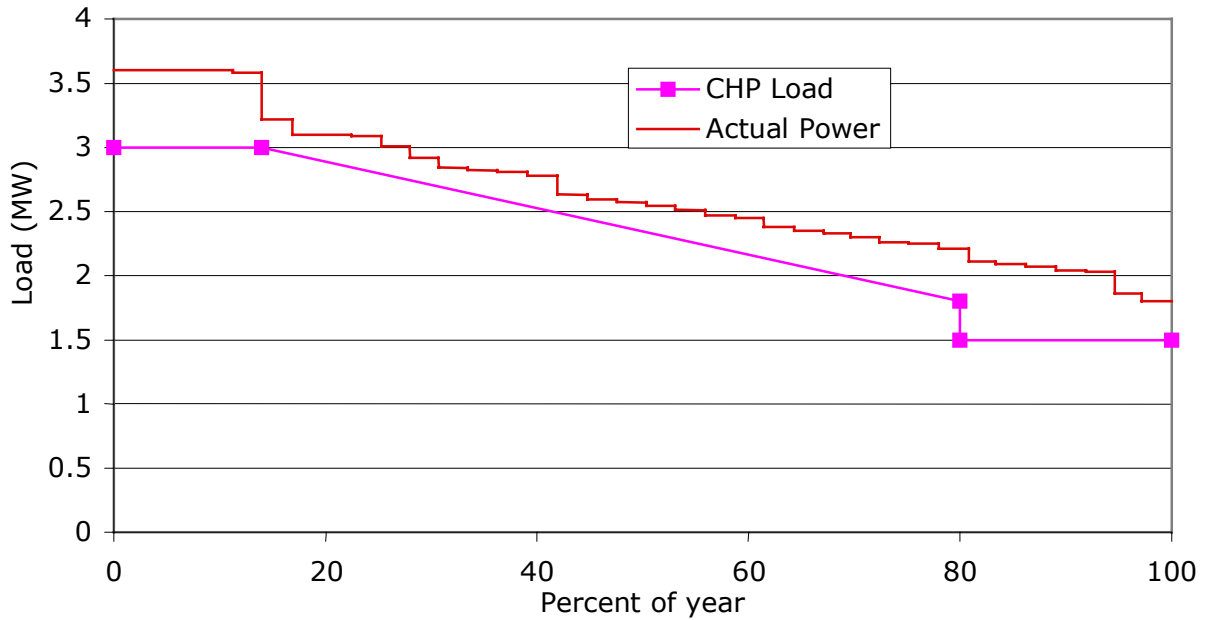
In Fig. 7, the hospital's steam needs did not match its electricity needs. Steam requirements were highest in winter months, when electricity needs were lower. To compensate, the hospital installed supplementary firing capability.

Fig. 7. Comparison of electricity and steam needs for Iowa Methodist Medical Center
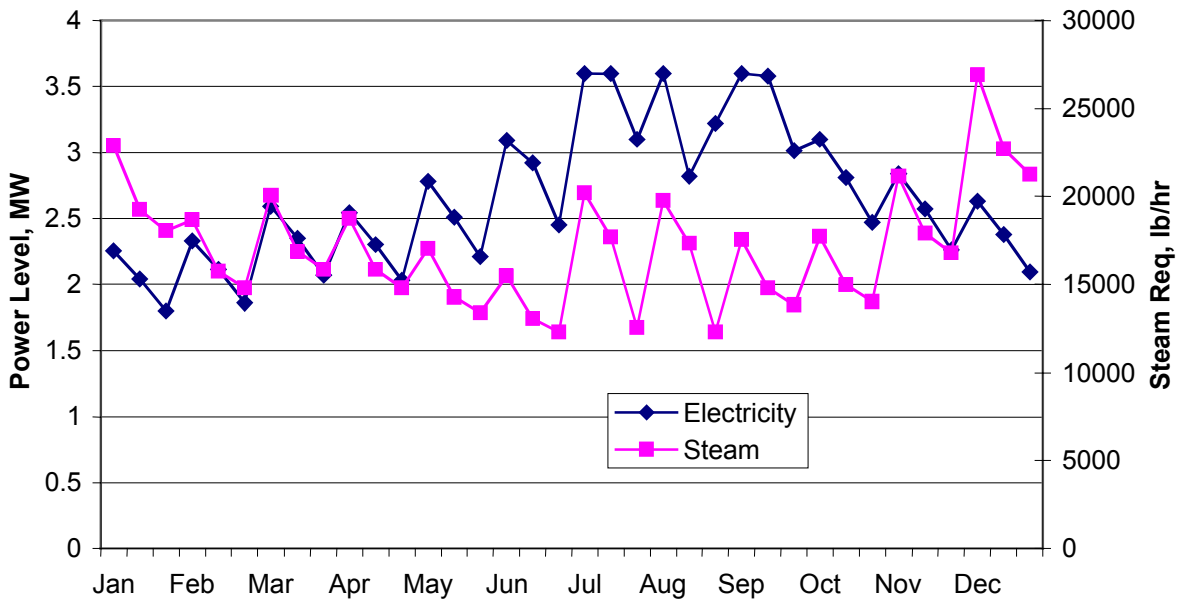
For the present analysis, offices, schools, R&D, and service buildings were assumed to have building load profiles similar to the first example, and a single unit CHP system is sized to provide 50% of the electric energy needs at a capacity factor of 35%. Hospitals, prisons, and industrial facilities used the parameters from the second example: 85% of electricity provided and a capacity factor of 75%.

It is important to stress that the design of a CHP system is highly site-specific, and is typically sized to fit a thermal load curve and to operate close to full power to the maximum degree possible (70–99% of the time). Sizing CHP systems to thermal loads was done as a sensitivity test in this model. That scenario is based only on heating loads and generated a total capacity slightly below the base case. Since CHP systems can also support cooling, dehumidification, and other applications, the estimate of CHP capacity sized to thermal demand must look at the timing, duration and other specifications for all the potential waste heat applications at a given site.

Returning to the California example of CHP capacity calculations in Table 10, the percentage of electricity provided by the CHP system is shown in row e, and the load factor of the CHP is shown in row h. Using the energy intensities for each building type and state, we calculated the amount of electricity needed by those sites. The letters in parentheses designate the respective rows in Table 10.

(f) GBtu electricity = (a) total ft^2 * (c) electric intensity * (d) % with piping * (e) % electric / 1000

(g) GWh electricity = (f) GBtu of electricity / 3.412 Btu/Wh

(i) Capacity, MW = (g) GWh of electricity / 8760 h / (h) load factor

Dividing the total capacity for the state by the number of sites (row b) and number of units per site (row j) gave the average capacity per unit (row k). For the load-following building types (hospitals, industrial, and prisons), we assumed that two equal sized units would be installed at a site. The corresponding CHP project efficiency (row l), equipment costs (row m), and O&M cost (row n) were calculated using information from Table 10 times the CHP total capacity (row i) and production (row g).

The amount of gas needed is the amount to make the electricity based on the CHP efficiency minus the amount of gas displaced by the CHP thermal exhaust. A limit can be placed on the amount of exhaust gas that can be used so that it does not exceed some fraction of the thermal energy demand (that was estimated based on the CBECS gas intensity data and the square feet of the facility). Allowance was made for the relative efficiency of a boiler (80%) versus the lower thermal efficiency of CHP (75%) due to extra thermal losses.

Gas exhaust used = minimum [(f) GBtu electricity / (l) efficiency – GBtu electricity, input fraction of thermal energy needs calculated using gas intensity]

o) Gas cost = [(f) GBtu electricity / (l) efficiency – gas exhaust used * 75% / 80%] * gas price / 1000

Electricity savings are based on the amount of electricity created by the CHP times the average state price used (Table 7). In the base case, we used the industrial price from 2000. Net savings are then calculated by subtracting the cost of gas and the operating cost of the CHP system. The simple payback for the system is then the capital cost of the project divided by the annual savings.

(p) electricity savings = (g) GWh of electricity * electricity price / 1000

(q) net savings = (p) electric savings – (n) operating costs – (o) gas costs

(r) payback = (m) equipment cost / (q) net savings

Note that in the example calculation for California (Table 10), the office category is shown to have a surprisingly high capacity (120 MW), but the payback is very near the 10-year limit. Thus, this capacity is marginal at present and very sensitive to small changes in assumptions (e.g., capacity factor, percentage of energy from CHP, electric intensity, and ability to use recovered heat), which could reduce this capacity to zero under the base case minimum pay back criteria. Also, note that the "schools" category for California has an average payback period of 12 years. Thus in Table 14, the analysis shows 0 MW of CHP potential for schools in California (they did not fall under the 10-year payback minimum). This highlights one of the limitations of using statewide averages, but without working with more detailed information on the specific sites, the authors believe that a more detailed analysis would simply generate a false appearance of precision.

Separate calculations were made for those buildings between 25,000 ft^2 and 100,000 ft^2 using the data sets for different energy intensities and different percentages of buildings with HVAC systems conducive to CHP. These smaller facilities offer little CHP potential under the base case assumptions (10 MW).

Simple paybacks do not include the "time value" of money (changing value of money due to interest and inflation). They just show in simple terms how long it would take for the initial investment to be recovered. Including the real cost of money (interest rate minus inflation) raises the number of years to payback, depending on the assumed cost and the number of years (Fig. 8). Note that with a simple payback of 10 years and a real cost of money of 6%, the actual payback is closer to 15 years, and a 15-year simple payback rises past 40 years.

Fig. 8: Effect of including cost of money in payback calculation.
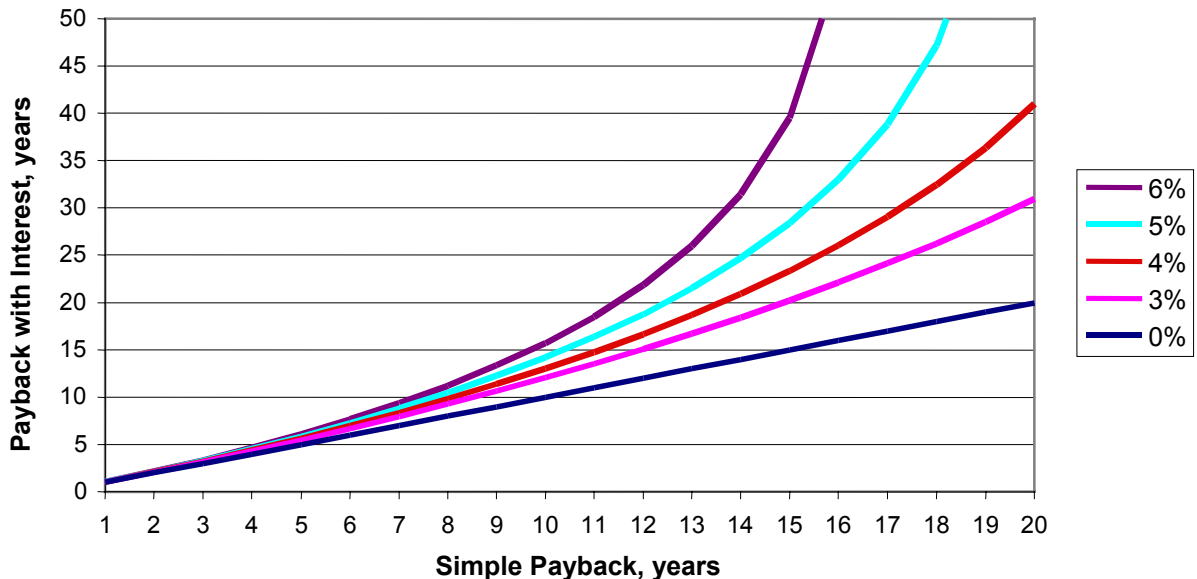
4 CHP Results

4.1 Potential Capacity

Using a cutoff of 10 years for simple payback and the set of base case parameters discussed earlier (Table 9), the total amount of CHP potential capacity for federal facilities nationwide is estimated to be between 1500 and 1600 MW (Table 11). Under the operating assumptions of the base case, the CHP systems would produce 7.7 TWh of electricity representing over 13% of the 57 TWh total electricity purchased by the federal government in FY 2000 (FEMP 2002). This CHP capacity would provide electricity and thermal energy for about 580M ft^2 of building space in 9% of all federal sites. The potential will be greatest in large sites with central plants or mechanical rooms and high electricity rates. These CHP capacity numbers are based on the set of base case assumptions discussed thus far:

- using reciprocating gas engines at their current estimated cost and efficiencies,
- energy prices at 2000 industrial rates for each state,
- covering 75% or 50% of estimated electric demand with load factors at 85% or 35%, depending on building type and size
- considering only the percentage of CHP-compatible federal facilities calculated from the categories of Table 6 with 25,000 ft^2 or more,
- assuming all recoverable waste heat is utilized by the site, and
- with a simple payback less than ten years.

Changing these parameters can give widely different amounts of CHP potential and energy savings.

Table 11: National CHP potential by building category at federal facilities using base case assumptions

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
Total Mft^2, all buildings[a]	141	115	514	41	144	136	463	2757[b]
Mft^2 buildings with CHP payback <10 years	113	80	146	16	100	42	82	579
Total number of sites[a]	331	181	2302	99	421	917	1033	8182[b]
Number of sites with CHP payback <10 years	235	75	167	38	70	42	74	700
% of sites with CHP potential	71	42	7	38	17	5	7	9
Potential TWh of electricity from CHP	2.93	2.25	0.76	0.24	0.81	0.06	0.65	7.69
Potential CHP capacity, MW	446	342	248	36	265	18	211	1567

[a] Includes buildings in GSA database >25,000 ft^2, even those without CHP potential
[b] Total includes other building types not shown

Under the base case, federal hospitals have the highest potential for CHP at 446 MW. Hospitals also show the most promising target of opportunity, since 71% of their sites over 25,000 ft^2 are estimated to have

potential (Fig. 9). Hospital numbers may be limited partly by the assumption that only 66%–88% of facilities have fuel and HVAC systems compatible with CHP (experience suggests that this is a conservative number). Industrial buildings are next in potential capacity, at 342 MW, and are also second in percentage of sites at 42%. Since these two categories were modeled using the 24/7 load-following CHP assumed to provide 85% of the facility's electricity at a relatively high capacity factor (75%), they provide more than two-thirds of the total electricity and potential savings estimated by this model.

Fig. 9. Percent of federal sites with CHP potential by building category and corresponding capacity (MW).
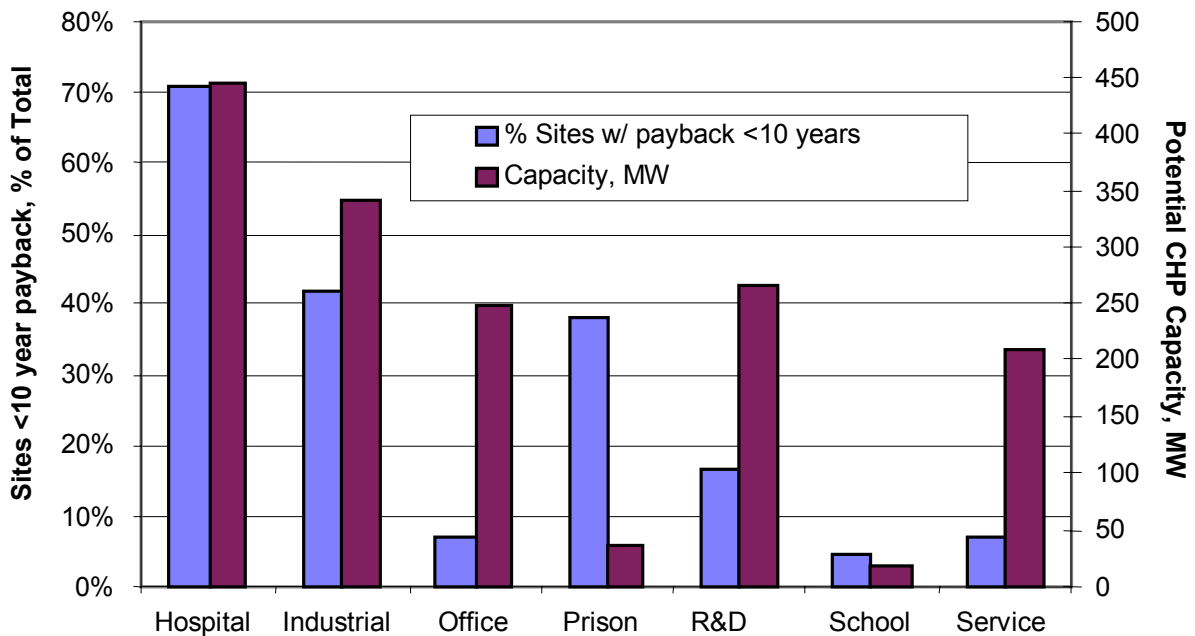
R&D facilities, office buildings, and service buildings provide similar amounts of capacity (265, 248, and 211 MW, respectively) under the base case. These three categories were modeled in the base case as using the weekday occupation load curve (CHP provides 50% of electricity at a 35% capacity factor) rather than the 24/7 load-following CHP profile. Some R&D and service facilities may be more appropriately modeled using the higher load curve similar to hospitals or industrial sites. Under that alternative load profile, R&D CHP capacity increases from 265 to 386 MW (45%). Service buildings under the alternative load scenario increase by a modest 10% to 233 MW.

The amount of CHP capacity estimated available in federal office buildings appears high compared with experience at federal facilities. First, it should be noted that the office category is nearly five times larger than most other building categories. Second, under the base case scenario, only 7% of large federal office facilities show potential for CHP. In the case of offices, we believe that this is still an optimistic estimate due to the assumptions. The base case assumption that all of the recoverable heat from the CHP system can be applied to off-set thermal energy needs at the site is more tenuous for office buildings than for other categories. Full exhaust heat utilization would often be more difficult or costly due to the typical location and load profiles for office buildings as compared to hospitals or industry. If the use of recoverable heat were limited to the amount estimated by CBECS based on the average gas intensity for office buildings, then the potential CHP capacity for federal offices would fall from 248 MW to 49 MW. Furthermore, typical federal office buildings will present more obstacles to retrofitting CHP than other

large facilities with existing central plants and boilers. Our assessment accounted for this using the "CHP compatible" factor in Table 6.

Another category with very high total floor space was service facilities. But CHP capacity is limited due to a low average energy intensity and lower percentage of building HVAC and distribution assumed to be compatible with CHP. Thus, service was fifth in potential capacity. Schools and prisons ranked relatively low in potential capacity, due both to relatively low floor space and energy intensities. A relatively high proportion of prisons (38%) show potential, so even though this may be a relatively small niche, there is a good likelihood of acceptability at those sites. Also, the methodology's data and assumptions for prison compatibility with CHP and energy intensity may be overly conservative.

Table 12 shows the investment cost, annual operating costs, and energy savings expected if all the CHP identified in the base case were implemented at federal sites. There are one-time installation, annual operating, and annual gas purchase costs. Savings come from reduced electricity purchases, and the net annual savings are these savings less annual costs. Simple payback is then just the installation cost divided by the net savings, to show the number of years until the installation cost is recovered. The payback numbers reflect national averages for each building category.

Table 12: CHP costs, savings, and payback, by building category, under base case assumptions

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
Capacity, MW	446	342	248	36	265	18	211	1567
Installation cost, M$	319	222	174	28	163	14	135	1055
Operating cost, M$	23	17	6	2	6	0	5	59
Gas costs, M$	55	42	15	4	16	1	12	145
Electricity savings, M$	138	100	44	11	44	3	35	375
Net annual savings, M$	60	41	23	5	22	2	18	171
Average payback, years	5.3	5.5	7.5	5.8	7.4	7.5	7.4	6.2

A CHP system is generally not more efficient at producing electricity alone than the central grid, and properly maintained boilers can be more efficient at producing thermal energy alone than a CHP system. But the combined generation of electricity and thermal energy on-site by a well-designed CHP system is more efficient overall than the combined efficiencies of these two alternatives. One key to ensuring an efficient CHP system is to maximize the use of thermal energy (waste heat) from the generation process. This may mean that the most economic system does not necessarily have the highest electrical efficiency. If the building requires a high amount of thermal energy (e.g., a commercial laundry or industrial food-processing plant), then the most economic system might be one with slightly lower electrical efficiency but with a larger amount of recoverable, high-temperature exhaust. Emissions or other site-specific factors may also override electrical efficiency when determining which CHP system best meets a facility's needs.

Because CHP uses energy to generate electricity on site, and because it is slightly less efficient for thermal purposes than a regular boiler, the energy use at the site will increase with a CHP system, and site-based energy savings will be negative. However, since losses associated with generating and distributing the electricity (from the alternate central source) will be avoided, CHP results in a net savings of primary (source) energy. Table 13 estimates the amount of source energy savings for each building type. The additional gas used at the site is higher in Btu value than the electricity generated on site.

However, using an average heat rate for central power generation of 10,346 Btu/kWh (FEMP 2001), the energy losses at the central generating plant avoided by CHP more than compensate for the extra gas used, giving a significant net primary energy savings when comparing site to source. The estimated annual source-based energy savings that would accrue if all 1.57 GW of CHP were implemented under the base case is 50.7 trillion Btu. This represents about 8% of total primary energy consumption reported for federal buildings and facilities in 1999 (FEMP 2001).

Table 13: Site and source energy savings from federal CHP, TBtu/year

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
Additional gas use at site	11.0	8.4	2.9	0.9	3.0	0.2	2.4	28.9
Avoided electricity purchases	10.0	7.7	2.6	0.8	2.8	0.2	2.2	26.2
Site energy savings	-1.0	-0.8	-0.3	-0.1	-0.3	0.0	-0.2	-2.7
Avoided source energy use	30.3	23.3	7.9	2.4	8.4	0.6	6.7	79.6
Source energy savings	19.3	14.8	5.0	1.5	5.4	0.4	4.3	50.7

4.2 CHP Potential by State

Under base case assumptions, the six states with the largest federal CHP potential are California, Texas, Florida, New Mexico, Colorado, and Tennessee (Table 14). Figure 10 shows the breakdown between building types for the top 20 states. As discussed earlier, California had high values for offices and for R&D facilities. As shown in Table 10, these are driven both by large numbers of buildings and the low capacity factor for CHP in these building types. The payback is close to ten years, so the projects are more difficult to justify economically than the hospitals or industrial facilities.

Fig. 10: CHP potential capacity by building type for top 20 states, MW.
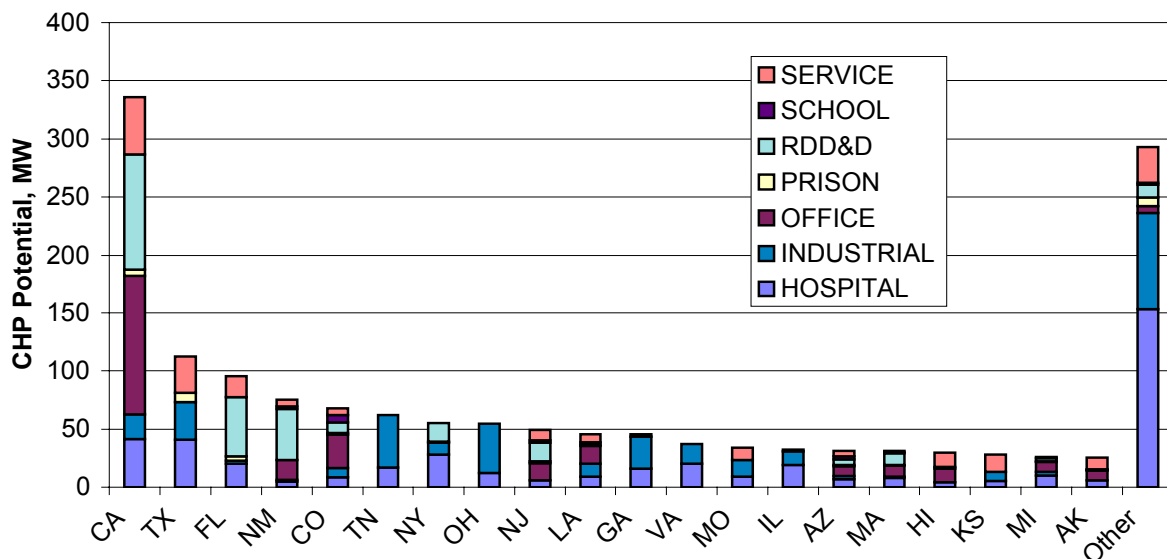
Table 14: State CHP potential capacity by building type under base case, MW

	Hospital	Industrial	Office	Prison	R&D	School	Service	Total
CA	42	21	120	5	99	-	49	336
TX	41	32	-	8	-	-	31	112
FL	20	3	-	4	51	-	18	96
NM	5	2	17	-	44	2	6	75
CO	8	8	29	2	9	6	6	68
TN	17	45	-	0	-	-	-	62
NY	28	10	-	1	16	-	-	55
OH	12	42	-	-	-	-	-	54
NJ	6	-	15	1	16	2	9	49
LA	9	11	16	1	2	-	7	46
GA	16	27	-	2	-	-	-	46
VA	20	17	-	-	-	-	-	37
MO	9	15	-	-	-	-	10	34
IL	19	11	-	2	-	-	-	33
AZ	7	3	8	1	5	3	5	31
MA	8	1	9	1	10	1	1	31
HI	4	0	12	-	0	1	12	30
KS	5	8	-	0	-	-	14	28
MI	10	3	8	0	3	-	1	26
AK	6	-	9	-	0	1	10	25
PA	17	4	-	2	-	-	-	24
DC	16	7	-	-	-	-	-	23
MN	6	11	-	0	-	-	3	21
WA	12	7	-	-	-	-	-	19
IN	7	10	-	1	-	-	-	18
AL	16	2	-	-	-	-	-	18
OK	6	11	-	1	-	-	-	18
AR	10	1	-	1	2	-	3	18
WI	9	8	-	-	-	-	-	17
NC	14	2	-	1	-	-	-	17
SC	-	13	-	-	-	-	-	13
ND	2	-	-	-	-	-	11	13
MS	9	2	-	0	-	-	-	12
CT	3	2	3	0	3	0	0	11
SD	4	-	-	-	-	-	8	11
NV	2	2	-	0	-	-	4	9
RI	1	-	2	-	5	1	1	8
WV	8	-	-	-	-	-	-	8
OR	5	-	-	-	-	-	-	5
IA	4	-	-	-	-	-	-	4
NH	1	-	1	-	1	0	1	4
ME	1	-	-	-	-	-	-	1
VT	1	-	0	-	0	0	0	1
DE	-	-	-	-	-	-	-	-
ID	-	-	-	-	-	-	-	-
KY	-	-	-	-	-	-	-	-
MD	-	-	-	-	-	-	-	-
MT	-	-	-	-	-	-	-	-
NE	-	-	-	-	-	-	-	-
UT	-	-	-	-	-	-	-	-
WY	-	-	-	-	-	-	-	-
Total	446	342	248	36	265	18	211	1,567

Besides the amount of floor space and energy intensity in any state, a key factor is the relative price of natural gas and electricity. States with low gas prices and high electricity prices are the best candidates for CHP. Contrarily, high gas prices and low electricity prices make CHP less attractive. Figure 11 shows the national amount of potential CHP capacity, based on Table 14. Figure 12 shows the states with the highest difference between electricity and gas prices. Note that there is a strong correlation between the two figures. Exceptions exist primarily because states with higher numbers of large federal buildings are more likely to have higher CHP potential.

Some industry personnel have suggested that high gas prices alone provide better economics for CHP. However, this is only true if the price of electricity in the region is tied to the price of gas, thereby increasing the spread in $/MBtu between the two as gas prices rise. Keeping the spark spread constant while raising the price of gas decreases the value of CHP slightly since it tends to be slightly less efficient in thermal utilization than regular boilers. Higher gas prices alone, without corresponding electricity price increases, reduce the calculated CHP capacity in the model.

CHP and emissions: EPA considers CHP to be a key pollution prevention tool. EPA estimates that electric power generation plants are responsible for:

- 67% of all emissions of sulfur dioxide (SO_2), the leading component of acid rain and fine particulates;
- 40% of all man-made emissions of carbon dioxide (CO_2), the leading greenhouse gas believed to contribute to global warming;
- 25% of all emission of nitrogen oxides (NO_x), a key component of ozone (smog), acid rain, and fine particulates; and
- 34% of all emissions of mercury (Hg), a toxic heavy metal that is concentrated through the food chain (EPA 2001).

The source energy saved through the higher efficiency of CHP lowers the amount of emissions that will occur. With 50 TBtu of source energy saved, CO_2 emissions would be reduced by 2.7M metric tons/year, assuming conservatively that all this energy would otherwise have come from natural gas. This is roughly equivalent to the output of 560,000 cars. In some regions of the country, the avoided fuel would be coal or oil for a portion of the energy. These have higher carbon intensities and additional harmful emissions, so pollution prevention benefits of CHP would be much higher. The actual emission benefits of a project will depend on several site-specific and technology specific factors. Using state of the art gas turbines and control technologies, CHP can meet stringent emissions requirements as a clean energy alternative.

Fig. 11: Federal CHP potential capacity under base case, MW.

CHP Capacity, MW

■ 37 to 336 (12)
■ 23 to 37   (9)
■ 17 to 23   (8)
□ 5 to 17   (9)
□ 0 to   5 (13)
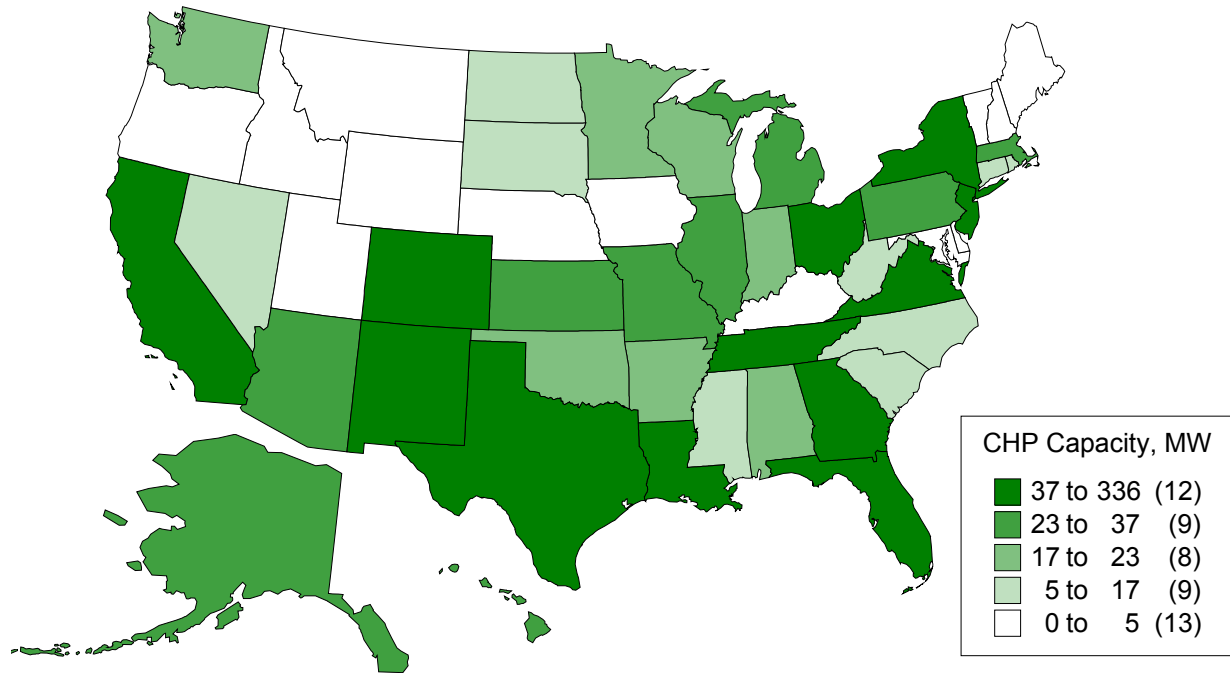
Fig. 12: "Spark spread" difference in electric and gas prices in $/MBtu.

Electric - Gas Prices
2000 Industrial $/MBtu

■ 11.1 to 22.3   (9)
■ 9   to 11.1 (11)
■ 7.3 to 9   (10)
□ 6.2 to 7.3   (9)
□ 3.8 to 6.2 (12)
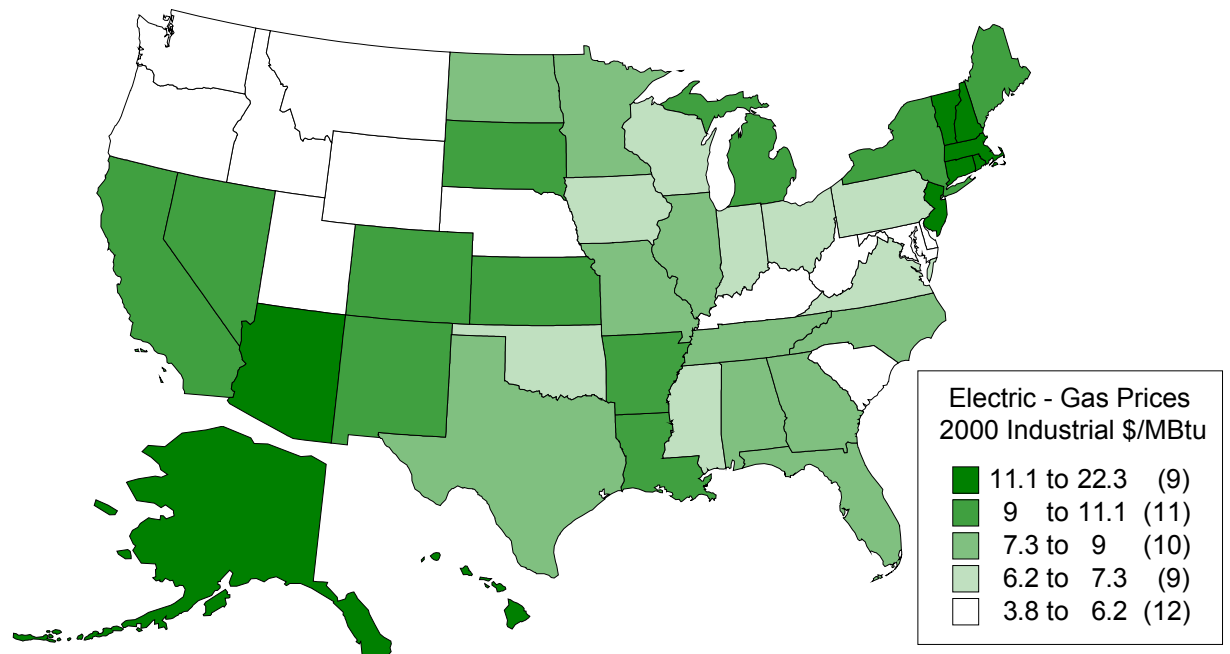
4.3 Federal CHP Potential by Agency

The analysis of potential CHP capacity by state did not distinguish among the agencies that own the facilities. The GSA database provides information on the agency and bureau that owns each building. By running the model using each of the 28 agencies' data, we can calculate the potential capacity for each agency in each state. Table 15 shows the total capacity by building type for each agency. Many agencies have little or no potential as calculated using the base case parameters. (The sum does not match the earlier analysis, because agency-by-agency averages by state have slightly different paybacks compared to the building category averages that go above or below the threshold ten years.)

Table 15: Potential CHP capacity by federal agency and building category, MW

| Agency	Hospital	Industry	Office	Prison	R&D	School	Service	Total
Air Force	43	57	31	0	85	7	116	339
Veterans Affairs (VA)	311	0	1	0	1	0	0	314
Army	55	101	52	2	24	3	33	270
Navy	27	36	39	0	43	2	58	205
Department of Energy	0	113	15	0	64	0	2	195
National Aeronautics and Space Administration (NASA)	0	17	10	0	43	0	3	73
General Services Administration	0	1	68	0	0	0	0	69
United States Postal Service	0	0	48	0	0	0	0	48
Justice	0	3	0	34	0	0	0	37
Health and Human Services	6	0	0	0	2	0	0	9
Treasury	0	8	0	0	0	0	0	8
Transportation	0	0	2	0	4	0	0	7
Interior	0	2	2	0	0	3	0	7
Agriculture	0	0	0	0	3	0	0	3
Commerce	0	0	0	0	2	0	0	2
Corps of Engineers	0	0	1	0	1	0	0	2
National Science Foundation	0	0	0	0	1	0	0	1
Environmental Protection Agency	0	0	0	0	1	0	0	1
Education	0	0	0	0	0	1	0	1
Grand total	443	338	269	36	274	16	212	1588

Note: Other agencies were considered, but did not show potential. These include Agency for International Development, Federal Communications Commission, Federal Emergency Management Agency, Government Printing Office, National Archives and Records Administration, Smithsonian, Department of State, Tennessee Valley Authority.

Nearly all CHP potential is found among nine agencies: the three military services, VA hospitals, DOE, NASA, GSA, the U.S. Postal Service, and the Department of Justice (Fig. 13). And the first three (military, VA and DOE) represent 83% of the total CHP potential identified in the base case. The military services (over 50% of total) have significant potential CHP capacity in all types of buildings (except prisons), but the VA has capacity mainly in hospitals (as expected). Energy and NASA capacity is concentrated in R&D and industrial buildings, while GSA and the Postal Service have capacity in the "office" category. It should be mentioned that the categories directly reflect the GSA database that appears to include Postal Service processing and distribution centers under the office category. The Justice sector capacity is in prisons.

Fig. 13: Potential CHP capacity for major federal agencies (% of 1588 MW total).
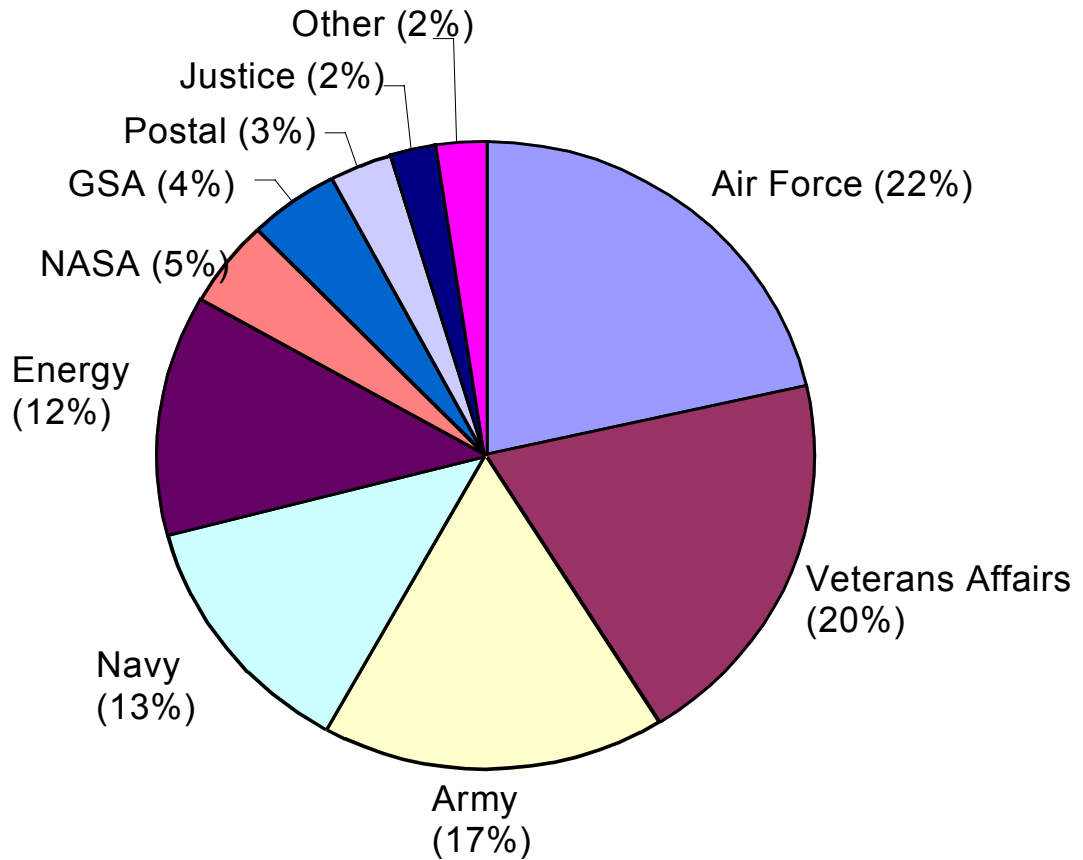
Showing a breakdown of the agency capacities by states gives an idea of where the major agencies have their potential (Table 16). Each agency has its main potential capacity in the states with large facilities and good spark spreads. All show large amounts in California. DOE capacities are in those states with large national laboratories or industrial plants registered in the GSA database. VA hospitals are fairly evenly scattered across the country. While the database is imperfect, the margin of error occurs in both directions: some facilities may close while others are expanding.

Table 16: Potential CHP capacity by state for leading agencies (MW)

| State	Air Force	VA	Army	Navy	Energy	NASA	GSA	Postal Service	Justice
AK	13	0	6	1	0	0	3	1	0
AL	1	12	4	0	0	1	0	0	0
AR	3	8	2	0	0	0	0	0	1
AZ	10	4	9	1	0	0	1	1	1
CA	75	27	13	99	29	25	32	26	5
CO	19	4	14	0	9	0	12	4	2
CT	0	2	3	4	0	0	1	1	0
DC	0	5	11	0	0	0	0	0	0
DE	0	0	0	0	0	0	0	0	0
FL	35	14	0	17	0	27	0	0	4
GA	32	10	6	0	0	0	0	0	4
HI	4	0	10	13	0	0	1	1	0
IA	0	4	0	0	0	0	0	0	0
ID	0	0	0	0	0	0	0	0	0
IL	2	15	8	2	1	0	0	0	2
IN	0	7	7	4	0	0	0	0	1
KS	6	4	16	0	0	0	0	0	1
KY	0	0	0	0	0	0	0	0	0
LA	5	6	10	3	0	10	5	2	1
MA	8	8	4	2	0	0	4	3	1
MD	0	0	0	0	0	0	0	0	0
ME	0	1	0	0	0	0	0	0	0
MI	2	9	7	0	0	0	3	4	0
MN	2	6	6	5	0	0	0	0	0
MO	10	7	9	0	7	0	0	0	0
MS	3	5	2	0	0	0	0	0	0
MT	0	0	0	0	0	0	0	0	0
NC	0	9	4	3	0	0	0	0	1
ND	11	1	0	0	0	0	0	0	0
NE	0	0	0	0	0	0	0	0	0
NH	1	1	1	1	0	0	0	0	0
NJ	10	4	17	5	1	0	3	5	0
NM	17	2	10	0	37	1	3	1	0
NV	4	1	1	0	4	0	0	0	0
NY	6	27	4	5	10	0	0	0	1
OH	3	9	7	0	34	0	0	0	0
OK	8	4	4	0	0	0	0	0	1
OR	0	5	0	0	0	0	0	0	0
PA	0	16	2	1	0	0	0	0	2
RI	0	1	0	7	0	0	0	0	0
SC	0	0	0	0	13	0	0	0	0
SD	8	2	0	0	0	0	0	0	0
TN	0	14	7	3	38	0	0	0	0
TX	38	22	40	19	4	10	0	0	8
UT	0	3	0	0	0	0	0	0	0
VA	0	10	13	10	0	0	0	0	0
VT	0	1	0	0	0	0	0	0	0
WA	0	6	5	0	7	0	0	0	0
WI	0	9	8	0	0	0	0	0	0
WV	0	8	0	0	0	0	0	0	0
WY	0	0	0	0	0	0	0	0	0
Total	339	314	270	205	195	73	69	48	37

5 Sensitivity Analysis

While our base case shows 1.5–1.6 GW of potential CHP capacity, it is based on certain assumptions about technology, costs, operating parameters, and building characteristics. If we modify these parameters, the amount of potential CHP capacity (defined as systems with less than ten-year simple payback) changes. Table 17 shows the amount of capacity under the base case and with changes to some of the key parameters.

Table 17: Sensitivity analysis on key CHP parameters

Technology	Cost & efficiency	Fuel prices	Sized for gas or electric	Building size	Potential CHP MW
Technology Cost					
Recip. engine	Current	2000 Industrial	85% or 50% electric	>25,000 ft^2	1570
"	Future	"	"	"	2040
"	Double current installed cost	"	"	"	390
CHP Sizing					
Recip. engine	Current	2000 Industrial	100% of gas	"	1760
"	Future	"	"	"	2690
"	Current	"	85% or 50% electric w/ credit for max of 100% of gas needs	"	960
"	"	"	100% of gas w/ credit for max of 100% electric		1080
Energy Price					
Recip. engine	Current	2000 Commercial	85% or 50% electric	"	2820
"	"	1999 Industrial	"	"	2010
Technology Type					
Turbine	Current	2000 Industrial	85% or 50% electric	"	1670
"	Future	"	"	"	2370
Fuel cell	Current	"	"	"	0
"	Future	"	"	"	90
Building Size					
Recip. engine	Current	2000 Industrial	85% or 50% electric	25K<x<100K	10
Turbine	"	"	"	"	9

The first row shows the base case described above. The second row shows the results if we used the costs and efficiencies that one recent source (RDC 2001) estimates will be available post-2005. The next row shows the effect if the installation cost is twice that reported by RDC. ORNL's experience with FEMP projects have shown a higher installation cost than in Table 8, although those costs have included additional equipment such as chillers and increased piping.

Fig. 14: CHP potential capacity (MW) under varying cost and efficiency assumptions.
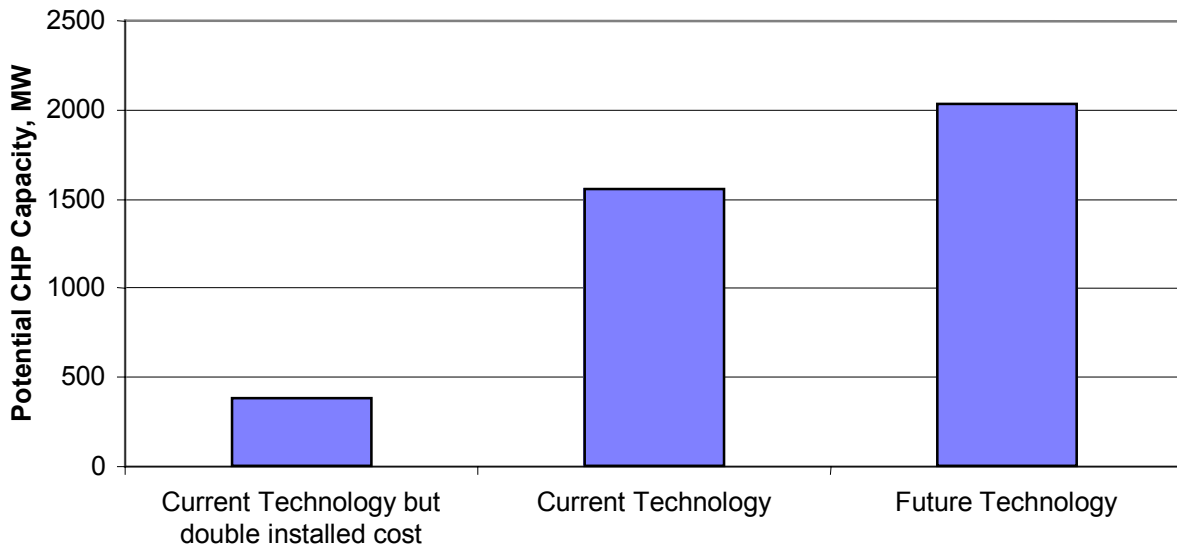
The amount of CHP is very sensitive to the cost and efficiency assumptions. Figure 14 indicates these graphically; there is some increased potential through future improvements that lower installation costs and increase efficiency, but the potential is significantly reduced if installation costs are double those reported by RDC.

Actual projects will have highly site-specific characteristics that influence the costs and potential benefits of a CHP system. While in some cases costs will be higher, in others they could be significantly lower. For example, the base case assumes that the site already has a heating system in good repair. If the site is going to have to replace its heating and cooling system anyway, the installation cost for CHP would be the incremental cost above installing a standard system. This may greatly improve the economics because the savings in power costs would only need to pay back this incremental cost.

The next set of sensitivity analyses varied the amount of energy that the CHP is sized for or receives credit for. The first two assume the same parameters as the base case, but with CHP sized to meet 100% of current gas needs (according to the CBECS energy intensity data) rather than the base case portion of the electric needs, as shown in row e of Table 10. The resulting capacity (1757 MW) is similar to but slightly higher than the base case. The gas intensities we used may be based partially on buildings using mechanical chillers or air conditioners. With CHP, they may convert to gas chillers and thereby have additional thermal load. This could raise the amount of CHP potential even higher. The next scenario has the same gas needs but with the future technology costs. Projected capacity rose to 2687 under this scenario, higher than with future technology meeting base case electric needs, since as equipment becomes more efficient it can generate additional electricity for the same amount of thermal exhaust.

Because our base case sized equipment solely on the electric needs of the building, the CHP units may be providing thermal energy in excess of what the buildings can use. If this thermal energy cannot by used in other processes or by neighboring buildings at the site, it will be lost. The next sensitivity sizes the CHP to provide the base case amount of electricity (85% or 50% depending on building type) but only gives financial credit for thermal exhaust up to 100% of the building's gas intensity energy needs. Any thermal energy over that is assumed lost. As a consequence, the potential capacity with payback less than 10 years drops significantly to 962 MW. Offices have the largest drop, going from 248 MW to 49 MW. Their thermal needs are modest in comparison to electrical needs, so if the excess thermal energy has no value,

then fewer offices have cost-effective potential for CHP. This illustrates the importance of assuring maximum use of recovered heat in CHP applications, both for efficiency and for economic reasons.

Similarly, if we size the equipment based on 100% of the estimated thermal needs but only give credit for up to 100% of estimated electric needs for the facility, then potential capacity drops to 1078 MW. This sensitivity reflects the assumption that excess electricity cannot be sold to other buildings. In this case, hospitals and service facilities reduce their capacities the most, going from 595 and 323 MW to 274 and 87 MW respectively, because their thermal needs are much higher than their electrical needs, so the loss of electrical credit for excess generation makes more of their capacity uneconomic.

The next two sensitivity analyses look at the prices of gas and electricity, adjusting them to either commercial rates in 2000 or industrial rates in 1999. In both cases, CHP potential is higher than the base case, rising to 2800 and 2000 MW respectively, because the price differential between electricity and gas are higher. The year 2000 saw large increases in gas prices, with non-weighted average prices going from $3.75 to $4.95/MBtu (27%). Industrial electric prices barely changed, going from $14.01 to $14.14/Mbtu. The difference (spark spread) was higher in 1999. Similarly, commercial prices in 2000 for gas and electric had a $14.05/Mbtu difference between gas and electric, while industrial prices had $9.19/Mbtu difference. Higher spark spread improves the economics of CHP.

Comparing technology options for the prime mover in a CHP system, current gas combustion turbines had costs and efficiencies similar to reciprocating engines; capital costs were higher but operating costs lower. Electrical efficiency was lower for turbines but since exhaust heat is used by the building rather than wasted, this factor is less important than for an electricity-only distributed generation project. Total capacity for turbines was slightly higher when compared to the base case with engines (Fig. 15). More improvement is expected with turbines than with engines. Using future expected cost and efficiencies, the potential capacity using turbines increased by 700 MW, while improvements in engines raised capacity by roughly 500 MW.

**Fig. 15: Potential CHP capacity with different technologies and performance parameters.**
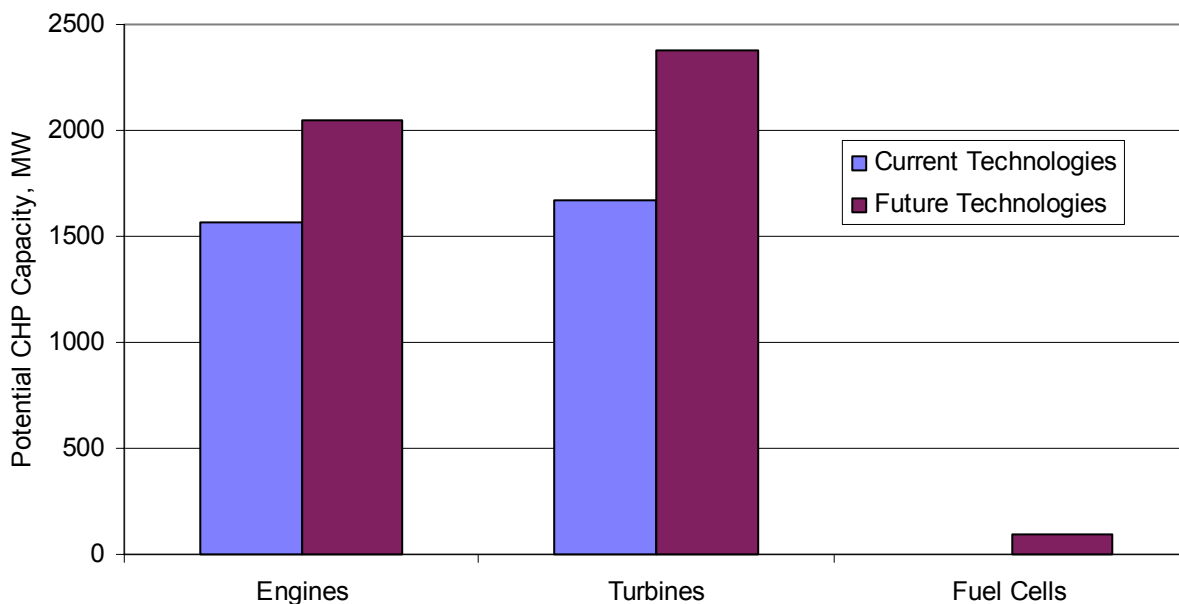
Fuel cells, under current installed costs near $5000/kW and 40% efficiency, had no capacity appear cost effective. Using proposed future installation costs of around $1500/kW and 50% efficiency, 90 MW of capacity falls within the ten-year payback, but no fuel stack replacement is assumed in the O&M costs. Further improvements in fuel cell costs will be needed for them to be able to penetrate the market.

Looking at the smaller buildings, there was very little CHP potential. At smaller sizes, the reciprocating engines are slightly more cost effective than the turbines. In smaller buildings (between 25,000 and 100,000 ft^2) there were 10 MW of engines that met the economic criteria, but only 9 MW of turbines.

Our base case used all projects with paybacks less than ten years. Some have paybacks significantly shorter than ten years, while there is additional capacity available if we consider longer-term paybacks. Figure 16 shows the amount of capacity in the base case that fell within different payback periods. Beyond the 1567 MW with paybacks less than ten years, there were more than 745 MW with simple paybacks between 10 and 15 years. Under some situations these projects could prove to be economic. However, the "time value" of money makes these less attractive (Fig. 8).

Fig. 16: CHP capacity in base case at different ranges of payback period.
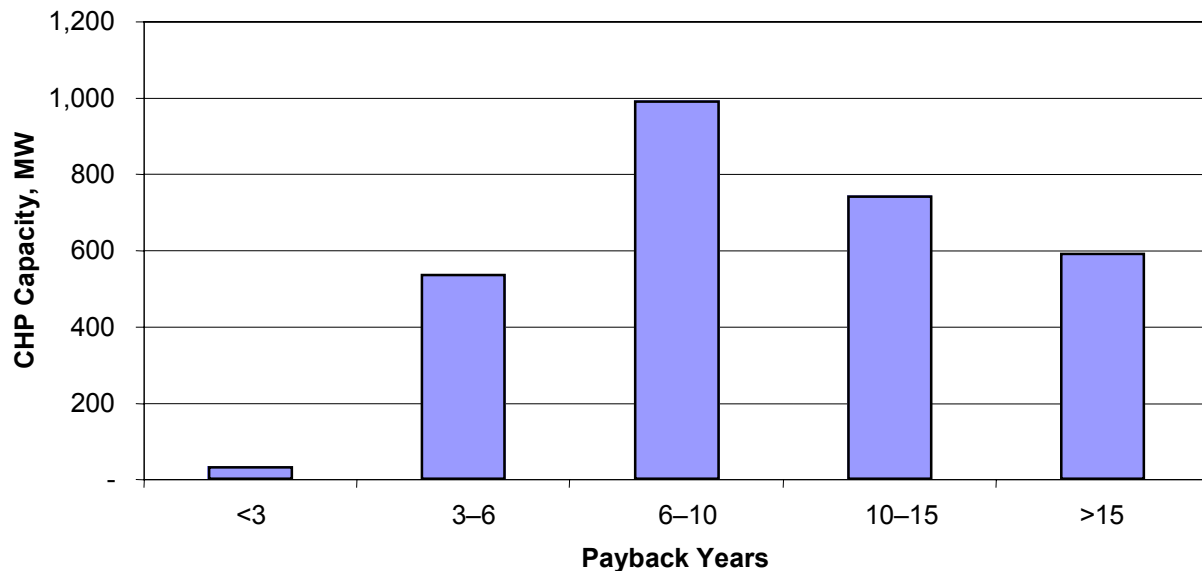
6 Conclusions

6.1 Data Limitations and Further Studies

Given the quality and types of data available and the methodology used in this analysis, it is impossible to make reliable predictions about specific sites and their respective CHP potentials. This analysis used state- or region-wide averages for various building types and energy variables; any actual site can have widely different values. In addition, so many site-specific conditions affect the economics of a CHP application that it is extremely difficult to make accurate predictions without more detailed, site-specific data. For example:

- The GSA facilities data provide square footage by building type but fail to identify those facilities served by district energy systems. District systems are significant enhancers to CHP economics since they allow for larger equipment and the aggregation of thermal and electrical needs for many smaller buildings. Most district systems are on military bases, so the data used may underestimate CHP capacity in that sector.

- The analysis assumes there is potential CHP capacity only if it can be shown to pay from savings within a given period of time and under a limited set of assumptions. Other factors will often determine whether a CHP system is installed. Energy security and other mission-critical factors may often be the overriding criteria in the decision to install a CHP system, and in some cases, emissions factors carry significant weight.

- Installation costs of recent CHP projects at federal sites have varied from less than 50% to 150% of the equipment costs. Some states and utilities may offer subsidies or reduced tariffs for CHP projects. The interconnection and standby fees can vary considerably from one utility district to another. (See Appendix C for a discussion of interconnection requirements, standby, and exit fees.) These cost factors can significantly affect project economics.

- The condition and type of current HVAC equipment may facilitate or prevent CHP from being deployed. Retrofitting in office buildings may be more costly than assumed here. On the other hand, if a site needs to replace or renovate boilers and HVAC equipment, the marginal cost of adding CHP may be small and the returns may be higher than assumed.

- The GSA database used does not necessarily reflect updated information on facilities and their use. We sponsored a survey of potential sites in California, Texas, and New York using the GSA list as a starting point. Many military facilities on the GSA list had either closed or significantly changed mission. Also, recent expansion by the Bureau of Prisons does not appear to be fully captured.

- The assumptions based on CBECS about the percentage of buildings with CHP-compatible infrastructure may be conservative for some categories (prisons in particular), and there is clearly the possibility that a CHP system could be cost-effective at sites that were assumed to not possess the prerequisite conditions (gas service and central heat or cooling systems).

- The energy intensities used may not accurately represent the actual building intensities. Federal buildings may be more or less energy intensive than regional averages for CBECS building types. Further, many of the buildings profiled in the survey likely used electricity for mechanical chillers, increasing the electrical intensity but lowering the gas intensity. CHP systems can use the thermal exhaust in absorption chillers for air conditioning, thereby altering the electric and thermal energy intensities of the buildings.

- And perhaps most important, specific sites will often have far different prices for electricity or gas than the state average used in this analysis. Those tariffs may be lower in some cases today, but are likely to rise as contracts expire and are renewed in the next few years. Also, this analysis did not attempt to look at the potential for CHP systems to be used in conjunction with peak shaving and load-reduction incentive programs that an increasing number of utilities are offering.

However, despite the many limitations, our analysis does provide reasonable approximations of state or national totals, and can easily show the impact of changing various parameters. Future effort needs to analyze site-specific information and should focus on the building sectors, agencies, and geographic regions with the highest potential.

The model developed for this report estimates the magnitude of CHP that could be implemented under various performance and economic assumptions associated with different applications. This model may be useful for other energy technologies. It can be adapted to estimate the market potential in federal buildings for any energy system based on the cost and performance parameters that a user desires to assess. The model already incorporates a standard set of parameters based on available data for federal buildings including total building space, building type, energy use intensity, fuel costs, and the performance of many prime movers commonly used in CHP applications. These and other variables can be adjusted to meet user needs or updated in the future as new data become available.

6.2 CHP Potential and FEMP

There is significant potential—1000 to 2000 MW of capacity —for CHP at federal facilities today. Regions with the greatest CHP potential are the Southwest (CA to TX), northeastern metropolitan areas (NY to DC), and the southeast (FL, GA, AL). Agencies with the most potential are the military, VA, and DOE, especially in hospital, industrial, and R&D facilities. As energy prices increase and CHP system costs decrease, the amount of cost-effective CHP potential will rise. The actual potential could be higher or lower depending on the specific conditions of any given site.

The 1.5 GW identified under the base case scenario would be sufficient to power more than a million homes and save the federal government $170M per year in energy costs. To install the 1.5 GW of electrical CHP generating capacity (all cases where the simple payback period is under ten years) would require an estimated $1.5–$2 billion in capital investments. Since the average simple payback period for these projects was 6.2 years, most could be financed through existing credit mechanisms supported by FEMP (ESPC, UESC, etc.). The net primary energy savings from this level of CHP investment are estimated to be 50 trillion Btus per year, the energy equivalent of over 8M barrels of oil per year. And projected carbon dioxide emissions would be reduced by 2.7M metric tons per year compared to gas-fired central electric power and thermal alternatives.

There has been a recent upsurge of interest in fuel-efficient distributed energy resources such as CHP among project developers, federal facility managers, and policy makers because these systems can offer significant benefits in terms of dollar savings, emissions reductions, and increased energy security. They also help mitigate other power constraints; meet increased energy demand; reduce transmission congestion; increase power quality and reliability; and in sufficient numbers, interconnected CHP systems can offer increased power security for the grid as well (Casten and Casten 2001).

CHP in buildings can also help facilitate a transition to cleaner fuels of the future (such as hydrogen) that would rely upon the same infrastructure as CHP and effectively utilize fuel cells when proven, commercial products that are economically feasible to apply become available. EPA considers CHP to be

"a proven pollution prevention technology" (EPA 2001a). Over 50,000 MW of CHP capacity was in place in the United States in 2001, primarily in the industrial sector. DOE and EPA would like to see current CHP capacity doubled by 2010 (USCHPA 2001). State public utility commissions, such as those in Texas and California, are leading the way to clarify local regulations for permitting and interconnection of DER in general and CHP in particular. DOE and EPA are collaborating to address several policy issues such as more equitable treatment of CHP systems when looking at air quality standards. (See Appendix D for a discussion of emissions permitting and siting issues.)

FEMP's mission is to reduce the cost to and environmental impact of the federal government by advancing energy efficiency and water conservation, promoting the use of renewable energy, and improving utility management decisions at federal sites. Federal agency sites are FEMP's customers and FEMP's programs are customer-driven. While FEMP is not a technology development program, it does monitor energy efficiency and renewable energy technology developments and mounts "technology-specific" programs to make technologies that are in strong demand by agencies easily accessible to them. Sometimes these technologies are the product of R&D sponsored by sectors within DOE's Office of Energy Efficiency and Renewable Energy (EERE). In those cases, FEMP's role becomes one of helping the federal government "lead by example" through the use of advanced EERE technologies in its own buildings and facilities.

CHP was highlighted in the Bush Administration's National Energy Policy Report as a commercially available technology offering extraordinary benefits in terms of energy efficiencies and emission reductions. FEMP's criteria for emphasizing a technology are that it be commercially available; be proven but underutilized; have a strong constituency and momentum; offer large energy savings and other benefits of interest to federal sites and FEMP mission; be in demand; and carry sufficient federal market potential. CHP meets all of these criteria, with the latter documented in this report and in subsequent site-specific screening activities.

Although CHP technologies are proven and the potential savings and benefits are significant, project development over the past decade has been modest in the federal sector. Given the potential for CHP, why haven't more federal facilities installed this technology? Preliminary discussions with federal facility managers suggest that the primary reasons include:

- low historical tariffs for electricity;
- high initial cost of CHP systems;
- limited budgets (agencies rarely have sufficient appropriations for even much smaller energy conservation investments);
- complexity of CHP systems due in part to the need for custom engineering and design of different components for each site;
- a lack of time and capability for facility managers to evaluate potential applications and benefits to their site;
- obstacles related to local regulations and policies for interconnection, standby/backup charges, siting and emissions (see Appendixes C and D); and
- a lack of trusted sources of information about the costs, operation and performance of CHP systems.

FEMP is working to address many of the obstacles through technical and project financing assistance, education and outreach. An initiative called "Accelerated Development and Deployment of Combined Cooling, Heat, and Power," or ADD CHP, is an integral part of FEMP's overall program. The strategy is to enable sound investments in CHP systems by providing qualified support to federal sites with champions motivated to develop a CHP project. FEMP services, resources permitting, include:

- conducting CHP quick technical screening for interested federal sites;
- performing site survey and feasibility verification;
- fostering partnerships between federal, state, and private sector project developers and financiers;
- collecting baseline data;
- fostering partnerships between federal sites and industry developers of "packaged" CHP;
- providing design and technical assistance to projects selected under FEMP calls for projects;
- providing support in addressing policy and regulatory constraints — siting and permitting, grid interconnection requirements, exit fees, backup charges;
- providing conceptual design, component matching, and sizing verification (thermal/power profiles); and
- evaluating technical/price proposals

6.3 How to Determine Whether a Facility Has CHP Potential

Many federal facility managers have no time to investigate whether CHP will work for their site. FEMP can assist through a free screening for CHP potential. The screening provides an initial estimate of site-specific economics for a CHP project and helps determine if further investigation of CHP opportunities is worth the effort. Some of the basic criteria that will influence the economics of a CHP project are listed in the sidebar. Several other factors affect the economics of CHP projects, for example, if CHP is linked to replacement of equipment nearing the end of its useful life, or if it is bundled with other energy-efficient measures with shorter payback periods, economics could improve significantly. And as demonstrated earlier, CHP economics are highly sensitive to utility rates. CHP systems could help a facility "flatten" the peaks in electric and gas loads, allowing sites to negotiate reductions in rates and demand charges or to move to a more favorable interruptible rate schedule for part of the load. On the other hand, there could be significant costs related to standby and exit fees. Therefore, once an initial screening indicates there is potential for CHP, it is recommended that sites investigate utility rate issues and opportunities that may arise with the CHP project along with siting and permitting issues (Appendixes C and D).

Do you have CHP potential?

Ideal sites will fit the following profile, but sites meeting only a few of these characteristics may also have a cost-effective CHP opportunity:

- ✓ high electric prices (more than 5 cents/kWh);
- ✓ average electric load greater than 1 MW;
- ✓ ratio of average electric load to peak load > 0.7
- ✓ a central or district heating and/or cooling system in place (or a need for process heat)
- ✓ "spark spread" (difference in price per million site Btu between gas and electricity) >$12
- ✓ high annual operating hours (> 6000)
- ✓ thermal demand closely matches electric load

Strong private partners can support the CHP project development process as well as offer a source of financing. And of course FEMP is available to assist federal sites in their efforts to identify appropriate partners and deploy CHP. FEMP recognizes the significant potential for CHP technologies to reduce the costs of government, increase energy security, and improve air quality and is actively working to make advanced CHP technologies more easily accessible to federal agencies throughout the nation.

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