Combined Heat & Power (CHP) Resource Guide for Hospital Applications

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Department of Energy United States of America

Midwest CHP Application Center
In Partnership with the US DOE

recycling energy™
CHP

Important Definitions

Heating Value of Fuels

- Higher Heating Value (HHV): Total thermal energy available, including heat of condensation of water vapors, from complete combustion of a fuel
- Lower Heating Value (LHV): Same as HHV, except it assumes heat of condensation is not available
- LHV is used for majority of calculations

	Units	LHV	HHV	LHV/HHV
Natural Gas	*Btu/SCF*	950	1,050	0.905
#2 Fuel Oil	*Btu/Gallon*	130,000	138,300	0.940
#6 Fuel Oil	*Btu/Gallon*	143,000	150,500	0.950
Propane	*Btu/Gallon*	84,650	92,000	0.920
Sewage/Landfill	*Btu/SCF*	350	380	0.921
Coal - Bituminous	*Btu/lb*	13,600	14,100	0.965

Capacity Factors

- Based on equipment output vs. capacity

Electric *(> 70% Desirable)* $= \dfrac{\text{Avg. kW output (for a period)}}{\text{System kW capacity}}$

Thermal *(>80% Desirable)* $= \dfrac{\text{Avg. Btu output (for a period)}}{\text{System capacity in Btu}}$

Steam *(>80% Desirable)* $= \dfrac{\text{Avg. lbs/h output (for a period)}}{\text{System capacity in lb/h}}$

Load Factors

- Based on site load data

Electric $= \dfrac{\text{Avg. kW (for a period)}}{\text{Peak kW (for the period)}}$

Thermal $= \dfrac{\text{Avg. Btu (for a period)}}{\text{Peak Btu (for the period)}}$

Calculating CHP Efficiency

- Based on Lower Heating Value (LHV)

$$\text{CHP Efficiency} = \frac{(\text{kWe} \times 3412.8) + (\text{Recovered Thermal Energy})}{\text{Fuel Input (Btu/hr in LHV)}}$$

Disclaimer

The information in the CHP Resource Guide represents the best efforts by the Midwest CHP Application Center at the time of publication. This Guide should be utilized ***ONLY*** as a reference document for screening and estimating purposes. It is ***NOT*** intended as a tool for developing detailed CHP designs or cost estimates.

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INTRODUCTION (PURPOSE OF THE GUIDEBOOK)

The primary objective of this guidebook is to provide a reference document of basic information for hospital managers when considering the application of combined heat and power (CHP) in the healthcare industry, specifically in hospitals. Hospital administrators are faced with rising and uncertain energy costs, the requirement for higher energy reliability, increasing environmental demands, and shrinking facility budgets. The need exists to constantly evaluate realistic alternatives to today's conventional approaches to meeting energy demands.

CHP is an approach that can help address these energy, environmental, and security issues in hospitals. Nationally, CHP exists in over 3,000 sites generating approximately 83,000 MW of electric power (approximately 9% of the total electric generation in the U.S.).[1] Today, CHP is installed in only approximately 4% of the active stock of U.S. hospitals.

This guidebook should be useful to energy engineers, facility operations directors/managers, energy auditors, and others that support and/or service the healthcare and hospital industry. The guidebook provides "packets" of information in the form of basic principles and "rules-of-thumb" regarding the evaluation and suitability of the use of CHP systems at their hospital facility.

The hospital guidebook was developed by the Midwest CHP Application Center (MAC) with assistance from Avalon Consulting Inc., Energy and Environmental Analysis Inc., and PEA Inc. The MAC is one of eight regional CHP application centers established by the U.S. Department of Energy (DOE) to develop technology application knowledge and the educational infrastructure necessary to foster CHP as a viable energy option and reduce any perceived risks associated with its implementation. The regional application centers provide:

- Targeted Education
- Unbiased Information
- Technical Assistance

For more information on the MAC, please visit our website at:
www.chpcentermw.org

Appendix C of this guidebook provides a list and contact information for all eight regional CHP application centers.

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[1] Hedman, Bruce. "The Role of CHP in the Nation's Energy System." *USCHPA Annual Meeting*. PowerPoint presentation. 2 November 2007. <http://www.uschpa.org/MembersOnly/2007Conf/Hedman.ppt>

SECTION 1: ENERGY CONCERNS OF U.S. HOSPITALS

1.1 Inefficient Electric Power

The national average for converting fuel to electric power (fuel-use efficiency) through conventional means (central station plants) is about 33%, which means that the remaining 67% of the fuel energy is wasted: either being exhausted into the atmosphere or discharged into water streams. CHP systems recover part of that wasted energy by recovering ~55% of the fuel energy in the exhaust to provide the heating, cooling, and/or dehumidification needs of co-located buildings and/or industrial processes. Combining that with a ~30% fuel energy conversion to electricity, CHP systems can have a fuel-use efficiency as high as 85%.

1.2 Electric Reliability

Electric grid reliability and the ability of electric utility customers to rely on continuous uninterrupted electric service is becoming an increasing problem. This is due in part to an aged electric utility grid infrastructure that is increasingly taxed each year as the nation's electric consumption continues to grow. The U.S. DOE Energy Information Agency projects over 360 GWe of new capacity over the next 10 years to meet growing demand and to compensate for power plant retirements. At a recent electric industry meeting, a representative from the Electric Power Research Institute (EPRI) stated that over $150 billion per year is lost to industry in the U.S. due to electric network (reliability) problems and that 500,000 customers are without electricity for a minimum of 1 hour every day in the US. Hospitals are taking a renewed interest in power reliability due to the events of Hurricane Katrina in 2005, the Midwest & Northeast Blackout of 2003, and the threat of possible man-made (terrorist) disasters. CHP systems have demonstrated their ability to keep hospitals up-and-running at full capacity during instantaneous as well as prolonged electric utility grid outages.

Mississippi Baptist Medical Center, located in Jackson, MS. experienced a complete electric utility grid outage for 52 hours during Hurricane Katrina in August of 2005. The installed CHP system allowed the hospital to continue 100% operation while providing shelter, food, and clothing to displaced patients from other area hospitals and stranded local citizens. The medical center is a 624 bed full service hospital. More information is available at: www.chpcenterse.org/reports/chp-mbmc.pdf

1.3 Status of the Hospital Construction Industry

Hospital construction remains strong and is projected to remain strong for at least the next five years. This is due in part to major rehabilitation of older facilities and to the expansion of existing facilities to accommodate business consolidations within the industry. Also, the U.S. Department of Labor (2005) predicts the number of people in older age groups, with much greater than average healthcare needs, will grow faster than the total population between 2002 and 2012. This will increase the demand for health services.

The capital investment in a CHP system is best justified during a major upgrade of a hospital facility that includes the operating systems (HVAC, Emergency Generators, etc).

1.4 Oversized Emergency Generator Sets

Another characteristic of the healthcare industry is the increase in the number and capacity of the emergency generator sets being installed in hospitals. The size of generators installed (in terms of kW), tend to go well beyond minimum code requirements to meet “life critical” loads. More and more circuits are being added to these generator sets to ensure a sense of added reliability. CHP systems, although usually more expensive to procure and install than diesel engine generator sets, provide significant advantages. They are installed to operate continuously and in parallel with the grid, thus providing substantial energy cost savings while also providing the increased reliability. Emergency generator sets can then be downsized to meet the code requirements of backing up the “life critical” loads of the facility.

1.5 Issues Facing Hospital Facility Managers

Finally, a presentation made at an American Society of Hospital Engineers meeting outlined several priority issues faced by hospitals in terms of facility operation and maintenance. They included:

- Managing budgets to meet growing utility costs
- Power reliability & redundancy
- Competing with clinical equipment for Capital $
- Environmental issues
- System (HVAC & Power) reliability for easier growth / expansion
- New technologies
- Test/inspect/maintain electric distribution system

Although CHP is not the only way to address these supply side priority issues, certainly CHP is one option.

SECTION 2: CHP BASICS

2.1 Definitions: Distributed Generation (DG) and Combined Heat & Power (CHP)

- **Distributed Generation (DG):**
  - An electric Generator
  - Located at a utility substation or near a building / facility
  - Provides at least a portion of the electric load required by the building / facility
  - Emergency generator sets utilized at hospitals are a form of DG

- **Combined Heat and Power (CHP):**
  - An integrated system
  - Located at or near a building or facility
  - Provides at least a portion of the electric load required by the building / facility
  - **Recycles the thermal energy from the generation equipment for**
    - Space heating / cooling
    - Process heating / cooling
    - Dehumidification
  - **CHP is a Form or Type of Distributed Generation**

2.2 The CHP Concept

2.2.1 Direct Fired

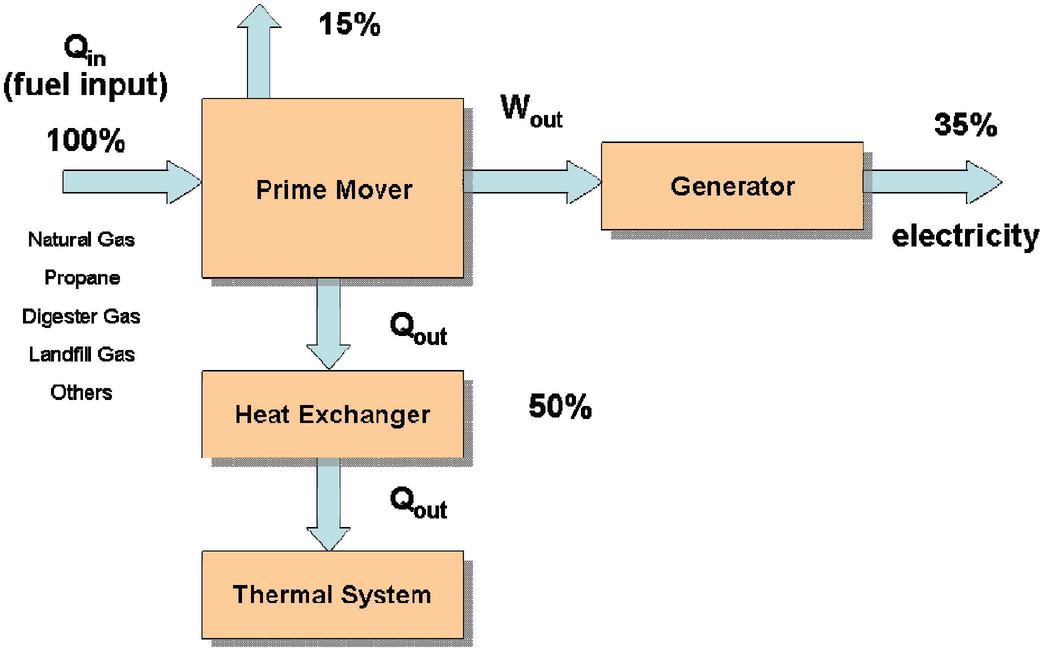

Figure 2-1 Combined Heat and Power Diagram – Direct Fired

- Electric generation efficiency is approximately 35% (not much better than central station power)
- Approximately 50% of the fuel input energy can be recycled for useful thermal energy purposes
- If the application has coincident & simultaneous use for the electric and recycled thermal energy, the CHP system can reach efficiencies of 80% to 85%
- Hospitals have long operating hours and require large amounts of thermal energy. Total system efficiency (electric and thermal) of a CHP system in a hospital has the potential to reach 70% to 80%, versus 40% to 55% when utilizing conventional energy systems.
- Higher system energy efficiency typically results in lower energy bills, lower carbon footprint for the hospital, and lower overall source emissions.

2.2.2 Indirect Fired Concept

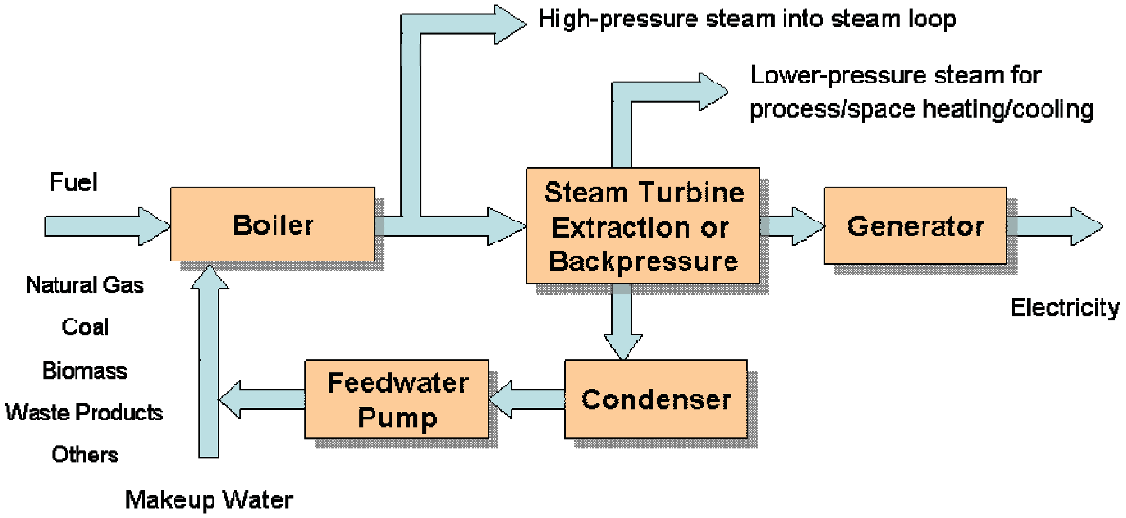

Figure 2-2 Combined Heat and Power Diagram – Indirect Fired

- The fuel is utilized to produce high pressure steam through a boiler (boiler efficiencies ~ 80% to 85% HHV)
- The steam is utilized for both the hospital thermal loads and to operate the CHP system
- The CHP system generates utility grade electricity by utilizing the pressure drop in the steam through a steam turbine
- Steam can be extracted from the turbine to assist in meeting the hospital thermal loads

The University of Iowa operates an indirect-fired 24.9 MW CHP plant that generates 100% of the required steam and 30% of the required electricity consumed by the campus. The system consists of 4 boilers with a 540,000 lb/hr steam generating capacity and 3 steam turbines of various sizes ranging from 3.5 to 17.4 MW. The University of Iowa Hospitals and Clinics are located on campus and are serviced by the CHP plant. More information is available at: http://www.chpcentermw.org/pdfs/Project_Profile_University_of_Iowa.pdf

2.3 Normal Operating Configuration

- CHP systems are normally installed in parallel with the electric grid (CHP does not replace the grid)
- Both the CHP and grid supply electricity to the customer
- Recycled heat from the prime mover is used for:
    - Space Heating (Steam or Hot Water Loop)
    - Space Cooling (Absorption Chiller)
    - Process Heating and/or Cooling (in hospitals this might include equipment sterilization, laundry, kitchen, general hot water needs, etc)
    - Dehumidification (Desiccant Regeneration)
- By sizing the CHP for the thermal requirements of the facility, we are most times, ensuring the highest coincidence of thermal and electric power requirements, thus providing the highest CHP system efficiency

SECTION 3: ENERGY SYSTEMS AT HOSPITALS

3.1 Conventional Energy System for Hospitals

- **Electricity:**
    - Purchased from the local utility (regulated market); purchased from the utility or competitive electric provider (deregulated market)
    - Power generated at central station power plants
    - Normally generated at approximately 30% energy efficiency (10 units of fuel in, 3 units of electric power (kW) out)
    - 70% of the fuel energy lost in the form of heat vented to the atmosphere

- **Thermal (heating):**
    - Normally generated on-site with multiple natural gas or coal-fired boilers
    - Either hot water loop or steam loop
    - Boilers generate steam or hot water at energy efficiencies between 60% to 80% (most new boilers are in the 80% range) – 10 units of fuel in, 6 to 8 units of heat out

- **Thermal (cooling):**
    - Normally use electric chillers with chilled water loop (operate on electric power supplied from the local utility)
    - May use absorption chillers (central heating/cooling plant or smaller systems located at specific buildings) in conjunction with electric chillers to offset peak electric demands.
    - Absorption chillers are either direct fired (natural gas fueled) or indirect fired utilizing hot water or steam generated from the boilers.

- **Conventional System Energy Efficiency (Grid Power + On-Site Thermal)**
    - System efficiency depends on heat/power ratio
    - Typical system efficiencies range from 40% to 55%

- **Emergency Generator Sets:**
    - A requirement at hospitals is for all “life critical” circuits to comply with the emergency generator requirements detailed in the National Fire Protection Association (NFPA) standards.
    - Many hospitals are increasing the capacity and number of emergency generator sets installed at their facility to accommodate loads well beyond those classified as “life critical”. This is to help ensure the reliability of operation of the entire facility during energy emergency situations.
    - Most emergency generator sets are diesel fueled, incapable of continuous extended operation, and normally have enough fuel on-site for hours versus days of operation.

A unique situation exists at Beloit Memorial Hospital located in Beloit, Wisconsin where a dual-fueled 3.0 MW CHP system replaced the aging diesel-fired emergency generator sets. The dual-fueled CHP system meets the 10 second start-up time requirements for emergency power generation approved by Wisconsin's Department of Health and Family Services. The system starts up operating primarily on diesel fuel. Once the system has reached full load, the fuel mixture converts to a higher concentration of natural gas enabling the CHP system to continuously operate. For more information visit: http://public.ornl.gov/mac/pdfs/factsheets/Beloit%20Hospital.pdf

3.2 Typical Hospital CHP System Configurations

- CHP system capacity for hospitals typically ranges from several hundred kilowatts to several Megawatts (usually below 10 Megawatts) depending on the size of the facility.
- Prime movers employed in hospital CHP systems normally include natural gas reciprocating engines, natural gas turbines, or steam turbines (operating on the steam generated by natural gas, oil, or coal boilers).
- Hospitals with steam loops and/or electric capacities of several megawatts often use gas turbines with heat recovery steam generators.
- Hospitals with hot water loops often times use reciprocating engines.
- Most Hospital CHP systems are sized for the thermal load requirements, with the resulting electric power generated used to first offset the power purchased from the utility grid and if/when the system is generating more electric power than required at the hospital, the excess power can be sold back to the utility.
- CHP systems do not replace the need for emergency generator sets to meet the "life critical loads" of a hospital, but they can reduce the number and capacity of the emergency generators required while increasing the total electric reliability for the hospital

Table 3-1 Emergency Generators vs. CHP Systems

Emergency Generators vs. CHP Systems

Emergency Generators	CHP System
- Minimum requirement, sized to meet "life critical loads	- Sized to meet thermal or electric loads – operates continuously to meet those loads
- Hospitals are installing larger generators to protect more and more hospital loads	- Natural gas fueled – low emissions
- Diesel fueled – high emissions & limited amount of stored fuel (hours versus days of operation)	- Does not replace emergency generator set for "life critical" loads
- Not designed or capable of continuous operation for long periods of time – rarely operates	- Reduces overall size and capacity of emergency generator sets
- Financial payback only in times of emergency	- Emergency generator sets become backup to the backup; much higher reliability
	- Good financial return

SECTION 4: CHP AND HOSPITALS – A GOOD MATCH

4.1 Key Factors for CHP Financial Attractiveness

1. **Good coincidence** between the electric and thermal loads
2. High cost differential ***(Spark Spread)*** between the purchase prices of electricity from the grid and fuel for the CHP system. Typically looking for spark spreads above $12/MMBtu
3. **Long operating hours** (greater than 3,000 hours annually)
4. High importance placed on electric power **quality and reliability**
5. Major building renovation, change-out of central heating/cooling plant, or new construction that allows comparison of cost differential with and without CHP installed (the smaller the premium the better)

In 1995, Northwest Community Hospital of Arlington Heights, Illinois, contemplated a $112 million capital investment for expansion while also facing an aging stock of boilers, chillers, and piping.[2] After reviewing several options, the hospital decided to build a new central utilities plant that included a $2.1 million incremental cost to install a 3.5 MW CHP system. The hospital expansion presented an ideal opportunity to investigate the concepts and benefits of CHP. For more information visit: http://www.chpcentermw.org/pdfs/Project_Profile_Northwest_Community_Hospital.pdf

4.1.1 Good Electric and Thermal Load Coincidence

The questions to be studied and evaluated are:

? ***Does*** the hospital ***need heat*** at the ***same time*** that it ***needs electricity***?

? ***How much heat*** (Btu/hr) does the hospital need at the ***same time*** it needs ***electricity*** (kWh)?

The ***better the match***, the ***higher the fuel use efficiency*** of the CHP system, and the more likely the ***financial payback will be favorable***.

? ***What*** should be considered in getting the ***best*** use of ***thermal energy***?

Winter	- Space Heating - Water Heating - Process Heating (laundry, sterilization, laboratory requirements, other hospital needs)
Summer	- Water Heating - Process Heating - ***Space Cooling**** - ***Space Dehumidification***** (operating rooms)
Fall / Spring	- Water Heating - Process Heating

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[2] Engle, David. "Miracle Cure for Utility-Rate Headaches." Distributed Energy – The Journal for Onsite Power Solutions. March/April 2005. 13 November 2007 <http://www.forester.net/de_0503_miracle.html>.

Intermittent Space Heating/***Cooling****

* *Utilizing* **absorption chillers** ***fueled by the exhaust thermal energy*** *from the prime mover has two benefits:*

1) ***Reduces peak electric demand and electricity charges*** *by reducing the operating time of electric chillers*

2) ***Increases the electric to thermal load coincidence*** *in the* ***summer*** *months providing* ***higher efficiencies****.*

** *Utilizing* **desiccants** ***regenerated by the exhaust thermal energy*** *from the prime mover has two similar benefits*

1) ***Reduces peak electric demand and electricity charges*** *by reducing the load on electric chillers by removing the latent heat load (condensing out the humidity)*

2) ***Increases the electric to thermal load coincidence*** *in the* ***summer*** *months by using thermal energy used to regenerate the desiccant system.*

Rule-of-Thumb: If **>** ***50%*** of the available thermal energy from the prime mover can be used on an ***annual*** basis, CHP makes good **$ense.**

- The ability to use ***as much*** of the available ***exhaust thermal energy*** from the prime mover ***throughout the entire year*** makes the ***savings*** from a CHP system ***higher*** and the ***payback quicker***.

4.1.2 Cost Differential Between Electricity and the CHP Fuel (Spark Spread)

The most common fuel utilized in Hospital CHP plants today is natural gas. For that reason, the following example for calculating Spark Spread is done assuming natural gas is the fuel of choice for the CHP system. However, if other fuels or combination of fuels are used for the CHP system, a similar approach would be used comparing the MMBtu cost of electricity to the MMBtu cost of the applicable CHP fuel.

For an ***accurate financial analysis*** of a CHP system, a model should be utilized that develops ***hour-by-hour electric and thermal load profiles*** and ***utilizes actual electric and gas rates*** applied to the hour-by-hour load profiles to determine annual savings

For *a* **first cut**, **very rough *“Rule-of-Thumb” screening*** of the viability of CHP at a hospital utilizing natural gas, the ***cost differential between electricity and* natural gas** (**“*Spark Spread*”**) can be ***estimated*** as follows:

Table 4-1 Estimating “Spark Spread”

1.	**Determine the Average Annual Electric Cost** *($/MMBtu)*:			
a.	**Sum** the total cost for electricity from the *last 12 months* of bills (including demand charge): **Total Cost**	$		
b.	**Sum** the number of kWh utilized over the *last 12 months* of bills: **Total kWh**			kWh
c.	**Divide** the Total Cost by the Total kWh: **Average Annual Electric Cost**	$		/kWh
d.	**Multiply** the **Average Annual Electric Cost** *($/kWh)* by 293 to convert to $/MMBtu: **Average Annual Electric Cost**	**$**		**/MMBTU**
2.	**Determine the Average Gas Cost** *($/MMBtu)*:			
a.	**Sum** the total cost for gas from the *last 12 months* of bills: **Total Cost**	$		
b.	**Sum** the number of Therms utilized over the *last 12 months* of bills: **Total Therms**	$		Therms
c.	**Divide** the Total Cost by the Total Therms: **Average Annual Gas Cost**	$		/Therm
d.	**Multiply** the **Average Annual Gas Cost** *($/Therms)* by 10 *(for NG)* to convert to $/MMBTU: **Average Annual Gas Cost**	**$**		**/MMBTU**
3.	**Determine** the ***“Spark Spread”***:			
a.	Average Annual Electric Cost (1.d.)	$		/MMBTU
b.	**Minus** Average Annual Gas Cost (2.d)	$		/MMBTU
	"Spark Spread"	**$**		
4.	**Is** the ***“Spark Spread”*** **>$12/MMBtu?**		**Yes / No**	

If **Yes,** than CHP has the potential for favorable payback.

If **No,** than CHP may not have the potential for a favorable payback unless there are other benefits such as increased electric reliability or a need for backup power, a desire to increase energy efficiency, governmental support or incentives, etc. that can be considered to make CHP attractive.

Operating hospital CHP systems only during peak electric demand periods of the day (approximately 10 to 12 hrs/day, 5 to 7 days/wk, 3,000+ hrs/year) can be **financially attractive.** This is due to the potential for significant differences in both electric energy and demand charges in on-peak versus off-peak periods of the day.

If the “**Spark Spread**” calculation results in a cost differential of less than $12/MMBTU, it is suggested that the “**Spark Spread**” calculation be redone utilizing on-peak electric and gas useage and costs. Many utility bills separate on-peak from off-peak useage and costs. For more information on how to calculate the true on-peak cost of purchased electricity, see Section 6.3 and Appendix D.

Table 4.2 below provides ***"Rules-of-Thumb"*** that *estimate* the conversion for a ***$12/MMBTU "Spark Spread"*** between electric and natural gas costs based on average annual fuel cost.

Table 4-2 "Rules-of-Thumb" for Acceptable Average Annual Fuel Cost

Average Annual Electric Energy Cost *(¢/kWh)*	**Maximum Acceptable Average Annual Fuel Cost** *($/MMBtu)*
≤ 4	insufficient spark spread
5	2.6
6	5.6
7	8.5
8	11
9	14
10	17

4.1.3 Long Operating Hours

The operating strategy for most CHP plants is rather simple in theory; ***operate the plant*** when you can ***generate electricity*** at a ***lower cost*** than you would pay if ***purchasing*** the ***electricity from the utility grid***, taking into consideration ***both electric energy (kWh) and electric demand charges (kW)***.

If the electric supplier has higher energy and demand rates for ***"peak"*** time, generally considered to be during normal weekday daytime business hours charges, it may be beneficial to look for the ***$12 spark spread*** during the ***"peak"*** hours and ***operate the CHP system only during those hours.***

- Often times, the facility managers will ***operate*** the CHP system only ***during the peak electric rate periods of the day***, which might be 12 to 14 hours per day. If you operate 12 hours per day, 5 days per week, the CHP annual operating hours will be approximately 3,000 hours per year.

? What constitutes Long Operating Hours?

It depends …

- Over ***6,000 hours/year***, typical in ***hospital*** applications where there is a 24/7 use for thermal energy, are normally good sites provided the $12/MMBtu differential is met.
- Between ***5,000 to 6,000 hours/year***, with ***good thermal utilization*** of the exhaust heat from the prime mover, the financial benefits may be favorable, but a ***more detailed assessment should be done***.
- Between **3,000 and *5,000 hours/year,*** payback may be sufficient enough to be financially favorable, but a ***more detailed analysis should be considered***.

- Less than ***3,000 hours/year*** will normally ***not generate enough energy cost savings*** to justify investing in a CHP system ***unless other factors*** as previously discussed ***are taken into consideration***.

4.1.4 Power Reliability and Power Quality

Power Reliability

- **Backup** and **Emergency** Power … are ***NOT*** the ***same***. Emergency power required for hospital "life critical" loads can not be replaced by a CHP system (***CHP*** will likely ***NOT meet*** the ***"quick" start requirements*** of less than 8 to 10 seconds). However, ***emergency generator sets*** are ***NOT designed*** to ***run continuously***, so lengthy electric outages can cause hospital operations to **shut down.**
- CHP can provide ***additional reliability*** to those sites that ***need emergency power*** by:
    - ***Reducing*** the number and capacity of the ***emergency generators*** by allowing non-life critical loads to be supplied by the CHP system,
    - ***Reducing*** the need for ***emergency generator starts***, because the **CHP** system provides the ***normal supply*** of power, which is in turn ***backed up*** by the ***utility grid***.
    - Further ***Reducing*** the need for ***emergency generator starts,*** because should the electric grid be de-energized (power outage), the CHP system can continue to supply power to the hospital. The emergency generator set becomes the backup to the backup, resulting in additional reliability.
    - Allowing more ***"business critical" loads*** to be ***kept on*** during utility grid ***outages*** or ***perturbations***.
    - Providing cooling ***("emergency cooling")*** if power is lost from the utility.
- If ***backup power*** is needed, **CHP** systems can generally meet those requirements, as they are ***capable of being started within minutes***.

Power Quality

- Since most of the CHP systems are paralleled to the grid, the **CHP** system and the ***utility grid synergistically support each other*** to provide better power quality. If there is a perturbation on the grid, the CHP prime mover will adjust to mitigate it; if there is a perturbation on the owners electrical system (such as from an elevator motor starting) the grid will serve to mitigate that perturbation.
- Hospitals are very susceptible to "voltage sags" or instantaneous electric grid outages. These conditions can trip large medical diagnostic equipment which results in patient delays and loss of revenue. CHP systems will ride through most voltage sags or instantaneous electric grid outages, providing better power quality, reliability and financial advantage.

Lake Forest Hospital, located in Lake Forest, Illinois reported that their 3.2 MW reciprocating engine CHP system reduced their instantaneous grid outages or voltage sags in year one of the system operation from over 50 occurrences to two. This was valued by the hospital of saving them over $640,000 in that year. More information is available at: http://public.ornl.gov/mac/pdfs/factsheets/Lake%20Forest%20Hospital%20%20Project%20Profile.pdf

Prior to the 1989 installation of a 3.8 MW CHP system at Little Company of Mary Hospital, located in Evergreen Park, Illinois, the hospital experienced approximately 30 instantaneous power outages per year affecting data processors, lab testing and other critical equipment and procedures. The CHP system eliminated nearly all instantaneous outages and frustations on behalf of the staff and patients due to the power outages. For more information visit: http://public.ornl.gov/mac/pdfs/factsheets/Lake%20Forest%20Hospital%20%20Project%20Profile.pdf

4.2 CHP Market Challenges

- ***Unstable & uncertain energy prices*** (usually results in hospitals taking a wait-and-see attitude toward energy investments of this magnitude)
- ***Lack of awareness*** of the technology concept, status, benefits, and issues
- ***Electric utility resistance*** to connecting CHP systems to their electric distribution grid
- Need for ***internal champions***: technical and financial
- Need to compete for ***capital development funds***
- ***Quantifying non energy saving benefits*** (reduced outages, emergency / disaster planning)
- Not enough ***“sizzle”*** versus wind, solar, and/or biomass

SECTION 5: CHP EQUIPMENT

5.1 Equipment Building Blocks

- ***Appendix A*** to this guidebook provides many useful characteristics and “rules of thumb” that can be utilized when considering the selection, size, and configuration of the CHP equipment. The appendix covers the ***prime movers, heat recovery, and thermally activated equipment.***
- The characteristics and “rules of thumb” for ***Generators and Grid Interconnection*** are provided in this section. This was done since the equipment and concept selections in these two areas are most scrutinized and discussed when dealing with the local electric utility and it is essential that one understands the viewpoints and preferences of the utilities versus the CHP application.

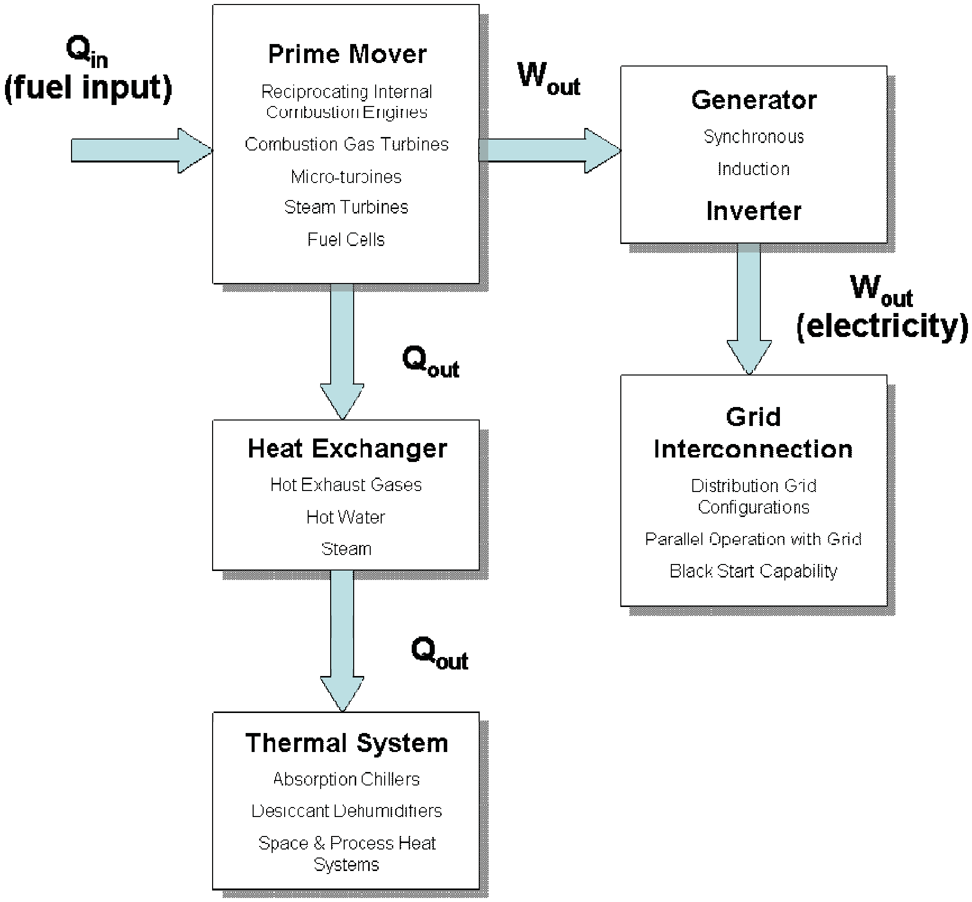

Figure 5-1 CHP Building Blocks Diagram

5.2 Prime Mover Selection

To initiate a discussion on CHP configurations for a particular installation and especially when doing a feasibility assessment, it is desirable to have a feel for ***which type of prime mover*** would be ***best suited*** for the application. There is a "***Rule-of-Thumb"*** that can be utilized to provide this first cut evaluation or feel. The approach utilizes the ***Thermal to Electric (T/P) Ratio*** that can be estimated using the hospital's utility bills. The following provides how to calculate the T/P ratio for your facility:

- **Calculate** the **T/P Ratio**

Table 5-1 Calculating the T/P Ratio

1. Determine Thermal Use			
a.	**Sum** the number of **Therms** utilized over the *last 12 months* of bills: **Total Therms**		Therms
b.	**Multiply** the **Total Therms** by 100,000 to get Thermal Btu: **Total Thermal Energy Purchased**		Btu
c.	**Multiply** the **Total Thermal Energy Purchased** by Boiler/Equipment Efficiency (typically 0.8) **Total Thermal Energy Delivered/Used**		Btu
2. Determine Electrical Use			
a.	**Sum** the number of **kWh** utilized over the *last 12 months* of bills: **Total kWh**		kWh
b.	**Multiply** the **Total kWh** by 3413 to get Btu **Total Electric**		Btu
3. Determine T/P Ratio			
	Divide Total Thermal *(Btu)* by **Total Electric** *(Btu):* **T/P Ratio**		

- ***Use*** **T/P Ratio** to find the recommended technology

Table 5-2 Recommended Prime Mover Technology Based on T/P Ratio

If **T/P =**	
0.5 to 1.5	Consider ***engines***
1 to10	Consider ***gas turbines***
3 to 20	Consider ***steam turbines***

5.3 Generators and Inverters

5.3.1 Generator Characteristics:

- CHP systems that utilize ***reciprocating engines, gas turbines, or steam turbines*** as their prime mover technologies convert the mechanical shaft power to electricity through the use of an **electric generator**.

- Generators produce AC power and operate on the principle that voltage is induced in a wire held in a rotating magnetic field

- The amount of voltage induced is proportional to the strength of the magnetic field and speed with which the wire is rotated relative to the magnetic field
- The frequency of the power depends on the generator's rotational speed (revolutions per minute – rpm)
- Generators require relays for voltage, frequency, and impedance protection

There are two types of generators utilized in CHP systems:

5.3.1.1 Synchronous Generators

- Internally (self) excited generators that do not need the grid to provide the source of excitation
- Preferred by CHP owners because the CHP system has the potential to continue to produce power through grid brownouts and blackouts (this is the same reason utilities prefer not to have synchronous generators interconnected to their grid – Without a synchronous generator, the CHP system can never feed back onto a de-energized grid)
- More complex and costly to safely interconnect to the grid (must ensure that when the grid is de-energized, the CHP system can not export power to the "downed" grid)
- Provides greater electrical power reliability to the customer – the CHP system provides backup during grid failure, the grid provides backup during CHP system failure
- To connect a synchronous generator to the grid,
    - ➢ Prime mover brings generator to correct speed (frequency matches the grid)
    - ➢ Generator then switched to the grid – frequency is locked into the grid and voltage is determined by the grid.
    - ➢ Changes in the prime mover speed only affects the power level (load following)
    - ➢ By varying the excitation current, reactive power can be drawn from or delivered to the grid (can aid in ***power factor*** correction)
- Once the generator is disconnected from the grid, the speed of the generator and engine must be tightly controlled in order to maintain proper frequency

5.3.1.2 Induction Generators

- Requires an external source of power to operate (grid provides the source of excitation)
- Preferred by Utilities because the CHP system can not operate if the grid is de-energized. This ensures that no power can be fed into a "downed" grid ensuring the safety and integrity of the grid and utility service personnel.

- Does not enhance electrical power reliability to the customer – the grid is de-energized, the CHP system shuts down.
- Simpler less costly to safely connect to the grid
- Since induction generators only draw reactive power from the grid, they can negatively affect ***power factor*** and may require adding capacitors for power factor correction

Power Factor is defined as the measure of the efficiency with which the total power delivered by a source is used for real work (real versus reactive power). All facilities (hospitals) contain a mixture of resistive and reactive (mainly inductive) loads. ***Low power factors occur when there is no correction for large inductive loads*** in a facility. Power factor is important to electric utilities and customers are required to correct for low power factors or pay higher utility bills. Adding capacitors to the facility is the most common way of correcting low power factors due to inductive loads. The effect of CHP installations with synchronous generators can have an overall positive effect on a facility's power factor.

5.3.2 Inverter Characteristics:

- CHP systems that utilize ***fuel cells and micro-turbines*** as their prime mover technology utilize inverter technology to provide utility grade electricity.
- Inverters are devices that convert DC power to utility grade AC power (used with fuel cells and micro-turbines)
- Inverter output voltage and frequency automatically synchronize with the voltage and frequency of the interconnected utility grid
- Provides improved power quality (greater flexibility in correcting/adjusting power factor
- Inverter based systems "shut down" when the grid is de-energized (outage)
- If an inverter based micro-turbine CHP system is equipped with "black start" capability, it can be restarted and operate the loads "independent" of the grid

Since CHP systems operate in parallel with the electric utility grid and must be interconnected to the grid, it is advisable to ***contact your local electric utility early in the evaluation process*** to understand their position on CHP and their rules and regulations for interconnecting to their grid. Failure to do this early in the process could result in high costs and long delays (especially if the utility is not favorable to CHP).

5.4 Grid Interconnection

Many states have either adopted or are in the process of adopting standard grid interconnection rules and procedures for DG and CHP systems that are interconnected to local utility distribution grids. These state standards are all based on the Institute of Electrical and Electronic Engineers technical interconnection protocols – IEEE 1547. You should ***check with your utility or state utility commission to see if such state standards exist in your state***. As of late 2007, see the map below regarding status in your state:

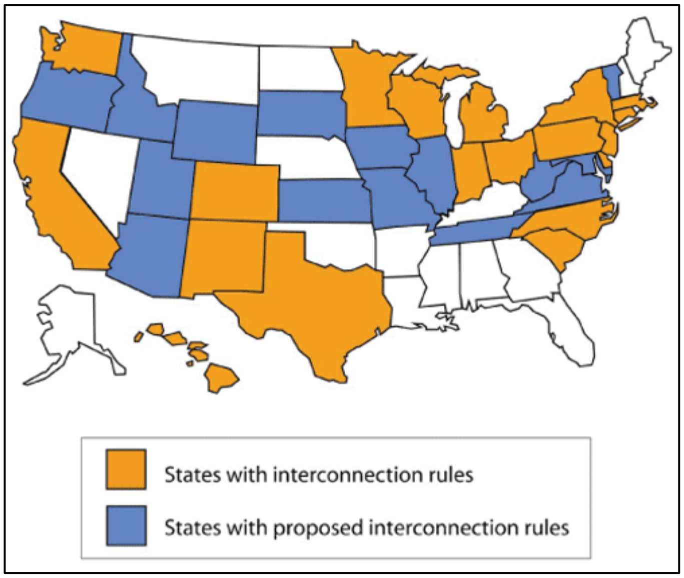

Figure 5-2 State Interconnecting Ruling Status[3]

- When connecting an on-site generator to a utility grid, the major concerns include:
    - **Safety** of customers, line workers, and general public
    - **Integrity** of the grid – quality of service
    - **Protection** of connected equipment (including the on-site generator)
    - **System Control** by the Utility

- **Power Safety**
    - An on-site generator can not feed power back onto a de-energized grid.
    - Utilities require interconnect designs that ensure this happens automatically
    - Most utilities require an additional external disconnect switch be installed that is accessible by utility personnel to disconnect and lock out the CHP system from the grid
    - Reverse power relays can be used in non-exporting installations to ensure no power flow onto the grid

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[3] "Interconnection Standards Fact Sheet." U.S. Environmental Protection Agency – Combined Heat and Power Partnership. 31 October 2007. <http://www.epa.gov/chp/state-policy/interconnection_fs.html>.

- **Grid Integrity**
  - An onsite generator can not degrade the quality of power supplied by the utility as measured by:
    - Voltage and frequency stability
    - Power factor
    - Harmonic content
  - Power supplied by CHP systems with synchronous generators normally exceed the power quality from the grid

- **Grid Operations & Dispatch**
  - Any CHP installation must be reviewed with the local utility to ensure that the utility's ability to manage grid operations is not compromised
  - Utilities require the right to request that a CHP system be isolated from the utility grid during periods of emergency or for grid safety.

5.4.1 Distribution Grid Configurations

The local electric utility ***distribution grid*** is the most common point of interconnection for CHP in hospital applications. The distribution grid is typically a lower voltage system (< 69 kV) that ties the hospital to the larger, higher voltage transmission system. The tie in between the transmission and distribution grids occurs at the utility substations. There are nominally two types of distribution systems applicable to CHP systems:

5.4.1.1 Radial Systems:

- This is the most common type of distribution grid system
- The radial system has a ***single path for power flow*** to all customers on a single radial line / feed. The system is made up of multiple radial lines.
- If a fault occurs in a radial feed, only the customers on that feed are affected. By using sectionalizing switches, the utility can often isolate the fault and keep some portion of the radial feed operating during repairs.
- The radial system is the easiest and least costly to interconnect a CHP system. Most utilities prefer CHP systems be installed on radial distribution systems
- Interconnection must assure that the CHP system will not feed power onto a de-energized grid.

5.4.1.2 Looped and Network Systems:

- These systems provide ***multiple paths for power flow*** to all customers on the system. If a fault occurs on these type of systems, the utility has the ability to keep more customers on-line while isolating and repairing the fault (due to multiple paths for power flow).
- The network systems are the most complex and are mainly found in large metropolitan areas.
- Utilities are more concerned about CHP systems interconnected to network systems due to the complexity of the grid.
- It is more costly and difficult to interconnect to the looped / network grids. Many utilities will prohibit interconnection to such grids. However, successful and safe interconnection to network grids **can be done.** Examples exist in New York, Chicago, San Francisco, and Boston, just to mention a few.

- Interconnection must assure that the CHP system will not feed power onto a de-energized grid.

5.4.2 Parallel Operation with the Utility Grid

Parallel operation is the preferred way of interconnecting and operating with the grid (provides the most flexibility). Both the on-site generator and the utility grid power the facility simultaneously. The CHP system can operate in either the Export or Non- Export mode.

5.4.2.1 Export Mode

- Provides the flexibility to purchase supplemental power from or sell excess power to the grid
- Most complex and costly to interconnect. Must assure the CHP system will not feed power onto a de-energized grid either by:
    - Utilizing induction generator (CHP shuts down when grid shuts down)
    - Circuitry to shut down the CHP system when it senses the grid shuts down
    - Circuitry to ensure transfer of CHP system off the grid and onto disconnected loads (now running independent of the grid – requires black start capability, synchronous generator, or inverter based micro-turbine).
- Flexibility in CHP system sizing (produce more electricity than required by the site, sell to the grid – produce less electricity than required by the site, purchase from the utility)
- Full advantage of the increased reliability of the electric system will not be captured since the CHP system is likely to stop generating and supplying power to the load if the grid is de-energized (blackouts and brownouts)

5.4.2.2 Non-Export Mode

- CHP system configured with reverse current relays that prohibit the CHP system from exporting power to the grid at any time (whether the grid is operating or de-energized).
- CHP and grid still simultaneously feed the loads. CHP system sized to always feed the building load, and the grid provides whatever power is beyond the capacity of the CHP system
- Requires the CHP system to operate in the electric load following mode or to size the system to never produce more than the required electric load.
- Should the CHP system generate more power than the load requires, the CHP system will be automatically shut down
- Should the grid be de-energized, the CHP system can continue to supply power to the load (uninterrupted and paralleled to the grid) providing the capacity of the CHP system is capable of handling the entire load and the CHP system includes a synchronous generator.

- Should the CHP system capacity not be large enough to handle the entire load when the grid goes “down”, loads can be shed fast enough to allow the CHP system to continue powering critical loads.
- Overall system reliability is increased in that:
    - CHP system backs up the grid (should the grid go down)
    - Grid backs up the CHP system (should the CHP system go down)
- An ongoing concern and debate is the fact that some utilities refuse to acknowledge the Non-Export mode of operation (reverse current relays) and still require expensive circuitry when utilizing synchronous generators and paralleling to the grid

5.4.3 Black Start Capability

Should the grid be de-energized and the CHP system also fails, the CHP system can be restarted without the grid if it has black start capability. The engines can be started with the use of a battery (similar to starting your car engines). Once up to speed, you must connect the system through a “generator breaker” to a load that allows you to supply power to the CHP parasitic loads (if you do not do this, the engines will overheat and shut down). The second step is to then engage the “tie breaker” that places the full load on the CHP system. To operate in this mode, the CHP system must be producing the electric power with a synchronous generator or inverter system.

SECTION 6: FEASIBILITY EVALUATION

Implementing a CHP system requires significant time, effort, and investment. With approximately 175 hospitals in the U.S. presently utilizing CHP systems with a generating capacity of over 686 MW of electricity on-site and recycling millions of Btus/hr of thermal energy for use within the hospital, the CHP concept is certainly one that has been proven to be technically and financially sound.

However, we have stated that CHP is not right for every hospital application in every sector of the country. There are many variables that must be considered when evaluating an investment that could easily reach several millions of dollars. These variables include capital costs, operating and maintenance costs, utility (electric and gas) rates, interconnection costs, environmental standards, energy load requirements corrected for local weather conditions, and regulatory requirements, just to mention a few.

Therefore, it is prudent to ***evaluate*** the ***technical and financial*** feasibility of a CHP system at your facility using a ***four step*** evaluation process:

- Level 1: Preliminary Analysis
- Level 2: Site Screening Analysis
- Level 3: Conceptual Design and Financial Analysis
- Level 4: Detailed Design and Engineering Analysis

6.1 Collect Site Data

- The first step in determining the feasibility of CHP at your hospital is to collect the appropriate data that can be utilized to conduct any level analysis.
- Minimum site data collection recommended includes
  - 12 months of electric and fuel bills (preferably the last full year of bills)
  - The operating hours of the facility
  - Existing & planned heating and cooling requirements (both space and process)
  - Number of electric feeds and meters to the facility

Appendix B provides a detailed ***Site Data Collection Sheet*** that can be utilized when visiting and collecting data for a potential CHP site. Collecting as much of the information requested in the data sheet will minimize the need for additional site visits and allow more detailed analyses to be performed. An ***electronic version*** of the ***Site Data Collection Sheet*** is available at:

www.CHPCenterMW.org/html/10_library.html#tools

6.2 Level 1: Preliminary Analysis

Provides for quick application of a few “rules-of-thumb” to provide a preliminary indication of whether CHP might make sense at your facility and to help make the decision to further investigate its viability through more detailed Level analyses. The approach can vary from a simple survey (a method developed by the US EPA) to a very quick estimate of the “spark spread” (differential between the cost of electricity from the grid and the cost of the CHP fuel).

- ***US EPA CHP Partnership Program Survey:*** The following is a simple survey (set of 12 questions). It is designed to provide a very simple indication whether pursuing more accurate evaluations is justified.

Is My Facility a Good Candidate for CHP?

(Survey developed by the U.S. EPA CHP Partnership)

STEP 1

Please check the boxes that apply to you:

☐ Do you pay more than $.06/ kWh on average for electricity (including generation, transmission and distribution)?

☐ Are you concerned about the impact of current or future energy costs on your business?

☐ Is your facility located in a deregulated electricity market?

☐ Are you concerned about power reliability? Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?

☐ Does your facility operate for more than 5000 hours/ year?

☐ Do you have thermal loads throughout the year (including steam, hot water, chilled water, hot air, etc.)?

☐ Does your facility have an existing central plant?

☐ Do you expect to replace, upgrade or retrofit central plant equipment within the next 3-5 years?

☐ Do you anticipate a facility expansion or new construction project within the next 3-5 years?

☐ Have you already implemented energy efficiency measures and still have high energy costs?

☐ Are you interested in reducing your facility's impact on the environment?

☐ Do you have access to on-site or nearby biomass resources (i.e. landfill gas, farm manure, food processing waste, etc.?

STEP 2

If you have checked the boxes for 3 or more of the questions above, your facility may be a good candidate for CHP.

The next step in assessing the potential of an investment in CHP is to have a Level 2 Site Screening Analysis or Level 3 Conceptual Design and Financial Analysis performed to estimate the preliminary return on investment. The U.S. DOE sponsored ***CHP Regional Application Centers*** or the ***US EPA CHP Partnership Program*** can be contacted for Level 2 or Level 3 analysis assistance.

Appendix C provides a listing of the 8 CHP Regional Application Centers and points of contact

- ***Spark Spread Approach:*** A second approach to determining a quick indication of the viability of CHP is to estimate the "Spark Spread" per table 2.2 located in section 2.6.2 of this guidebook. If the estimated spark spread is approximately $12/MMBtu or greater **(either for on-peak electric periods or for both on-peak and off-peak periods)** , you might want to proceed with a Level 2 or Level 3 analysis

6.3 Level 2 Site Screening Analysis

- This level analysis is normally based on annual or monthly average utility costs, makes several assumptions on load profiles and equipment size, has no correction for weather conditions, but does provide an estimate of savings, installation cost, and simple payback. The accuracy of the stated results of a Level 1 feasibility analysis might be in the 30% range, but is intended to simply provide another more detailed indication as to whether further analysis should be undertaken.

- ***Appendix D*** provides a sample Level 2 analysis approach referred to as the ***CHP Tool Kit***. It is only one of several available Level 2 Site Screening Analysis tools. The following steps are utilized in the tool kit:

  - ➢ Calculate the true cost of electricity purchased from the grid
  - ➢ Estimate the cost of generating electricity with the CHP system providing credit for the amount of recycled energy utilized
  - ➢ Estimate the savings (if any)
  - ➢ Estimate the capital cost of the CHP equipment
  - ➢ Perform the economic calculation (simple payback)

6.4 Level 3 Conceptual Design and Financial Analysis

- The purpose of this level analysis is to determine if CHP is a viable option, both financially and technically at your facility

- A Level 3 analysis uses a detailed engineering and financial model. It is highly recommended that the model use hourly load profiles (at a minimum monthly profiles). If hourly load data are not available from the site, the load profiles can be developed by the computer program.

- Equipment sizing and conceptual one-line design diagrams are included in a Level 3 analysis

- A Level 3 analysis should be conducted by a qualified CHP analyst. When requesting such an evaluation, the hospital facility manager should inquire of the evaluator (consultant, engineering company, manufacturer, or university):
    - Experience level of performing CHP evaluations
    - References from other clients on their analysis techniques and performance
    - A detailed understanding of the type model and/or spread sheet analysis utilized (type load profiles, weather correction factors, assumptions on equipment costs, assumptions on interconnect, permitting, and operational & maintenance costs (to mention a few).

- Although a Level 3 analysis does not substitute for detailed design and engineering, it can & should be utilized to obtain financial commitment for capital funds to initiate the first stages of the project.

- The following is a non-inclusive list of software tools available for conducting a detailed economic evaluation of CHP systems:

Table 6-1 CHP Software Evaluation Tools[4]

Software	Cost	URL	Primary Use
BCHP Screening Tool	FREE	http://www.ornl.gov/sci/engineering_science_technology/cooling_heating_power/success_analysis_BCHP.htm	Commercial Buildings
Building Energy Analyzer	$780	http://www.interenergysoftware.com/BEA/BEAAbout.htm	Commercial Applications (some Industrial)
Cogen Ready Reckoner	FREE	http://www.eere.energy.gov/de/chp/chp_applications/feasibility_analysis.html	Industrial Applications
D-Gen Pro	$675	http://www.interenergysoftware.com/DGP/DGPAbout.htm	CHP Heating Applications in Commercial Buildings
GT Pro	$7,000	www.thermoflow.com	Industrial Gas Turbine Applications
Heatmap CHP	$4,000	http://www.energy.wsu.edu/ftp-ep/software/heatmap/Heatmap_CHP_5_flyer.pdf	CHP and District Heating and Cooling Applications
Plant Design Expert (PDE)	$3,000	www.thermoflow.com	Industrial Applications using Gas Turbines
RECIPRO	$1,500	www.thermoflow.com	Small Commercial / Industrial
SOAPP-CT .25	$7,500	http://www.soapp.com/soapp/dg/	Industrial Gas Turbine Applications

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[4] Hudson, Randy. "Survey of DER/CHP Survey." *Midwest CHP Application Center*. PowerPoint (February 2003). 16 November 2007. <http://www.chpcentermw.org/pdfs/20040206_ORNL_der_chp_software_survey_HudsonR.pdf>.

For more detail on the software packages identified in Table 6-1, visit the Midwest CHP Application Website Center: www.chpcentermw.org/10-00_tools.html

6.5 Level 4 Detailed Design and Engineering Analysis

- The purpose of this level analysis is to develop and design the material necessary to build or request bids on building the CHP system. The analysis would include:
  - Detailed engineering design and installation / construction drawings
  - Procurement specifications
  - Detailed cost estimates
  - Project implementation requirements

SECTION 7: HOSPITAL ENERGY LOADS

Hospitals are energy intensive facilities with long operating hours. Hospitals in the U.S. spend on average, approximately $1.67 per square foot on electricity and approximately 48 cents per square foot on natural gas annually.[5]

In this section, we took one of the Level 3 simulation tools (Building Load Analyzer) and generated energy load data for a 240,000 square foot full service hospital (average size U.S. hospital[6]). The information is shown for the same hospital located in four different major regions of the country with different climate conditions (Chicago, New York, Miami, and Los Angeles). The intent of providing this data is to allow the reader to better understand where and how energy is utilized in hospitals.

This information is not intended to substitute for your specific facility's energy data. It is important that any CHP and/or energy analysis for your facility be based on the energy characteristics and data obtained from your facility. See Appendix B for a Site Walkthrough Data Collection guide when collecting data at your facility

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[5] "Managing Energy Costs in the Hospital/Healthcare Sector Managing Energy Costs in the Hospital/Healthcare Sectors." Florida Power and Light Company. 12 November 2007. <http://www.fpl.com/business/savings/energy_advisor/PDF/CEA_Hospitals.pdf>

[6] "Table B1. Summary Table: Total and Means of Floorspace, Number of Workers, and Hours of Operation for Non-Mall Buildings, 2003." Energy Information Administration – Official Energy Statistics from the U.S. Government. 14 November 2007. <http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set1/2003html/b1.html>

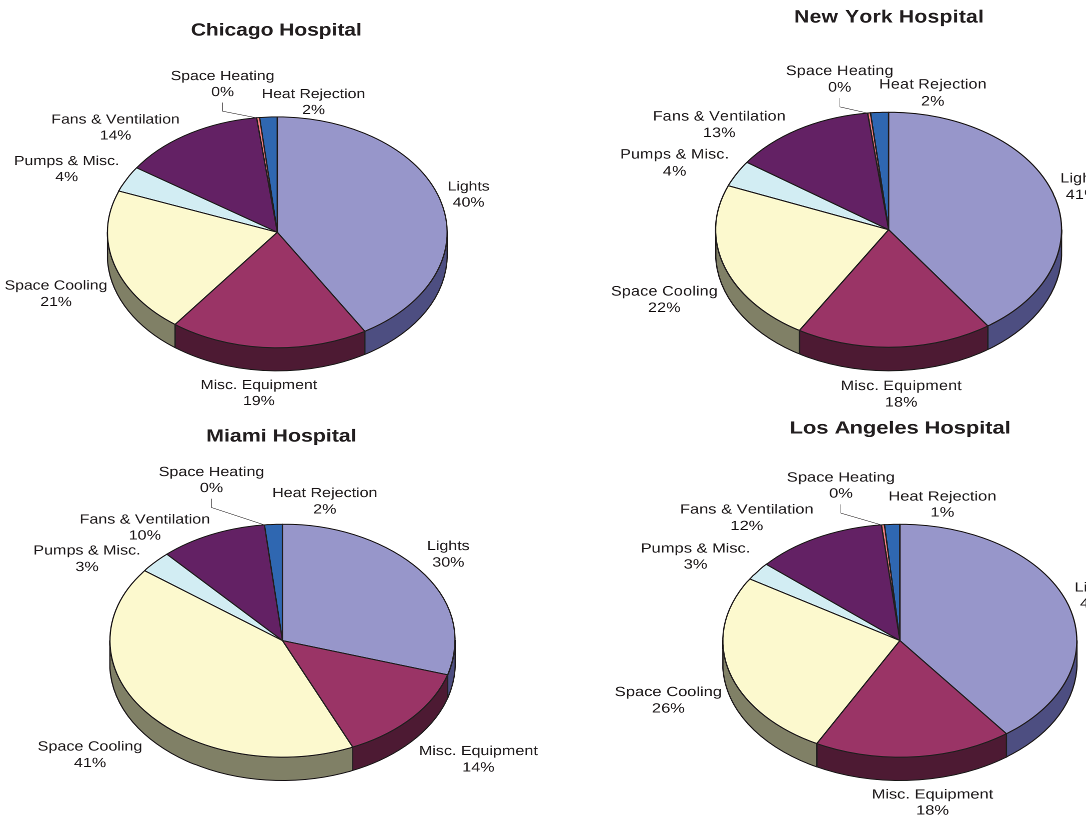


Figure 7-1 Electric Energy Distribution in Hospitals

(Chicago, New York, Miami, Los Angeles)

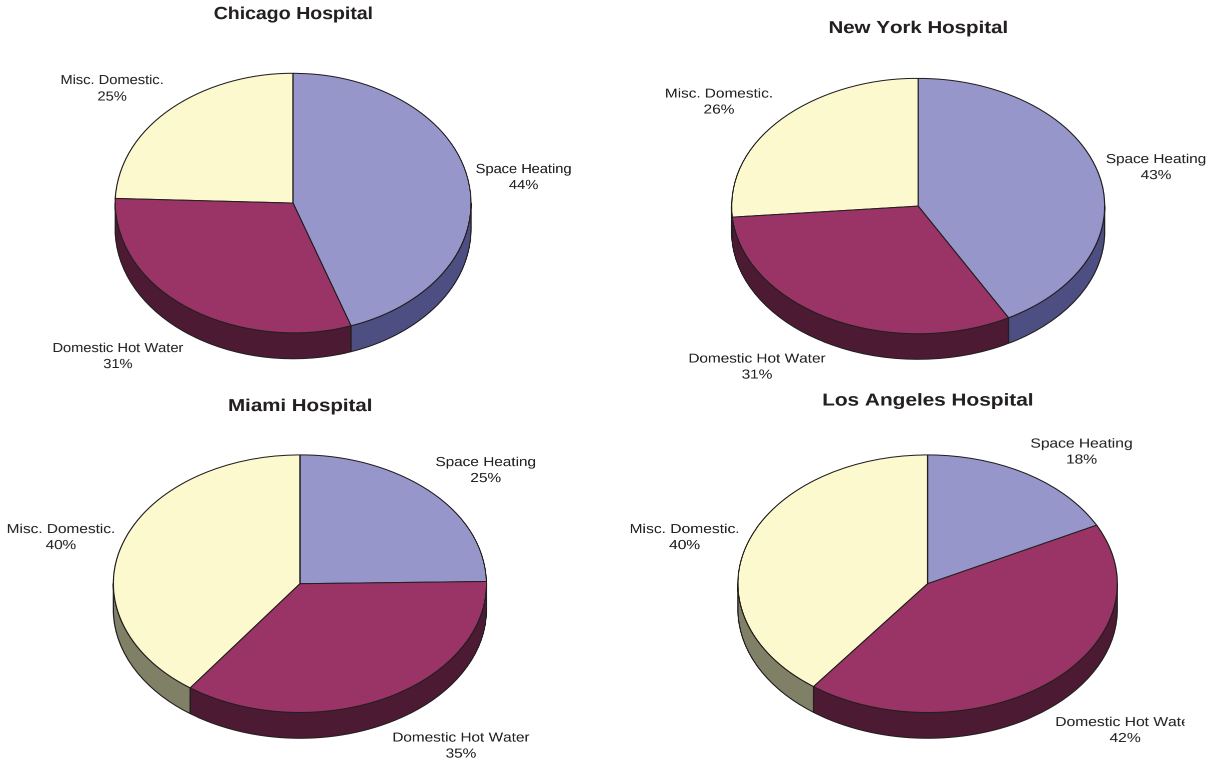


Figure 7-2 Natural Gas Distribution in Hospitals

(Chicago, New York, Miami, Los Angeles)

In order to better manage a hospital's energy costs, it helps to understand how a hospital is charged for those costs. Most utilities charge for the natural gas based on the amount of energy (therms) delivered to the facility. Electricity, however can be charged on two measures: consumption (kWh) and demand (kW). The consumption portion of the bill is based on the amount of electricity (kWh) consumed. The demand portion is the peak demand (kW) occurring within the month or for some utilities, during the previous 12 months. Demand charges can range from a few dollars per kilowatt-month to upwards of $20 per kilowatt-month. In evaluating your facility, it is important to understand:

- How energy is utilized in your facility (above charts)
- The energy consumption within the facility (seasonal and peak demands)
- How you are being billed by the utilities (gas and electric)

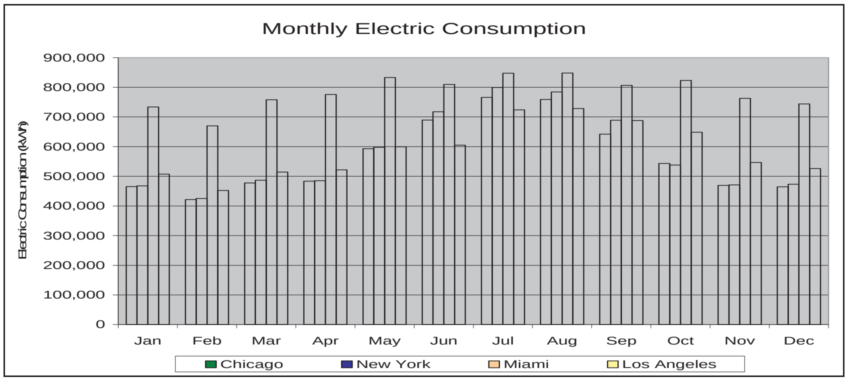


Figure 7-3 Monthly Electric Consumption – 240,000 SF Hospital

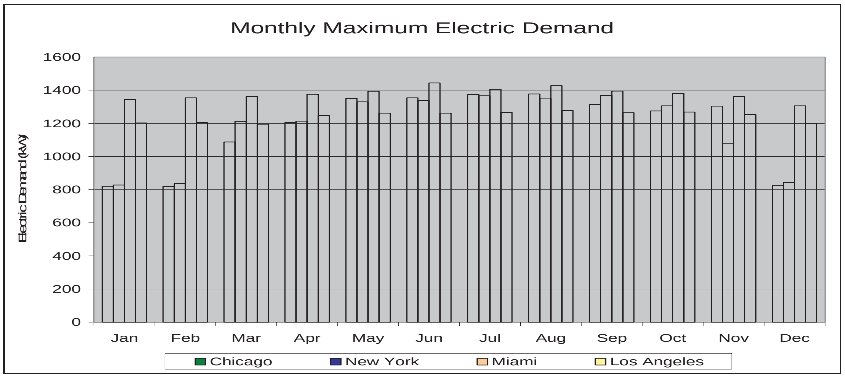


Figure 7-4 Monthly Maximum Electric Demand – 240,000 SF Hospital

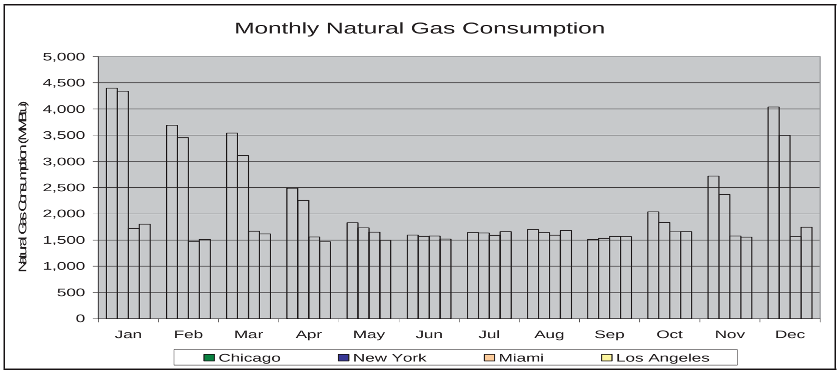


Figure 7-5 Monthly Natural Gas Consumption – 240,000 SF Hospital

SECTION 8: HOSPITAL CHP INSTALLATIONS

The database utilized to identify hospitals in the U.S. that have active CHP systems is the U.S. DOE CHP database located at http://www.eea-inc.com/chpdata/index.html._ It is difficult to account for all hospitals with CHP, since the data base provides separate data categories for colleges/universities and hospitals. The data does not distinguish which of the universities with CHP have teaching hospitals included on their campus and are therefore serviced by the University CHP system.

The purpose of this section is to inform you that CHP installations in the healthcare industry are not a new and novel idea. Utilizing the U.S. DOE CHP database, one can see that:

- 175 hospitals have stand alone CHP systems with a generating capacity of 686 MW. The average system size is 3,924 kW and the median is 1,050 kW. These systems are located in 30 states.

- 213 colleges and universities have CHP systems installed with a total generating capacity of 2,612 MW. At least several dozen of these campuses include hospitals serviced by the CHP system. These systems are located in 41 states. The average system size is 12,264 kW and the median system size is 3,100 kW.

The University of Illinois at Chicago’s West Campus operates a 21.0 MW natural gas-fired combustion turbine CHP system that supplies electricity and high pressure steam to the university’s hospital and outpatient buildings, School of Nursing, School of Dentistry, and School of Pharmacy. The CHP plant also supplies high pressure steam to the neighboring Rush Presbyterian Hospital and Cook County Hospital. More information is available at: http://public.ornl.gov/mac/pdfs/factsheets/UIC%20West%20Campus%20-%20Project%20Profile.pdf

- Finally, nursing homes are another segment of the healthcare industry that are good applications for CHP systems. The database shows that 114 nursing homes, located within 11 states, include CHP systems with a total capacity of 22.4 MW. The average system size is 197 kW and the median system size is 75 kW.

Presbyterian Homes, a nursing home located in Evanston, Illinois, lost power for nine hours during an ice storm in the winter of 1998. Both of the facility’s electric utility feeds were knocked out and over 600 senior residents were without electricity. This event coupled with the premise of avoiding such future outages prompted Presbyterian Homes to install a 2.1 MW natural-gas fired CHP system in January, 2001. More information is available at: http://public.ornl.gov/mac/pdfs/factsheets/Presbyterian%20Homes%20-%20Project%20Profile.pdf

In 2004, the Sisters of Notre Dame installed two 75 kW CHP systems at their Notre Dame Long Term Care & Assisted Living Centers facilities, located in Worcester, Massachusetts. The two CHP systems were installed at $125,000 a piece and experienced simple paybacks within 3 years. More information is available at: http://www.chpcentermw.org/rac_profiles/Northeast/NotreDameLongTermCareCHPprofile.pdf

Appendix E provides a list of the installed CHP systems located in hospitals by prime mover type, fuel type, size of system, and year of installation. The figures below provide a snapshot of the types of CHP installations that are installed in U.S. hospitals. Clearly, natural-gas fired reciprocating engine CHP systems are the preferred fuel and prime mover among hospitals.

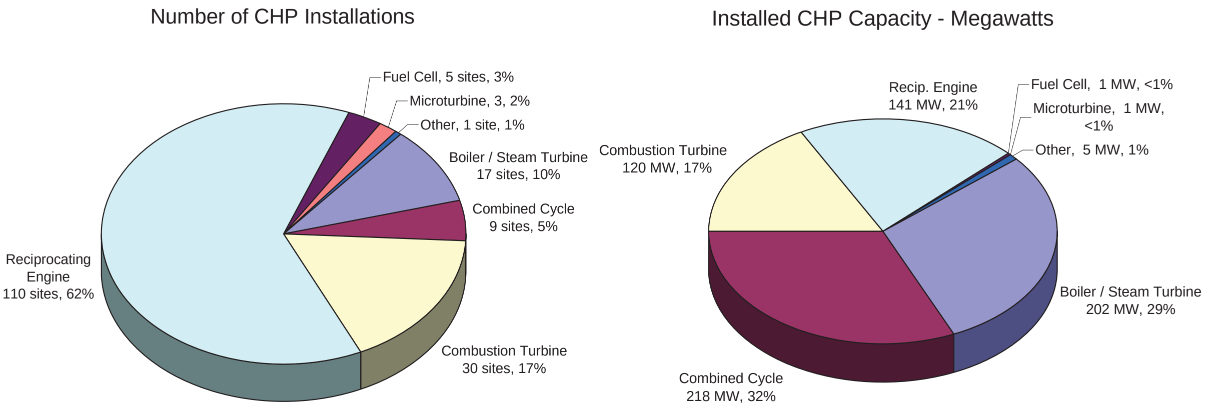


Figure 8-1 Number of CHP Installations and Installed Capacity (Megawatts) in U.S. Hospitals by Prime Mover Type

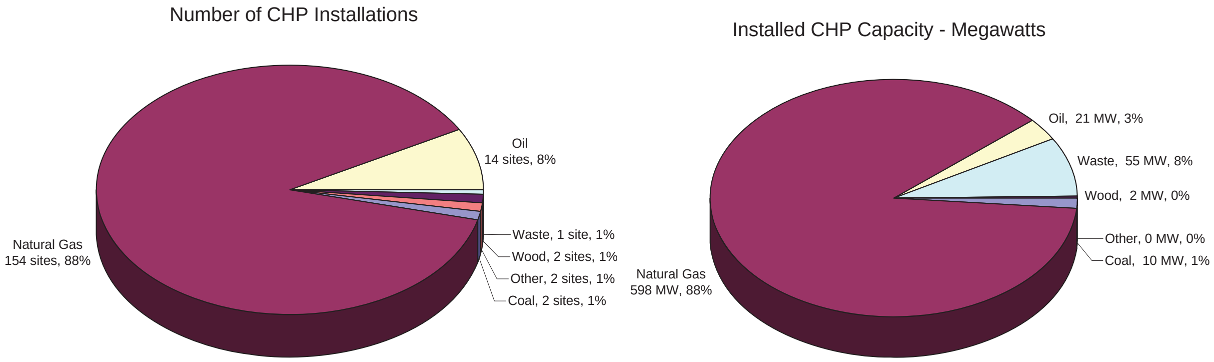
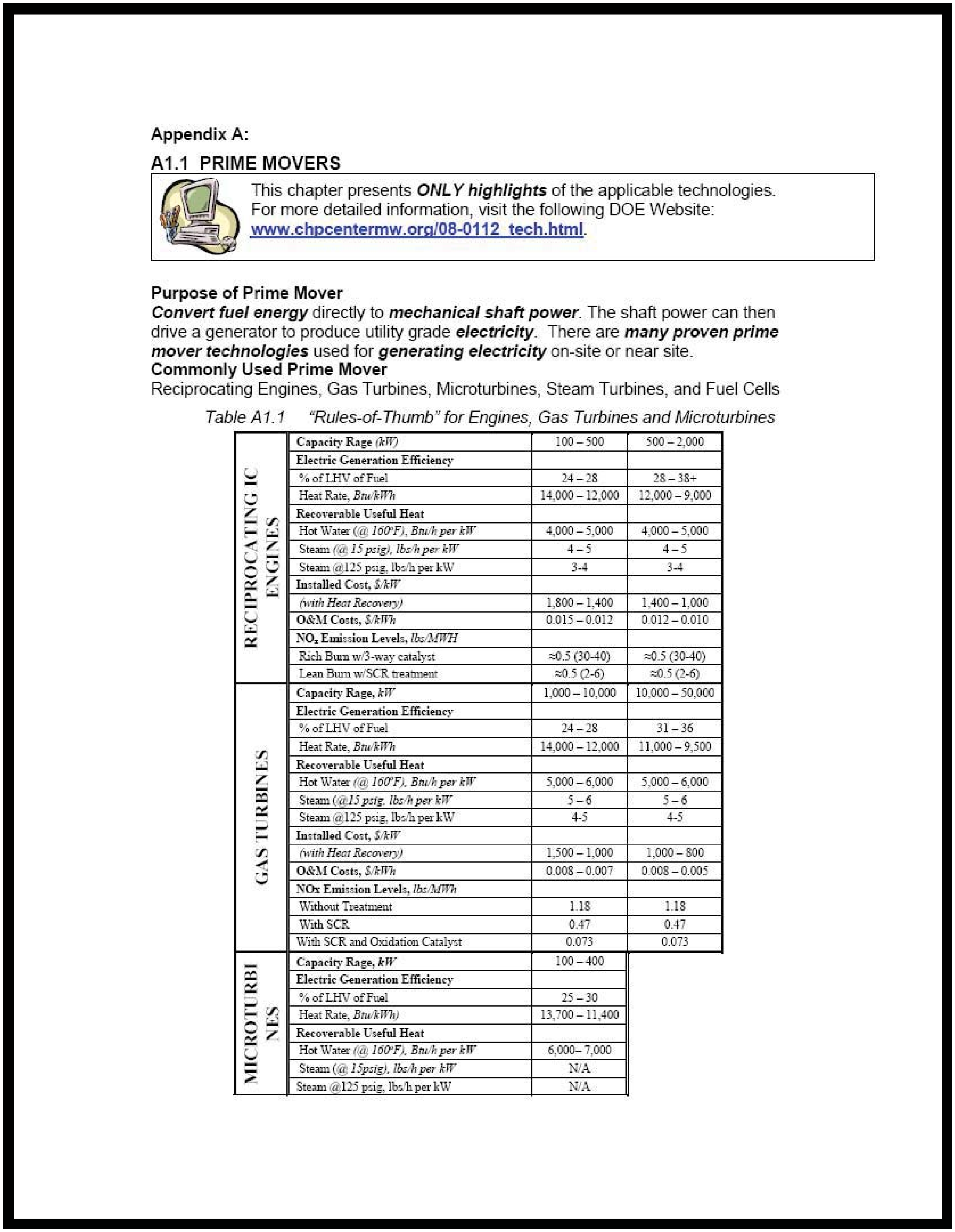


Figure 8-2 Number of CHP Installations and Installed Capacity (Megawatts) in U.S. Hospitals by Fuel Type

APPENDICES

Appendix A: CHP Resource Guide Reference



Appendix A:

A1.1 PRIME MOVERS

This chapter presents ***ONLY highlights*** of the applicable technologies. For more detailed information, visit the following DOE Website: www.chpcentermw.org/08-0112_tech.html.

Purpose of Prime Mover

Convert fuel energy directly to ***mechanical shaft power***. The shaft power can then drive a generator to produce utility grade ***electricity***. There are ***many proven prime mover technologies*** used for ***generating electricity*** on-site or near site.

Commonly Used Prime Mover

Reciprocating Engines, Gas Turbines, Microturbines, Steam Turbines, and Fuel Cells

Table A1.1 "Rules-of-Thumb" for Engines, Gas Turbines and Microturbines

RECIPROCATING IC ENGINES	**Capacity Rage** *(kW)*	100 – 500	500 – 2,000
	Electric Generation Efficiency		
	% of LHV of Fuel	24 – 28	28 – 38+
	Heat Rate, *Btu/kWh*	14,000 – 12,000	12,000 – 9,000
	Recoverable Useful Heat		
	Hot Water *(@ 160°F), Btu/h per kW*	4,000 – 5,000	4,000 – 5,000
	Steam *(@ 15 psig), lbs/h per kW*	4 – 5	4 – 5
	Steam @125 psig, lbs/h per kW	3-4	3-4
	Installed Cost, *$/kW*		
	(with Heat Recovery)	1,800 – 1,400	1,400 – 1,000
	O&M Costs, *$/kWh*	0.015 – 0.012	0.012 – 0.010
	NO$_x$ Emission Levels, *lbs/MWH*		
	Rich Burn w/3-way catalyst	≈0.5 (30-40)	≈0.5 (30-40)
	Lean Burn w/SCR treatment	≈0.5 (2-6)	≈0.5 (2-6)
GAS TURBINES	**Capacity Rage,** *kW*	1,000 – 10,000	10,000 – 50,000
	Electric Generation Efficiency		
	% of LHV of Fuel	24 – 28	31 – 36
	Heat Rate, *Btu/kWh*	14,000 – 12,000	11,000 – 9,500
	Recoverable Useful Heat		
	Hot Water *(@ 160°F), Btu/h per kW*	5,000 – 6,000	5,000 – 6,000
	Steam *(@15 psig, lbs/h per kW*	5 – 6	5 – 6
	Steam @125 psig, lbs/h per kW	4-5	4-5
	Installed Cost, *$/kW*		
	(with Heat Recovery)	1,500 – 1,000	1,000 – 800
	O&M Costs, *$/kWh*	0.008 – 0.007	0.008 – 0.005
	NOx Emission Levels, *lbs/MWh*		
	Without Treatment	1.18	1.18
	With SCR	0.47	0.47
	With SCR and Oxidation Catalyst	0.073	0.073
MICROTURBINES	**Capacity Rage,** *kW*	100 – 400	
	Electric Generation Efficiency		
	% of LHV of Fuel	25 – 30	
	Heat Rate, *Btu/kWh)*	13,700 – 11,400	
	Recoverable Useful Heat		
	Hot Water *(@ 160°F), Btu/h per kW*	6,000– 7,000	
	Steam *(@ 15psig), lbs/h per kW*	N/A	
	Steam @125 psig, lbs/h per kW	N/A	

	Installed Cost, *$/kW*	
	(with Heat Recovery)	2,000 – 1,000
	O&M Costs, *$/kWh*	0.015 – 0.01
	NO_x Emission Levels, *lbs/MWh*	< 0.49

Table A1.2 “Rules-of-Thumb” for Steam Turbines

CONDENSING	Electric Generation Efficiency, %	30-40
	Steam Exhaust Pressure	Below atmosheric
	Steam Required, lb_m/hr per kW	7-10
	Installed Cost*, *$/kW*	$500-$700
	O&M Costs, *$/kWh*	0.0015-0.0035
	NO_x Emission Levels, *lbs/MWH*	Not Applicable
BACKPRESSURE	Electric Generation Efficiency, %	15-35
	Steam Exhaust Pressure	At or above atmospheric
	Steam Required, lb_m/hr per kW	See Figure 2-6
	Installed Cost*, *$/kW*	$300-$400
	O&M Costs, *$/kWh*	0.0015-0.0035
	NO_x Emission Levels, *lbs/MWH*	Not Applicable

* Without boiler or heat recovery steam generator (HRGS)

Table A1.3 “Rules-of -Thumb” for Fuel Cells

Proton Exchange Membrane (PEMFC)	Electric Generation Efficiency, %	33-45
	Operating Temperature, °F	175
	Heat Utilization	Hot Water
	Availability	Demonstration
Phosphoric Acid (PAFC)	Electric Generation Efficiency, %	38-45
	Operating Temperature, °F	480
	Heat Utilization	Hot Water
	Availability	Commercial >$3,500/kW
Molten Carbonate (MCFC)	Electric Generation Efficiency, %	50-60
	Operating Temperature, °F	1,200
	Heat Utilization	Medium to High-Pressure Steam
	Availability	Demonstration
Solid Oxide (SOFC)	Electric Generation Efficiency, %	40-45
	Operating Temperature, °F	1,800
	Heat Utilization	High-Pressure Steam
	Availability	Demonstration

A1.1.1 Reciprocating Internal Combustion Engines (IC Engines)

One of the ***most common*** technologies used for power generation. These engines are the ***largest segment*** of the market for CHP systems < ***5 MW***.

Sizes

Capacities range from about ***5 kW*** **to** ***10 MW***.

Characteristics

- ***Better at load following and part load operation*** than most of the other prime mover technologies
- Can be ***fueled*** by ***natural gas, propane, diesel*** or ***gasoline***
- CHP systems ***most commonly*** use ***natural gas*** because it results in ***significantly lower emissions*** than those fueled by diesel or gasoline

> Most **backup** and **emergency** generator sets using IC engines are fueled with ***diesel*** or ***gasoline*** and are similar to ***automotive designs.*** They are generally ***NOT*** designed for **continuous** operation nor are they set up to ***recover thermal energy*** from the engine exhaust streams.

- CHP systems generally use ***industrial grade*** engines because these are designed for ***continuous*** (24/7) ***operation***
- Two types of ignition systems: **spark** and **compression**. **Spark** ignited engines can use natural gas, propane or gasoline as fuel and **compression** ignited engines can only use diesel fuel or a combination of diesel and natural gas.
- Designed to operate in one of the two modes:
  1) **Rich-burn** operation uses ***higher*** fuel-to-air ratios than the stoichiometric ratio (defined as the fuel-to-air ratio theoretically required for complete combustion of the fuel).
     - More common for engine capacities ***<500 kW*** (670 hp)
     - Normally produce **NO_x** emissions in the range of ***30 to 50 lbs per MWh*** (or 625 to 1,060 ppm @15% oxygen) with ***no exhaust treatment***. Therefore, most installations using **rich burn** engines will ***REQUIRE*** a ***3-way catalyst*** to treat the engine exhaust. This can reduce NO_x emissions to as low as ***0.5 lb/MWh (~10 ppm @15% oxygen)***, (but adds approximately ***$50/kW*** to the engine's installed cost.
  2) **Lean-burn** operation uses ***lower*** fuel-to-air ratios than the stoichiometric ratio.
     - The **energy efficiency** is ***slightly higher*** than that for rich-burn engines.
     - Normally produce **NO_x** emissions in the range of ***2 to 6 lbs per MWh*** (42 to 127 ppm @ 15% oxygen) with ***no exhaust treatment***
     - Most installations using **lean-burn** engines do **NOT** ***require exhaust treatment***. ***If*** exhaust treatment is needed to reduce **NOx** emissions, the ***most common*** treatment is the use of ***Selective Catalytic Reduction (SCR)***. Use of an SCR is **very expensive**. It adds approximately ***$100/kW***

to the engine installed cost and **\$1400/ton of NO_x removed** to the operating cost.

> In order to put the emissions of engines in some perspective, it is important to note that the ***average*** for all ***central power plant*** in the U.S. produces approximately ***3 lbs of NOx per MWh***. *(Per e-Grid data for the year 2000)*

- The **fuel utilization efficiency** of IC engines for producing electricity ranges from approximately ***25% to 40%*** on the basis of lower heating value (LHV). Usable ***thermal energy*** from these prime movers is normally ***recovered*** from two streams:
    1. ***Engine exhaust gases***, and
    2. ***Engine-jacket coolant***.
- About15% of the exhaust heat is not recoverable to allow the exhaust to maintain a high enough temperature to avoid condensation.
- ***Distribution of energy*** for a typical engine is shown in *Figure A1-1*

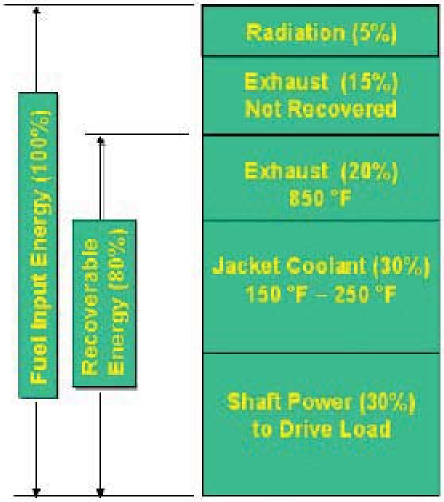


Figure A1-1 Energy Distributions for a Typical Reciprocating Engine

A1.1.2 Combustion Turbines (a.k.a. Gas Turbines)

Likely the ***second*** most common technology used for power generation. They are generally used for ***larger systems*** *(>4 MW)* or where a lot of ***high-pressure steam is required per unit of electric power.***

Sizes

Capacities range from approximately ***500 kW to 100s of MW***, and compete well with reciprocating engines in CHP applications where the capacity is ***> several MW***. The ***typical*** capacity range of combustion turbines for CHP applications is from ***several MW to 10s of MW***.

Characteristics

- ***Best suited*** for ***base-load*** applications; can also handle ***peaking*** and ***load following*** applications as well
- Can be fueled by ***high-pressure natural gas*** or ***liquid fuel***
- Combustion turbines are much ***more compact*** and ***lighter*** than similar capacity reciprocating engines
- **NO$_x$** emissions from combustion turbines are ***lower*** than those from IC engines
- The hot products of combustion expand through specially designed blades mounted on a shaft, producing a ***high-speed rotary motion*** that is generally used for driving an electric generator that ***produces electric power***
- ***Exhaust* gases** leaving a turbine are at a ***high temperature (900°F to 1,100°F)***. This high-quality heat is ***excellent*** for producing ***high-grade steam (150 psig and higher)***.

The electric generation efficiency of gas turbines may be given in two forms:
% Efficiency, *and*
Heat Rate *(Btu / kWh)*
Both efficiencies are generally based on utilizing the lower heating value (LHV) of the fuel.

To convert between **% Efficiency** and **Heat Rate**:
% Efficiency = 3413 Btu/kWh ÷ Heat Rate (Btu/kWh)
Heat Rate *(Btu / kWh)* = 3413 Btu/kWh ÷ % Efficiency

- **Rated capacity** of combustion turbines is measured with the inlet air temperature to the turbine set at 59°F and 14.7 psia (sea level); and therefore:
    - ***Summer operation*** of gas turbines (inlet air temperatures > 59°F) results in a ***derating*** of the output ***capacity,*** a ***reduction in fuel use efficiency,*** *and* ***reduction in thermal energy of exhaust gases***
    - *Figure A1-2* shows the effects of **air inlet *temperature*** on gas **turbine power output and heat rate.**
    - Many large power plants deploying gas turbines **cool the inlet air** during summer to boost the gas turbine performance (visit www.turbineinletcooling.org for more information). **Turbine inlet cooling** should be considered for CHP systems. In these systems, turbine inlet cooling results in a larger power output, a lower heat rate, and a higher thermal energy in the exhaust gases.
    - *Figure A1-3* shows the effect of air inlet ***temperature*** on gas turbine **exhaust gas flow rate and temperature**

- Operation of gas turbines at elevations ***above sea level*** (*lower than* 14.7 psia) results in a ***derating*** of the output ***capacity*** and a ***reduction in fuel use efficiency***
- *Figure A1-4* shows the effects of altitude on gas turbine ***performance***

➢ **Operating Cycle Configurations**

Combustion turbine systems can be operated in one of three primary cycle configurations:

1. ***Simple Cycle***
2. ***Recuperated Cycle***
3. ***Combined Cycle***

The ***most common*** configuration utilized for the CHP applications in the capacity range covered in this Resource Guide is the ***Simple Cycle***.

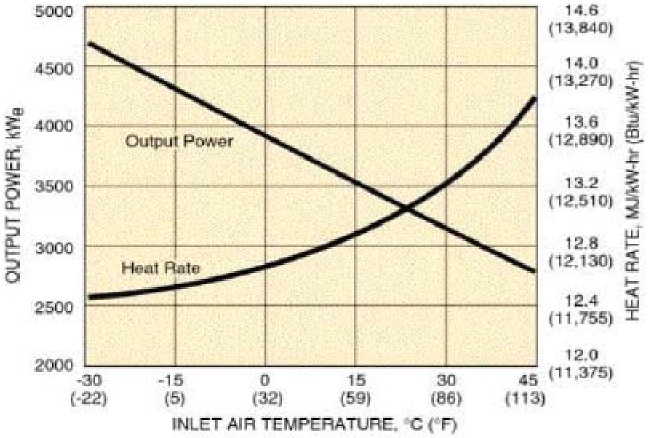


Figure A1-2 An Example of the Effect of Ambient Air Temperature on Power Output and Heat Rate

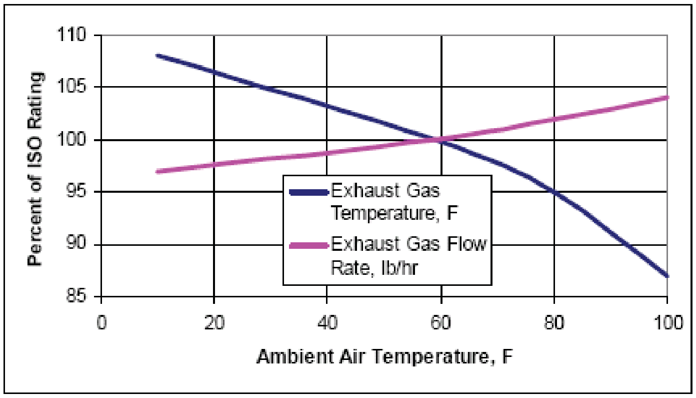


Figure A1-3 An Example of the Effect of Ambient Air Temperature on the Flow Rate and Temperature of Exhaust Gases

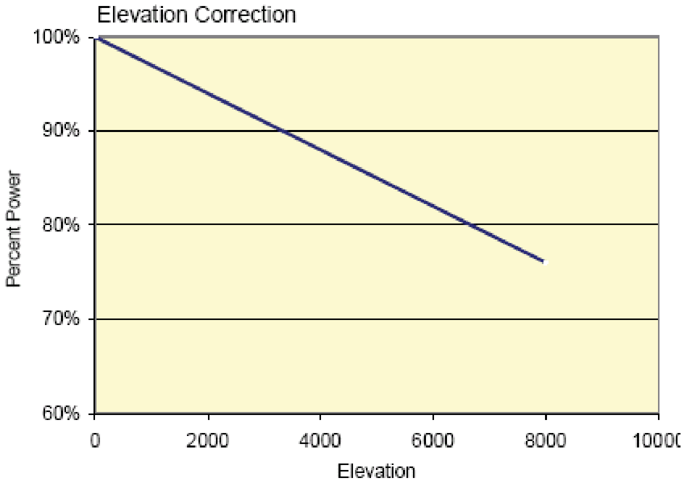


Figure A1-4 An Example of the Effect of Altitude (above sea level, feet) on the Electric Power Output

A1.1.3 Microturbines

Microturbines are a newer generation of **smaller combustion turbines** *that have entered the market place during the last few years. Microturbines are* **compact in size**, *can be* **brought on-line quickly**, *offer fuel flexibility and require* **less maintenance** *because they have a* **fewer number of moving parts**. *Because of these favorable characteristics, microturbines have* **tremendous potential** *for on-site power generation, especially for* **commercial building applications**.

Sizes

Capacities of microturbines range from approximately ***25 kW to 400 kW***.

Characteristics

- Very ***fuel flexible***; capable of burning natural gas, propane, and gases produced from landfills, sewage treatment facilities, and animal waste processing plants. The fuel source versatility of microturbines ***allows their application in remote areas***.
- **Fuel energy utilization efficiencies** of microturbines for producing electricity range from approximately ***25 to 30%***
- ***Exhaust gases*** are at about ***500°F***, making them a ***good source*** of ***high-quality heat*** for producing ***hot water***
- **Emissions** of ***NO$_x$*** from microturbines are ***lower*** than those for ***reciprocating engines*** without exhaust treatment and ***higher*** than those from ***combustion turbines***, and are typically < ***0.49 lbs/MWh*** (or about **10** ***ppm*** on a per volume basis)
- Similar to the larger combustion turbines, the **rated capacities** of microturbines are measured with the inlet air temperature to the microturbine set at 59°F and 14.7 psia (sea level)
  - ***Summer operation*** of gas turbines (inlet air temperatures *greater than* 59°F) results in a ***derating*** of the output capacity and a ***reduction in fuel use efficiency***.
  - Figure shows the typical effect of inlet air ***temperature*** on microturbine performance.
  - Cooling inlet air to a microturbine would improve its performance, just as it does for a large turbine. However, it is not generally practiced.
  - Operation of gas turbines at elevations above sea level (lower than 14.7 psia) results in a derating of the output capacity and a reduction in fuel use efficiency.

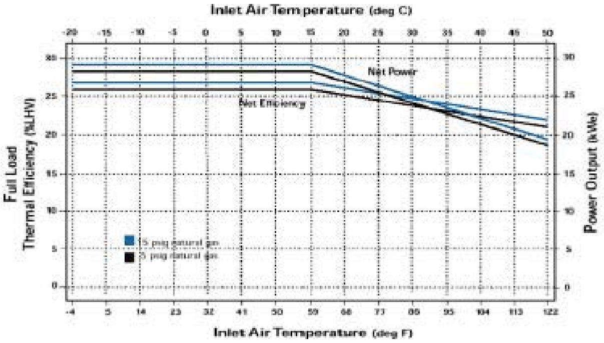


Figure A1-5 Effects of Ambient Temperature on the Electric Power Output and Fuel Efficiency of a Typical Microturbine

1.1.4 Steam Turbines

Steam turbines extract heat from steam and transform it into mechanical work by expanding the steam from high pressure to low pressure. These are one of the oldest prime mover technologies still in use.

Sizes
Capacities range from <1 MW to over 500 MW

Characteristics

- High-pressure steam flows through the turbine blades and turns the turbine shaft
- Steam turbine shaft is connected to an electric generator for producing electricity
- Power output is proportional to the steam pressure drop in the turbine (the larger the pressure drop of the steam, the larger the output capacity of the turbine/generator)
- No emissions from a steam turbine (emissions are from the boilers used to produce the steam)
- There are two classes of steam turbines of interest in CHP systems:

1. **Condensing**
    - Operate with an exhaust pressure less than atmospheric (vacuum pressure)
    - Experiences the maximum pressure drop through the turbine which results in greater energy extracted from each lb_m of steam input
    - Turbine efficiencies approx. 30% to 40%
    - The condenser can be either air or water cooled – condenser cooling water can be utilized for process or space heating loads
    - Usually more expensive than Non-Condensing Backpressure turbines

2. **Non-Condensing (Backpressure)**
    - Operate with an exhaust pressure equal to or in excess of atmospheric pressure
    - Exhaust steam is used for lower pressure steam process loads
    - Available in smaller sizes and pass large amounts of steam per MW of output (low efficiencies)
    - Produces less useful work than a condensing turbine, but since the unused steam from the turbine is passed on to process loads, the lower turbine power generation efficiencies (15% to 35%) are not a concern
    - Very cost effective when paralleled with pressure reduction valves (PRV), providing an efficient use of the pressure reduction requirements
    - Usually less costly than condensing turbines

- Extraction Steam Turbines (either condensing or backpressure) are multi-stage turbines that are designed with one or more outlets to allow intermediate pressure steam (between inlet & exhaust pressures) to be withdrawn for process applications.
- When steam turbines are utilized in a CHP system, they can be considered as a:
  - **Prime Mover** – when operated directly by steam generated on-site in a boiler and used to generate electricity through an electric generator
  - **Thermally Activated Machine** – when operated by steam generated by recycling waste thermal energy or by replacing steam pressure reduction valves (PRVs)

Table A1-4 When Do Backpressure Steam Turbines Make Sense?

	Probably Not A Good Application	**Probably a Good Application**	**Probably a Great Application**
Steam Flow Rate	< 4,000 lbm/h	> 4,000 lbm/h	> 10,000 lbm/h
Inlet Pressure to Turbine	< 125 psig	>125 psig	> 150 psig
Pressure Drop thru PRV	< 100 psig	>100 psig	> 150 psig
Capacity Factor	< 25%	> 25%	> 50%
Price of Purchased Electricity	< 1.5 ¢/kWh	> 1.5 ¢/kWh	> 6.0 ¢/kWh

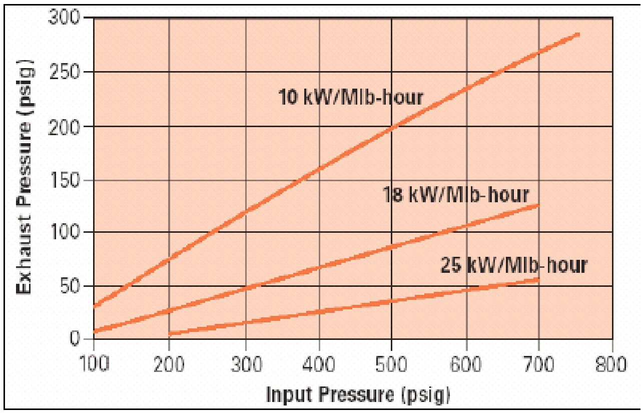


Figure A1-6 Effect of Steam Input and Exhaust Pressures on Electric Power Produced

Table A1-5 Determining the Available Power of a Backpressure Turbine

Power Available from Backpressure Turbine				
1	**Inlet Pressure**	From Owner		**psig**
2	**Outlet Pressure**	From Owner		**psig**
3	**Steam Usage**	From Owner		**pounds/hour**
4	**Steam Usage**	Divide Line 3 by 1,000		**Mlb per hour**
5	**Power Gen Heat Rate**	Get Value from Chart		**kW/Mlb-hour**
6	**Power Available**	Multiply Line 4 by Line 5		**kW**

A1.1.5 Fuel Cells

Fuel cells use a technology that is ***significantly different*** from the other power generation technologies in that it does ***NOT*** first ***produce shaft power*** that is used for operating an electric generator. Fuel cells ***directly generate electricity*** and ***heat*** through ***electrochemical reactions*** without any moving parts. Fuel cells are ***very quiet*** and are environmentally the ***cleanest*** technology for producing electric energy.

Sizes

Capacities of existing fuel cell modules range from a ***few kW up to 250 kW*** and can be ***integrated*** into fuel cell ***systems*** delivering ***several MWs*** of electric power.

Characteristics

- The ***electrochemical reactions*** in fuel cells ***require hydrogen*** or ***hydrogen-rich gases***. ***Hydrogen gas is normally not available*** as a fuel at economically attractive prices. Therefore, in most commercial applications, a ***fuel (like natural gas) has to be first converted*** to hydrogen-rich gases.
- A fuel cell power generation system has three main components:
    1) **Reformer** - Coverts a fuel, like natural gas, to hydrogen rich gas by reacting the fuel with steam in the presence of a catalyst

2) **Power Section** - Hydrogen is reacted electrochemically with oxygen to produce electric power in the form of direct current (DC)

3) **Inverter** - Converts the DC to electric utility grade alternating current (AC)

- *Figure A1-7* shows a process schematic of a fuel cell system.

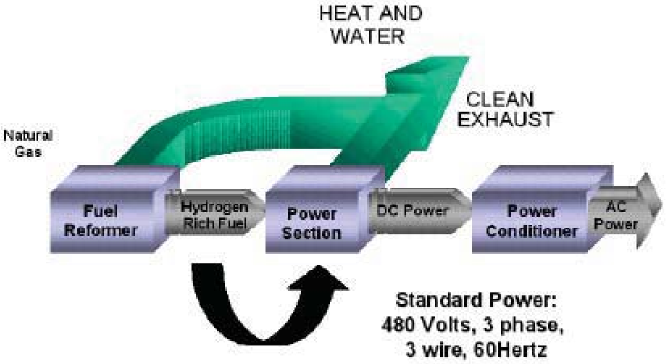


Figure A1-7 Process Schematic of a Fuel Cell

- ***Emissions*** from fuel cells are ***so low*** that several Air Quality Management Districts in the United States have ***exempted*** fuel cells ***from requiring a permit*** to operate
- There are four types of fuel cells that differ by the operating temperature and the type of electrolyte used: **proton-exchange membrane (PEMFC), phosphoric acid *(PAFC)*, molten carbonate *(MCFC)*, and solid oxide *(SOFC)***
- Only ***PAFC***s are currently ***commercially available***. Other types of fuel cells are at various stages of technology and system demonstrations.
- **Attributes/characteristics** of various fuel cells are shown in *Table A1-6*

Table A1-6 Characteristics of Different Types of Fuel Cells

Fuel Cell Type	Technology Status	Fuel Efficiency For Electric Power *(% LHV of Fuel)*	Operating Temperature	Heat Utilization Potential
Phosphoric Acid *(PAFC)*	Commercially Available	38-45	480°F	Hot Water
Solid Oxide *(SOFC)*	Demonstration	40-45	1,800°F	High Pressure Steam
Molten Carbonate *(MCFC)*	Demonstration	50-60	1,200°F	Medium and High Pressure Steam
Proton Exchange Membrane *(PEMFC)*	Demonstration	33-45	175°F	Hot Water

A1.2 HEAT RECOVERY

- ***Recoverable*** thermal energy from the various prime movers discussed above is available in one or all of the following forms:
    1) ***Hot Exhaust Gases***
    2) ***Hot Water***
    3) ***Steam***

- Two options exist for recovering heat from the hot exhaust gases from the prime movers:
    1. ***Direct*** use of the exhaust for providing ***process heat***, operating ***absorption chillers*** (discussed later in Section A1.2.1.1) specially designed for such a heat source, or ***regenerating desiccant dehumidifiers*** (discussed later in Section 0).
    2. ***Indirect*** use via heat exchangers for ***producing steam*** or ***heating water***, ***air*** or other ***gases***.
        - ✓ ***Steam*** produced can be used to meet the needs for ***space heating***, ***process heating,*** operating absorption systems for cooling or refrigeration, or operating steam turbines for ***producing mechanical shaft power for operating chillers, air compressors, or generators for more electric power.***
        - ✓ ***Hot water*** or ***air*** produced could be used for ***space*** or ***process heating, regenerating desiccant dehumidifiers, or operating some models of absorption chillers***

- In applications that require ***more thermal energy*** or ***higher temperatures*** than that available from power generation equipment, ***supplemental heat*** is supplied using a ***duct burner*** or ***boiler/furnace***

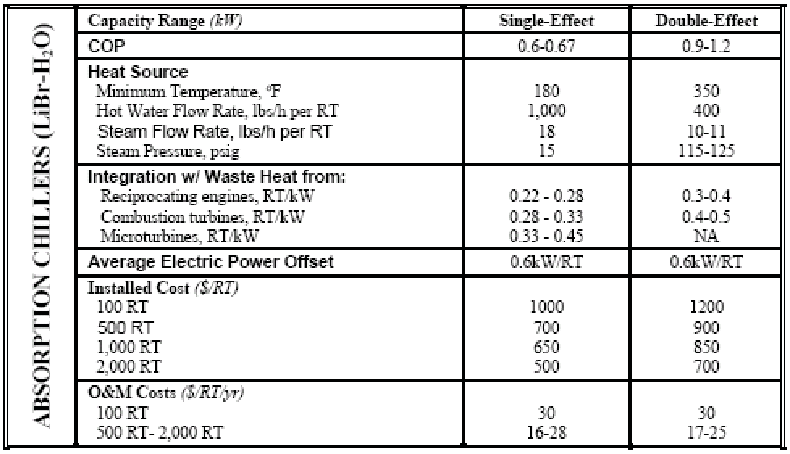
A1.2.1 THERMALLY-ACTIVATED MACHINES

The machines that use ***thermal energy*** as the ***primary energy*** for their operation are collectively called **"Thermally Activated Machines."** The four most common machines that are applicable to CHP systems are as follows:

1. **Absorption Chillers/Refrigeration Systems**
2. **Desiccant Dehumidifiers**
3. **Space and Process Heat Systems**
4. **Steam Turbines**

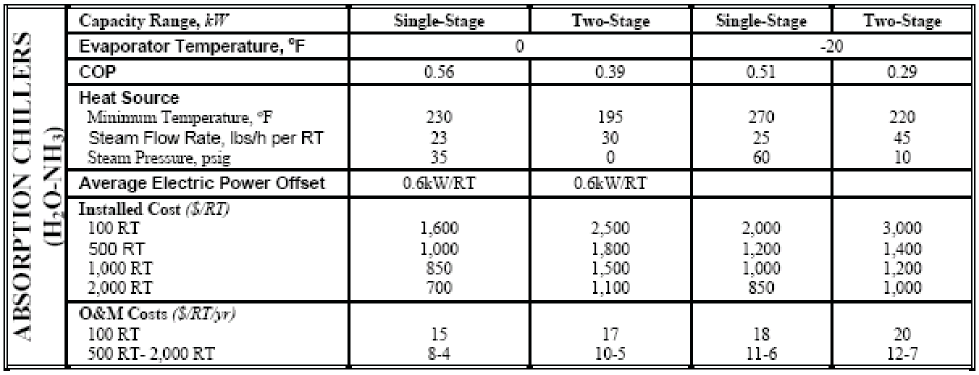
For a detailed discussion on thermally-activated machines, visit our website (www.chpcentermw.org/08-0114_tech.html)

Table A1-7 Absorption Chiller (lithium-Bromide-Water) System "Rules-of-Thumb"



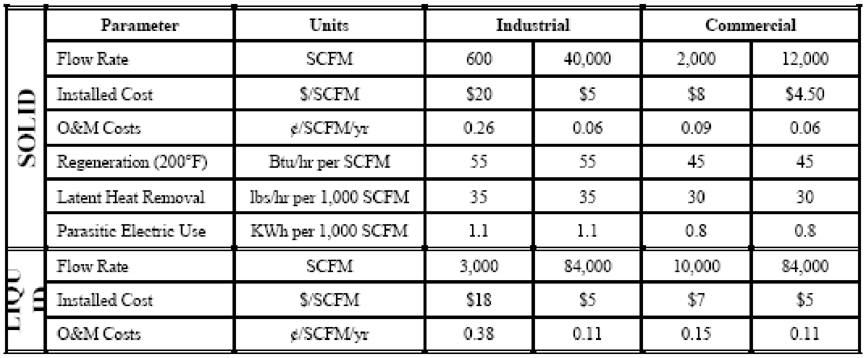
ABSORPTION CHILLERS ($LiBr-H_2O$)	Capacity Range *(kW)*	Single-Effect	Double-Effect
	COP	0.6-0.67	0.9-1.2
	Heat Source		
	Minimum Temperature, °F	180	350
	Hot Water Flow Rate, lbs/h per RT	1,000	400
	Steam Flow Rate, lbs/h per RT	18	10-11
	Steam Pressure, psig	15	115-125
	Integration w/ Waste Heat from:		
	Reciprocating engines, RT/kW	0.22 - 0.28	0.3-0.4
	Combustion turbines, RT/kW	0.28 - 0.33	0.4-0.5
	Microturbines, RT/kW	0.33 - 0.45	NA
	Average Electric Power Offset	0.6kW/RT	0.6kW/RT
	Installed Cost *($/RT)*		
	100 RT	1000	1200
	500 RT	700	900
	1,000 RT	650	850
	2,000 RT	500	700
	O&M Costs *($/RT/yr)*		
	100 RT	30	30
	500 RT- 2,000 RT	16-28	17-25

Table A1-8 Absorption Refrigeration (Aqua-Ammonia) System "Rules-of-Thumb"



ABSORPTION CHILLERS (H_2O-NH_3)	Capacity Range, *kW*	Single-Stage	Two-Stage	Single-Stage	Two-Stage
	Evaporator Temperature, °F	0		-20	
	COP	0.56	0.39	0.51	0.29
	Heat Source				
	Minimum Temperature, °F	230	195	270	220
	Steam Flow Rate, lbs/h per RT	23	30	25	45
	Steam Pressure, psig	35	0	60	10
	Average Electric Power Offset	0.6kW/RT	0.6kW/RT		
	Installed Cost *($/RT)*				
	100 RT	1,600	2,500	2,000	3,000
	500 RT	1,000	1,800	1,200	1,400
	1,000 RT	850	1,500	1,000	1,200
	2,000 RT	700	1,100	850	1,000
	O&M Costs *($/RT/yr)*				
	100 RT	15	17	18	20
	500 RT- 2,000 RT	8-4	10-5	11-6	12-7

Table A1-9 Desiccant "Rules-of-Thumb"



	Parameter	Units	Industrial		Commercial	
SOLID	Flow Rate	SCFM	600	40,000	2,000	12,000
	Installed Cost	$/SCFM	$20	$5	$8	$4.50
	O&M Costs	¢/SCFM/yr	0.26	0.06	0.09	0.06
	Regeneration (200°F)	Btu/hr per SCFM	55	55	45	45
	Latent Heat Removal	lbs/hr per 1,000 SCFM	35	35	30	30
	Parasitic Electric Use	KWh per 1,000 SCFM	1.1	1.1	0.8	0.8
LIQUID	Flow Rate	SCFM	3,000	84,000	10,000	84,000
	Installed Cost	$/SCFM	$18	$5	$7	$5
	O&M Costs	¢/SCFM/yr	0.38	0.11	0.15	0.11

	Regeneration (200°F)	Btu/hr per SCFM	45	45	35	35
	Latent Heat Removal	lbs/hr per 1,000 SCFM	30	30	30	30
	Parasitic Electric Use	KWh per 1,000 SCFM	1.3	1.3	1.3	1.3

A1.2.1.1 Absorption Chillers

Absorption chiller/refrigeration systems are ***similar*** to ***vapor compression*** systems with a few ***key differences***.

- Basic ***difference*** is that a:
  - ***Vapor compression*** system uses a ***rotating device*** (electric motor, engine, combustion turbine or steam turbine) to ***operate the compressor*** to raise the pressure of refrigerant vapors, while an
  - **Absorption system** uses ***heat*** to ***compress*** the ***refrigerant*** vapors to a high-pressure, therefore this ***"thermal compressor" has no moving parts***.
    - *A process schematic of an absorption chiller is shown in Figure A1-8*

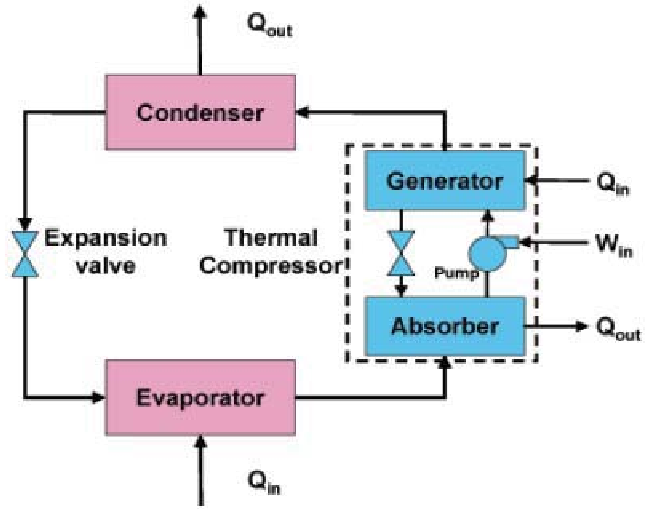


Figure A1-8 Process Schematic of an Absorption Chiller/Refrigeration System

- Commercially available **absorption systems** that can be utilized within a CHP system can ***operate on***:
  - Steam,
  - Hot Water, or
  - Hot Exhaust Gases
- Current ***absorbent/refrigerant pairs*** for absorption systems are ***either***:
  - ***Lithium bromide and water***, or
  - ***Water and /Ammonia***

- In **lithium bromide/water (LiBr-water) systems,** water is the refrigerant and these systems are typically used for **cooling** fluids to as low as 40°F and thus, cannot be used for freezing applications (refrigeration)

- In **water/ammonia systems** (aqua-ammonia refrigeration, AAR), ammonia is the refrigerant, and these systems are typically used for **refrigeration** (< 32°F) applications, down to –60°F.

- Although water/ammonia systems can be used for cooling (non-freezing) applications, they are significantly more expensive (higher installed cost) than the lithium bromide/water chillers and therefore, are not generally used for cooling applications.

A1.2.1.1.1 Lithium Bromide-Water Absorption Chiller

- Two types of these chillers are commercially available:
  1. **Single Effect**
     - **Lower efficiency** than a double-effect chiller and therefore, more expensive to operate (uses more energy)
     - ***Lower installed cost*** than a double-effect chiller
     - Requires about ***18 lbs/h of steam at 15 psig or about 1,000 lb/h of hot water (~200°F) for 1 ton of cooling***
     - ***Most*** CHP systems ***utilize single effect absorption chillers***, because the heat utilized for these chillers is recycled thermal energy and the lower operating temperatures of these chillers allow more heat to be recovered from the generator. With engine generators, a single-effect absorption chiller will generate more cooling per kW of engine generator than a double-effect chiller and cost significantly less to purchase.
  2. **Double Effect**
     - **Higher efficiency** than a single-effect chiller and therefore, less expensive to operate (uses less energy)
     - ***Higher*** installed cost than a single-effect chiller
     - Requires about 10 ***lbs/h of steam at about 120 psig for 1 ton of cooling***
     - Some **newer models can operate directly on hot Exhaust gases** from prime movers
- Rated ***capacities*** of these chillers are based on producing ***chilled water*** at ***44°F*** *(ARI standard)*.
- Absorption chillers can also be used in chilled water storage systems to ***produce chilled water during off-peak electric load periods*** when ***the cost of electricity is low*** and the demand for cooling is also low. The ***stored chilled water is then***

drawn upon during the peak cooling periods when ***electricity costs are high***, to supplement the chiller operation. The storage system helps to reduce the chiller capacity requirement and total installed cost of chillers.

A1.2.1.1.2 Aqua-Ammonia Absorption Refrigeration Systems

- Two types of systems are commercially available:
  1. **Single Stage:**
     - ***Flexibility to achieve temperatures in the range of 40°F to –60°F***
     - Can utilize heat source temperatures in the range of 203°F to 356°F
     - Lower refrigeration temperatures require higher heat source temperatures
     - Requires about **24lbs/h of steam for 1 ton of refrigeration**
     - More energy efficient (**higher COP**) than the two-stage system
     - ***Most*** CHP systems ***utilize single –stage systems*** to keep initial cost low.
  2. **Two Stage:**
     - Systems with **two absorption stages** *provide* ***two different refrigeration temperatures*** *from the same system*
     - Systems with **two desorption stages** can utilize a **lower temperature** (195°F) **heat source** than that for a single-stage systems
     - Requires about **35 lbs/h of stream for l ton of refrigeration**
     - Less energy efficient (**lower COP**) than the single-stage systems
     - **Higher Cost** than the single-stage systems

A1.2.1.2 Desiccant Dehumidifiers

Desiccants ***remove*** the ***humidity*** (*latent heat*) from the air. Many ***industrial facilities***, including ***food products***, ***pharmaceuticals***, ***batteries*** and ***computer components*** require good humidity control to ***improve product quality*** and ***prevent production problems***. Control of humidity is also important for ***improving indoor air quality*** (***IAQ***) in building applications by ***preventing*** or ***minimizing*** the growth of ***mold***, ***fungus***, and ***dust mites***.

- There are two separate aspects of space conditioning for comfort cooling:
  1. ***Lowering*** the ***temperature*** of the air (**sensible cooling**)
  2. ***Reducing humidity*** in the air (**latent cooling**)
- Traditionally, ***lowering*** of ***temperature AND humidity*** has been accomplished using a ***single piece of equipment*** (either an electric chiller or an absorption chiller) that ***lowers*** the air ***temperature below its dew point*** temperature. Moisture in the air is removed when it condenses on the outside of the air conditioners cooling coil (latent heat removal) as the air is cooled (sensible cooling). The cooled air, containing less moisture, is sent to the space being conditioned. Reducing humidity in the air by cooling often requires ***lowering the air temperature below a comfortable level*** and might necessitate ***some reheating*** of the dehumidified air.
- **Desiccant dehumidifiers** reduce humidity in the air by using materials that ***attract AND hold moisture***. The use of desiccant equipment to remove moisture from the air is ***preferred over using chillers alone*** (the conventional method) because of the following potential benefits:

- Allows ***control*** of ***humidity independent*** of the ***temperature***
- Allows ***use*** of ***potentially wasted thermal energy*** to ***reduce the latent (moisture) cooling load***
- ***Scrubs out bacteria and virus (liquid*** *desiccants* ***only****)*

➢ Two types of desiccant dehumidifier are ***commercially*** available:

1) **Solid Desiccants** (*Figure A1-9*)
   - Usually used for dehumidifying air for ***commercial*** HVAC systems.
2) **Liquid Desiccant** (*Figure A1-10*)
   - Generally used for ***industrial*** applications or in hospital ***operating rooms***.

Figure A1-9 Solid Desiccant

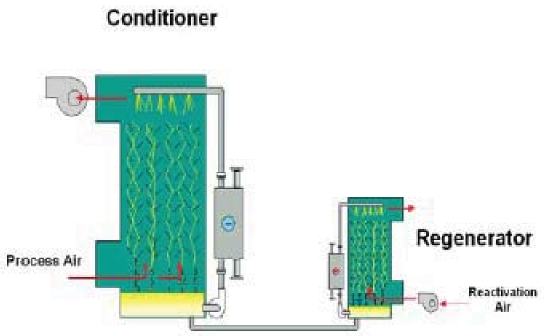


Figure A1-10 Liquid Desiccant

A1.2.1.3 Space and Process Heat systems

A ***professional engineer*** should be involved in ***designing*** and ***sizing*** of the ***waste heat recovery*** section. The ***design*** of the ***heat recovery*** section ***involves*** consideration of ***many related factors***, such as the thermal capacity of the exhaust gases, the exhaust flow rate, the sizing and type of heat exchanger, and the desired parameters over a wide range of operating conditions of the CHP system — ***all of which need to be considered for proper AND economical operation***.

- **Space Heating**: ***Exhaust gasses*** from the prime mover normally ***indirectly*** heat the building ***air heating system*** via some form of ***heat exchanger***, either by heating water or air that will be distributed by the space heating system.

- **Process Heating**: ***Exhaust gasses*** may be used either ***directly*** in the process or they may be used ***indirectly*** to heat water or air via a heat exchanger.

- **Supplemental Heating**: In some cases the exhaust may ***NOT*** be ***hot enough*** to provide the necessary thermal energy, so it may be used to ***preheat*** water or air to a secondary system, or ***duct firing*** may be ***added*** to raise the temperature of the exhaust gasses.

A1.2.1.4 Steam Turbines

"Rules-of-Thumb" for Steam Turbines are provided in Section 1.1.4 (Prime Movers)

Appendix B: Site Walkthrough Data Collection

Questions for the Facility Operator

RESPONSE

Obtain 12 Months of Electric Bills

	☐
Do Bills Contain Monthly Demand Values?	☐
Bills Contains On-Peak and Off-Peak Consumption?	☐
Name of Rate Schedule(s) Used	☐ ☐

Obtain 12 Months of Gas Bills

	☐
Do Bills Contain Energy Usage?	☐
Is Gas Purchased Under Contract?	☐
Name of Rate Schedule(s) Used	☐ ☐

Obtain 12 Months of Fuel Oil Bills (If Used)

	☐
Do Bills Contain Amount Used	☐ ☐
Type of Fuel Oil Used	☐ No. 2 ☐ No. 6

Industrial Loads - Ask for Information on Operating Schedules

Number of Hours of Operation on Weekdays?	☐ Hrs./Day
Number of Hours of Operation on Weekends?	☐ Hrs./Day
Schedule of Major Process Heat Loads?	☐ Hrs./Day
Does the Plant Have a Steam System?	☐
Operating Pressure	☐ psig

Commercial Loads - Ask for Information on Operating Schedules

Hours Facility is Open for Business or Largely Occupied?	☐ Hrs./Day
Type of Heating System(s)? Indicate All Types	☐ ☐ ☐
Type of Cooling System(s)?	☐ ☐ ☐

z

Electric Parameters

Certain Issues with the Current Electric Power Service Can Impact CHP Economics. These Questions Investigate Power Service Issues.

How Many Electric Services Drops Are There to the Facility?		
How Many Electric Meters Serve the Facility?		
Estimate the Distance Between the Multiple Meters in Your Facility		Feet
Do All of Your Service Drops Originate at the Same Utility Feeder?		
Has the Facility Experienced Problems with Power Quality Such as:		
Low Voltage?		*If Yes, Please Describe:*
Poor Frequency Quality?		*If Yes, Please Describe:*
Does the Facility Have Any Significant Need for UPS Systems?		*If Yes, Please Describe:*
Estimate the Number of Momentary Electric Power Outages		
Momentary Power Drops are Power Fluctuations that Cause Computer Equipment to Reset a Full Blackout		
Estimated Cost of a Momentary Power Outage		
Estimate the Number of Non-momentary or Complete Electric Power Outages		Occurances per year
Estimate Cost of a Non-MomentaryPower Outage		per Hour
Does the Facility Have Back-Up Generation?		
What is the Size of the Back-Up Generators		kWe
Are the Back-Up Generators Diesel Fuel?		
How Old are the Back-Up Generators		Years
(This Question Can Generally be Skipped for Commercial Buildings)		
What is the Facilities Current Power Factor		

Overall Location and Equipment Questions

Overall Location Questions: It is Important to Find a Location for the CHP System That Allows the System to be Affordably Connected to the Electric and Thermal Loads.

If CHP is Installed - Where Can it Be Located?

How Close are the Existing Electric Feeders to This Location? Feet

Does a Single Electric Distribution System Exist that Can be Used?
(Question Important for Multi-Building Campuses)

Does a Hot Water or Steam Piping System Exist that Could be Used?

How Close is the Existing Heating Plant? Feet

Existing Equipment: A CHP system will need to tie into existing heating and cooling systems. The current state of these systems will affect the savings and the first cost

What is the Approximate Efficiency of the Existing Heating System? %

How Old is the Current Heating System? Years

How is Heat Distributed to the Building? Steam, Hot Water, or Hot Air

If Steam, What Operating Pressure? If Water, At What Delivery Temp?

What Sizes are the Existing Heating Equipment?

	Type	*Capacity*	*Units*
No. 1			
No. 2			
No. 3			
No. 4			
No. 5			

Please Mark Type of Heating System:

GSB = Gas Fired Steam Boiler
OSB = Oil Fired Steam Boiler
ESB = Electric Steam Boiler
OHW = Oil Hot Water Boiler
ERT = Rooftop Units-Electric Heat
GHW = Gas Hot Water Boiler
OHW = Oil Hot Water Boiler
EHW = Electric Hot Water Boiler
O = Other (Please Describe)
GRT = Rooftop Units-Gas Heat

Estimate the Maximum Cooling Load? Tons

Does the Facility Have a Chilled Water Distribution System?

How Long is the Distance to the Existing Chiller Room? Feet

How Old are the Existing Chillers Years

What Sizes and Type are the Existing Chillers?

No. 1			Tons
No. 2			Tons
No. 3			Tons
No. 4			Tons
No. 5			Tons

Please Indicate the Type of Chillers:

AS = Absorption (Steam Fired), AD = Absorption (Direct Fired)
AH = Absorption (Hot Water Fired), E = Electric Chillers
ED = Engine Driven, SD = Steam Turbine Driven, O = Other

Are There Concerns about Noise at the Selected System Location? *If Yes, Please Describe*

Are There Concerns about Vibration at the Selected System Location? *If Yes, Please Describe*

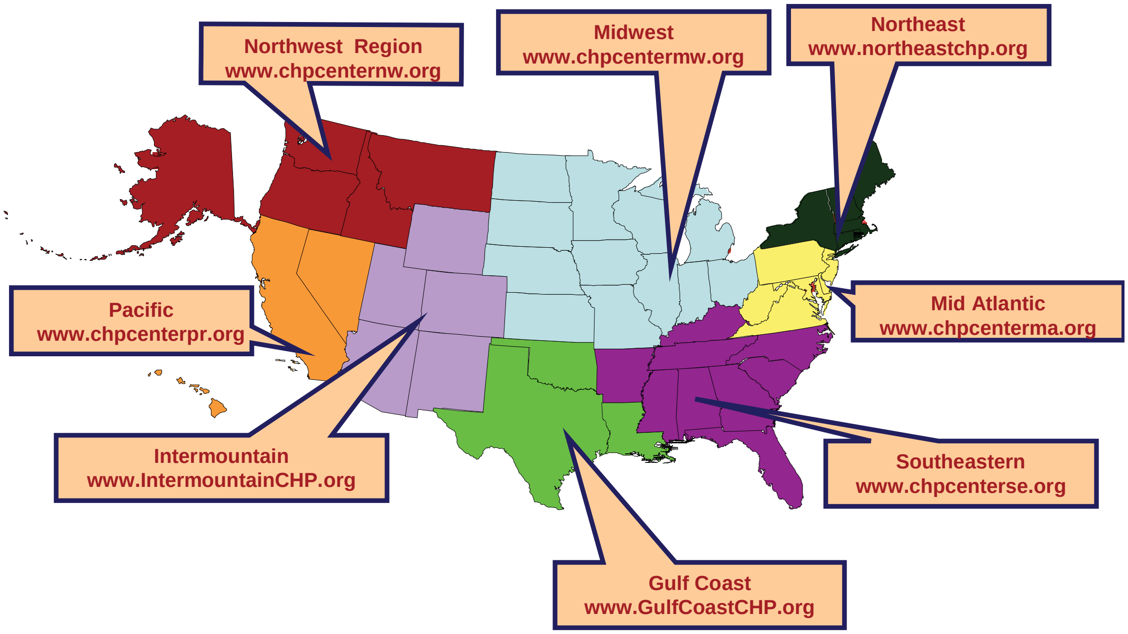
Other Questions

Questions to Consider that Facility Operators May Be Able to Help With

Would the Facility be Able to Obtain Gas at a Lower Rate if the Gas Consumption of the Facility Were Larger?	
What are the Electric Utility Stand-By Charges in This Area?	$/kW/Mo
Is the Facility Eligible for any State/Federal/Utility Rebate Programs?	
Is the Facility Owned by a For-Profit Company?	
If Yes, What is Their Marginal Corporate Tax Rate?	
Would the Facility be Interested in Leasing a CHP Plant?	*Please Explain:*
Would the Facility be Interested in Having a Third Party Own the CHP Plant and Sell Them Power/Heating/Cooling?	*Please Explain:*

Appendix C: List of RACs with Contact Information

Regional Application Centers



Northwest Region
www.chpcenternw.org

Midwest
www.chpcentermw.org

Northeast
www.northeastchp.org

Pacific
www.chpcenterpr.org

Mid Atlantic
www.chpcenterma.org

Intermountain
www.IntermountainCHP.org

Southeastern
www.chpcenterse.org

Gulf Coast
www.GulfCoastCHP.org

Midwest: John Cuttica
312/996-4382
Cuttica@uic.edu

Northeast: Tom Bourgeois
914/422-4227
tbourgeois@law.pace.edu

Mid Atlantic: Joe Orlando
301/405-4681
orlandoj@umd.edu

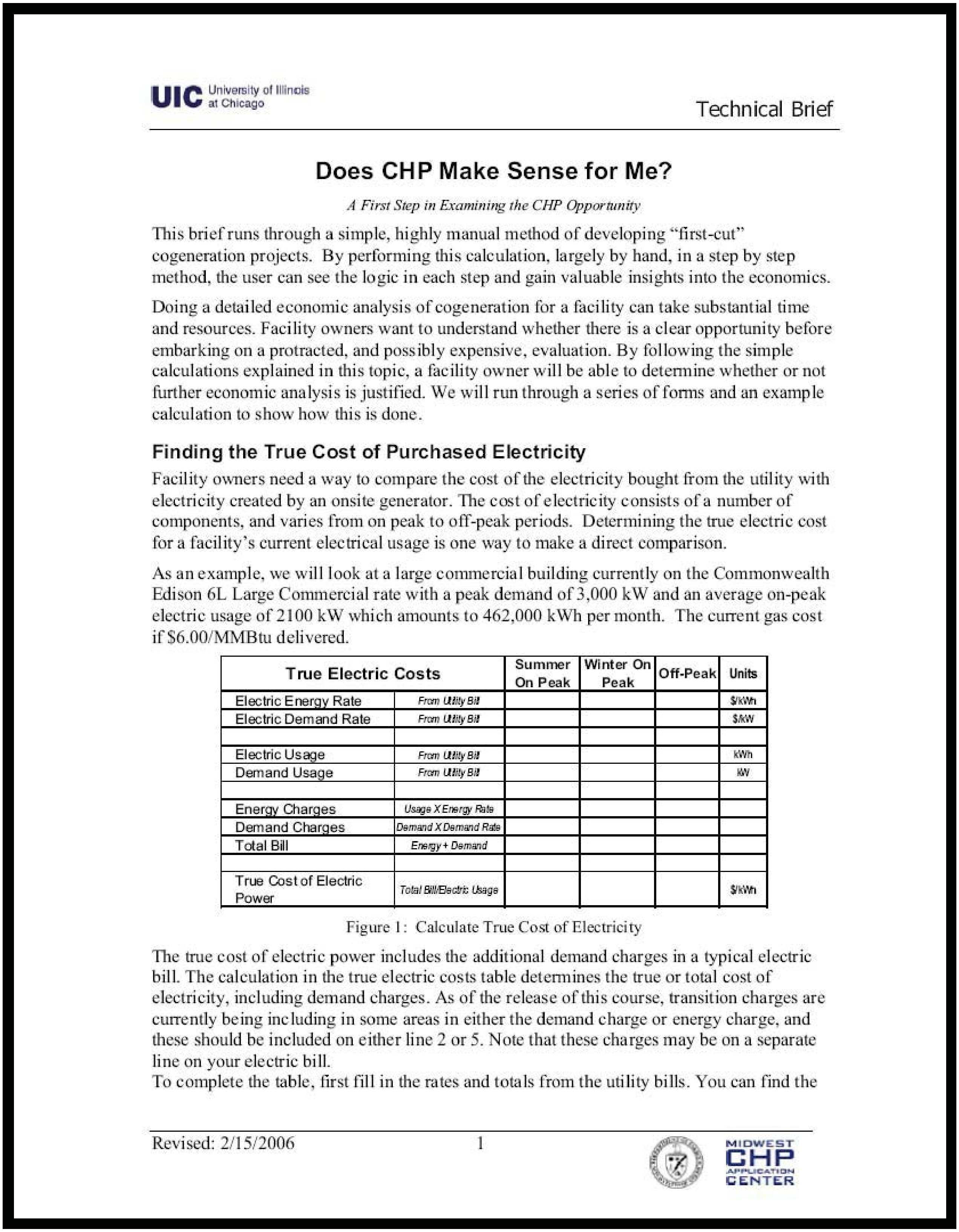
Southeast: Louay Chamra
662/325-0618
chamra@me.msstate.edu

Gulf Coast: Dan Bullock
281/364-6087
dbullock@harc.edu

Intermountain: Patti Case
801/278-1927
plcase@etcgrp.com

Northwest: David Sjoding
360/956-2004
Sjoding@energy.wsu.edu

Pacific: Tim Lipman
510/642-4501
telipman@berkeley.edu



UIC University of Illinois at Chicago

Technical Brief

Does CHP Make Sense for Me?

A First Step in Examining the CHP Opportunity

This brief runs through a simple, highly manual method of developing "first-cut" cogeneration projects. By performing this calculation, largely by hand, in a step by step method, the user can see the logic in each step and gain valuable insights into the economics.

Doing a detailed economic analysis of cogeneration for a facility can take substantial time and resources. Facility owners want to understand whether there is a clear opportunity before embarking on a protracted, and possibly expensive, evaluation. By following the simple calculations explained in this topic, a facility owner will be able to determine whether or not further economic analysis is justified. We will run through a series of forms and an example calculation to show how this is done.

Finding the True Cost of Purchased Electricity

Facility owners need a way to compare the cost of the electricity bought from the utility with electricity created by an onsite generator. The cost of electricity consists of a number of components, and varies from on peak to off-peak periods. Determining the true electric cost for a facility's current electrical usage is one way to make a direct comparison.

As an example, we will look at a large commercial building currently on the Commonwealth Edison 6L Large Commercial rate with a peak demand of 3,000 kW and an average on-peak electric usage of 2100 kW which amounts to 462,000 kWh per month. The current gas cost if $6.00/MMBtu delivered.

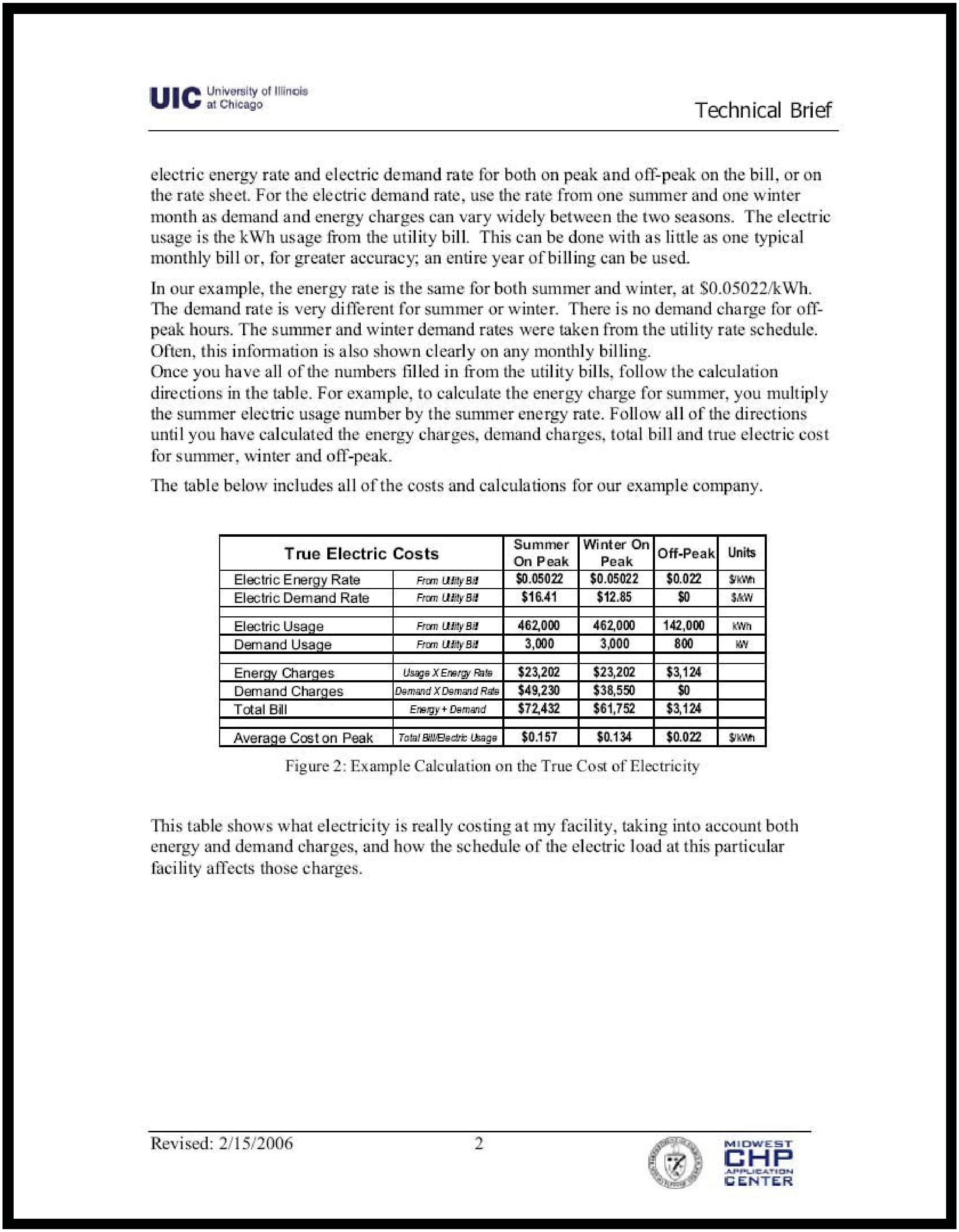
True Electric Costs		Summer On Peak	Winter On Peak	Off-Peak	Units
Electric Energy Rate	*From Utility Bill*				$/kWh
Electric Demand Rate	*From Utility Bill*				$/kW
Electric Usage	*From Utility Bill*				kWh
Demand Usage	*From Utility Bill*				kW
Energy Charges	*Usage X Energy Rate*				
Demand Charges	*Demand X Demand Rate*				
Total Bill	*Energy + Demand*				
True Cost of Electric Power	*Total Bill/Electric Usage*				$/kWh

Figure 1: Calculate True Cost of Electricity

The true cost of electric power includes the additional demand charges in a typical electric bill. The calculation in the true electric costs table determines the true or total cost of electricity, including demand charges. As of the release of this course, transition charges are currently being including in some areas in either the demand charge or energy charge, and these should be included on either line 2 or 5. Note that these charges may be on a separate line on your electric bill.
To complete the table, first fill in the rates and totals from the utility bills. You can find the

Revised: 2/15/2006 1

MIDWEST CHP APPLICATION CENTER



electric energy rate and electric demand rate for both on peak and off-peak on the bill, or on the rate sheet. For the electric demand rate, use the rate from one summer and one winter month as demand and energy charges can vary widely between the two seasons. The electric usage is the kWh usage from the utility bill. This can be done with as little as one typical monthly bill or, for greater accuracy; an entire year of billing can be used.

In our example, the energy rate is the same for both summer and winter, at $0.05022/kWh. The demand rate is very different for summer or winter. There is no demand charge for off-peak hours. The summer and winter demand rates were taken from the utility rate schedule. Often, this information is also shown clearly on any monthly billing.
Once you have all of the numbers filled in from the utility bills, follow the calculation directions in the table. For example, to calculate the energy charge for summer, you multiply the summer electric usage number by the summer energy rate. Follow all of the directions until you have calculated the energy charges, demand charges, total bill and true electric cost for summer, winter and off-peak.

The table below includes all of the costs and calculations for our example company.

True Electric Costs		Summer On Peak	Winter On Peak	Off-Peak	Units
Electric Energy Rate	*From Utility Bill*	$0.05022	$0.05022	$0.022	$/kWh
Electric Demand Rate	*From Utility Bill*	$16.41	$12.85	$0	$/kW
Electric Usage	*From Utility Bill*	462,000	462,000	142,000	kWh
Demand Usage	*From Utility Bill*	3,000	3,000	800	kW
Energy Charges	*Usage X Energy Rate*	$23,202	$23,202	$3,124	
Demand Charges	*Demand X Demand Rate*	$49,230	$38,550	$0	
Total Bill	*Energy + Demand*	$72,432	$61,752	$3,124	
Average Cost on Peak	*Total Bill/Electric Usage*	$0.157	$0.134	$0.022	$/kWh

Figure 2: Example Calculation on the True Cost of Electricity

This table shows what electricity is really costing at my facility, taking into account both energy and demand charges, and how the schedule of the electric load at this particular facility affects those charges.

Finding the Cost of Electricity from an On-Site Generator

Once you have calculated the true cost of electric power, you will use the graph below to compare those costs with the costs of generating your own power onsite with a typical engine generator. The graph below shows the cost curves for generating your own power, depending on how the engine is used.

The cost of the generated power is plotted on the y-axis and the current cost of gas is plotted on the x-axis. As the cost of gas increases, the cost of operating the engines also increases. Both the cost of gas consumed by the engine and a maintenance allocation of $0.011/kWh are included in the cost of generated electricity. For this reason, the cost of generated electricity does not go to zero when the cost of gas goes to zero, as, even if the engine is operating on some free waste gas stream, the engine still requires maintenance This maintenance allocation is considered typical for engine-generators in the 1 –5 MW range.

The way you use the engine also drastically affects the cost of generating electricity. If you do not recover any of the waste heat from the engine operation, your cost of generating electricity will be higher than if you used the waste heat for space heating or some other heating load in the facility. This is because there will be boiler gas consumption that is avoided by using this recovered heat. The reduction in gas consumption to the boiler is credited against the cost of electricity, which greatly simplifies this economic calculation method.

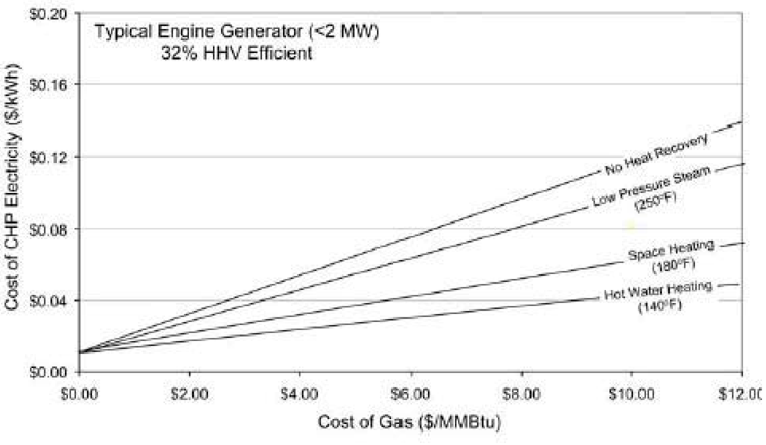


Figure 3: Cost of Electricity Graphs for Engines

Chart assumes an engine heat rate of 10,660 Btu./kWh and a maintenance allocation of $0.011/kWh for engines of under 2 MW. Larger engine often have lower maintenance allocations. Engines are not recommended for high-pressure steam applications (>15 psig). See Figure 11 for a chart for gas turbines

Our first step is to plot the true cost of electricity – for summer on peak, winter on peak and off-peak. Draw the true cost of electricity as a horizontal line across the chart. In our example, the summer on-peak cost of electricity is $0.157, the winter on-peak cost of electricity is $0.134, and the off-peak cost of electricity is $0.022. In Figure 4, these horizontal lines have been added to the chart.

Next, draw the current cost of gas as a vertical line on the graph. In our example, the cost of gas is $6/MMBtu.

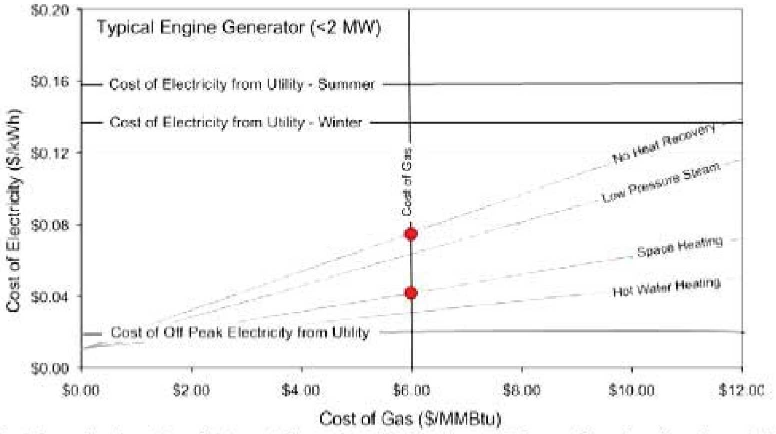


Figure 4: Electric Cost Graph From Figure 3 with Horizontal Lines Showing the Cost Of Utility Supplied Electricity At Various Times and a Vertical Line For The Current Gas Cost.

The points where the cost of gas line intersects the cost curves for generating electricity are the actual costs of generating electricity. For a system that does not recover any heat, the cost of generating electricity is just under $0.08/kWh. But when the facility can recover heat for space heating, the cost of generating electricity is approximately $0.04/kWh.

Most facilities will not be able to use all the recoverable heat. As an approximation, we can assume that 50% of the heat will be recovered. A point half way between No Heat Recovery and Heat Recovery to Space Heating can be used, as shown in Figure 5.

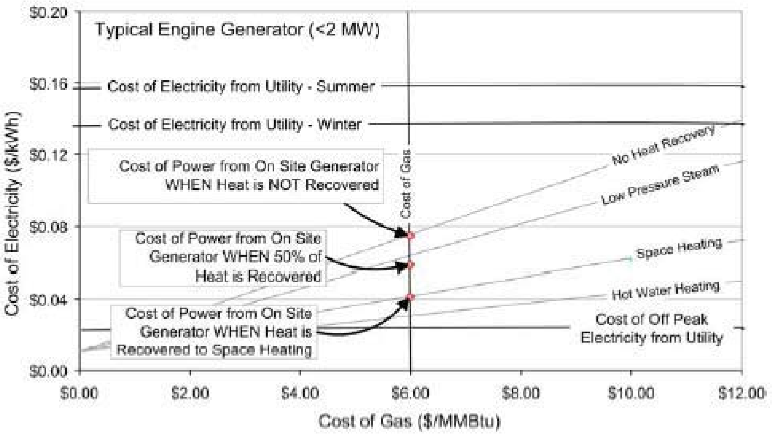


Figure 5: Electric Cost Graph comparing the Cost of Electricity Generated on-Site to Utility Supplied Electricity.

The distance between your intersection point and the true cost of utility supplied electricity is the amount that you would save for each kilowatt-hour generated, as shown in Figure 6.

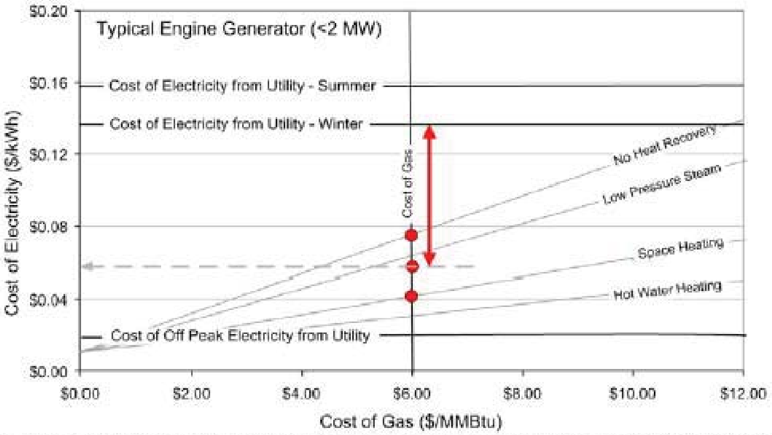


Figure 6: Electric Cost Graph Showing the Savings per Kilowatt Hour When 50% of the Heat is Recovered During Winter On-Peak Periods

In this example, there is no savings during off-peak periods. This is a common result. When this happens, cogeneration systems are run during on-peak hours only. The savings during winter peak periods is $0.074 per kWh and during summer peak periods is $0.97 per kWh. In the next section, we will see how much this translates into yearly savings.

The cost of gas does not always stay the same. In the U.S., the price fluctuates because it is an openly traded commodity. Prices change depending on current demand and supply issues.

What happens to your cost analysis when the cost of gas changes? As the cost of gas changes, re-draw the vertical cost of gas line on your chart. After you have drawn your new cost of gas line, just find where that line intersects with the heat recovery usage you want, and you can find the new cost of generating electricity. How high does the cost of gas have to get before generating your own electricity is no longer economically feasible?

In this section, we have determined the true cost of electricity currently being purchased from the utility and the cost of electricity from an on-site distributed generation or cogeneration system. If the cost of generated electricity is higher than the utility price – cogeneration will never justify itself, and no further work is warranted. If the cost of electricity generated on-site is below the utility price, cogeneration MAY be justified. This answers the critical "first-cut" question we can ask about cogeneration.

Economic Practicality of a DG or CHP System

For any Distributed Generation of Cogeneration project to be practical, the cost of generating electricity at the customer's facility must be lower than the cost of buying the electricity from the local electric utility. In the last section, we determined whether this was true. However, the do not yet know if there is enough savings from on-site generation or cogeneration to justify the installed cost of building the generation/cogeneration system In this section, we will use approximate installed costs for DG systems to find the "Payback Period" which is the number of years the system must operate to pay for itself. If this period is quite long, the systems may be judged by the customer to be impractical.

The criteria the customer uses to decide what period is or is not too long depends on the customer. Private commercial or industrial companies tend to have short payback periods, as using their available lending line to expand their manufacturing capacity may have a shorter payback. Conversely, institutional customers may be able to finance projects on low interest public bond issues, giving them very long payback criteria.

First, we need to develop an estimate of what the generation/cogeneration system will cost. In the following figure, the installed costs for a typical cogeneration system are shown. This cost curve is based on a number of successful projects constructed in urban areas in the Midwest. These numbers should be viewed as only an approximate installed costing for carrying out initial financial calculations. If this initial calculation shows an acceptable payback period, this is used to justify proceeding to a concept design, which includes a more detailed cost estimate that takes into consideration specific issues for a particular customer.

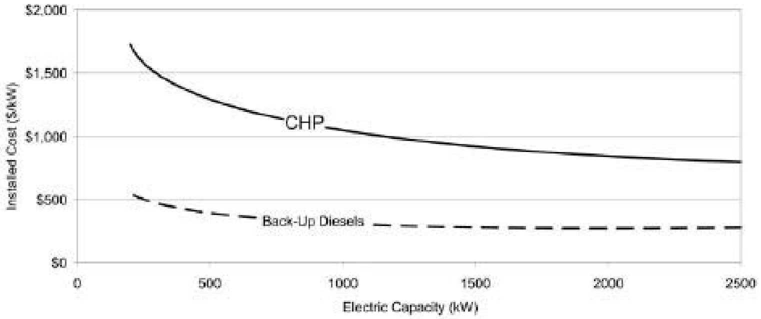


Figure 7: Typical Costs for Cogeneration Systems Based on the Size of the Systems

Chart Includes Typical Costs for Heat Recovery Equipment, Installation, and Housing. This particular set of curves is based ion engine generator systems, which tend to be most practical in this size range.

Figure 7 shows the installed cost per kW of capacity for differing size systems. For example, a 1,500 kW (1.5 MW) system tends to cost roughly $900/kW installed. Then the overall cost of the 1500 kW system would be $900/kW multiplied by 1,500 kW.

Notice that the cost of a cogeneration system declines dramatically as the size of the system increases. For this reason on site generation or cogeneration systems are more commonly practical for larger customers.

We have assumed that one engine-generator is being used. If, for example, the customers asks that his 1,500 kW system consist of two 750 kW engine-generators, then the chart should be used to find the cost for a 750 kW system, which is roughly $1100/kW. The overall cost of the two-engine system would then be this $1100/kW multiplied by 1500 kW

We have not yet decided how large a cogeneration system should be proposed to the customer. Cogeneration systems tend to produce the best financial results when sized to between 40-60% of the peak electric load of a commercial facility. Larger systems will increase first cost for added capacity that is rarely used.

At this point, preliminary economics can be done. The following table is used.

Line			On Peak		Off Peak
			Summer	Winter	
1	On Peak Hours of Operation	From Rate Schedule or Utility Bill			
2	True Cost of Electricity	From Table in Figure 1			
3	Cost of Generating Electricity	From Figure 2			
4	Cost Savings per kWh	Line 2 - Line 3			
5	System Size	Use 50% of the Maximum Demand			
6	Cost Savings per Year	If Line 4 >0, Line4 X Line 5 x Line 1			
7	Total Savings per Year	Add 3 Values in Line 6 Together			
8	First Cost of System ($/kW)	From Figure 3			
9	Total First Cost	Line 8 x Line 5			
	Payback	Divide Line 9 by Line 7			

Figure 8: Economics Calculating Table

We need to understand each line of this table

Line 1 is based on the local electric rate. Most electric rates consist of on peak and off –peak power rates. The on-peak rates may vary from winter to summer. T fill out the first line, determine how many hours the customers facility operates during the on peak period and during the off peak period. Then check the rate schedule to determine the number of months of considered to be winter or to be summer. For our example, the facility operates around the clock, but on-peak hours are 9 hours per day, 5 days per week (weekdays only). The billing period for summer is 16 weeks, resulting in 720 hours of on-peak summer operation. The remaining 2145 on-peak hours are at the winter rate, and all other hours are off-peak. If the customer is only operates the generator part time, this should be accounted for on line 1.

Line 2 should be filled in with the true cost of electricity results from the first section

Line 3 is the cost of generated electricity from the chart in the previous section

Line 4 is the cost savings per kilowatt-hour, and is found by subtracting Line 3 from Line 2

Line 5 shows the system size that you are suggesting to the customer. The generator should be sized for 40-60% of the customer's peak load. These economics will assume that the generator is operated at full capacity throughout the established operating hours from line 1.

Line 6 is the dollars saved in each year for each column. This number is found by multiplying line 4 by line 5. If the number in Line 4 is negative, leave this result out. In the example, the off-peak number in line 4 is negative, indicating that it is not economic to operate the generator during off-peak hours, and the economics then assume that the generator will be shut off during off peak hours

Line 7 is the total savings from the generation/cogeneration system for the year, and is the total of the numbers in Line 6

Line 8 is the cost of the cogeneration system per kilowatt from Figure 6.

Line 9 is the product of multiplying line 5 by line 8 to find the total installed cost for the generation/cogeneration system.

Finally, the last line is the payback period for the system, found dividing Line 9 by Line 7.

Line			On Peak		Off Peak
			Summer	Winter	
1	Hours of Operation	From Rate Schedule or Utility Bill	715	2145	5900
2	True Cost of Electricity	From Table in Figure 1	$0.157	$0.134	$0.022
3	Cost of Generating Electricity	From Figure 2	$0.04	$0.04	$0.04
4	Cost Savings per kWh	Line 2 - Line 3	$0.12	$0.09	-$0.02
5	System Size	Use 50% of the Maximum Demand	1,500		
6	Cost Savings per Year	If Line 4 >0, Line 4 X Line 5 x Line 1	$125,483	$302,445	NA
7	Total Savings per Year	Add 3 Values in Line 6 Together	$427,928		
8	First Cost of System ($/kW)	From Figure 3	$900.00		
9	Total First Cost	Line 8 x Line 5	$1,350,000		
	Payback	Divide Line 9 by Line 7	3.15		

Figure 9: Economic Calculating Table for the Example

Notice that the cost savings for off peak operation are negative. The CHP system should be shut down at night. Therefore, the off-peak column is not used after line 4 The 1,500 kW size of the CHP system was set at 50% of the peak demand for the facility.

Figure 9 indicates a good payback (3.15Years) IF all of the recoverable heat can be used, which may happen in applications where there is a very large heat load available. However, in many applications, particularly in commercial buildings, the recovered heat is largely used only for space heating and cooling, and actual useful recovery equal ~50% of the total recoverable heat. This causes payback periods to increase.

To account for this, change the cost of generated electricity from the $0.04 value, which requires 100% of the recoverable heat to be used to the $0.06 value, which assumes that only 50% of the heat is recovered. The result is shown in Figure 10.

Line			On Peak		Off Peak
			Summer	Winter	
1	Hours of Operation	From Rate Schedule or Utility Bill	715	2145	5900
2	True Cost of Electricity	From Table in Figure 1	$0.157	$0.134	$0.022
3	Cost of Generating Electricity	From Figure 2	$0.06	$0.06	$0.06
4	Cost Savings per kWh	Line 2 - Line 3	$0.10	$0.07	-$0.04
5	System Size	Use 50% of the Maximum Demand	1,500		
6	Cost Savings per Year	If Line 4 >0, Line 4 X Line 5 x Line 1	$104,033	$238,095	NA
7	Total Savings per Year	Add 3 Values in Line 6 Together	$342,128		
8	First Cost of System ($/kW)	From Figure 3	$900.00		
9	Total First Cost	Line 8 x Line 5	$1,350,000		
	Payback	Divide Line 9 by Line 7	3.95		

Figure 10: Economic Calculating Table for the Example with 50% of Heat Recovered

To this point, there have been no credits given for other benefits of having the CHP system. If the facility is using the CHP systems as an alternative to putting in emergency generators or an alternative to replacing existing dilapidated generators, then the cost of "Back-Up Diesels", as shown in Figure 5, should be subtracted from the first costs of the CHP.

For our example, the First Cost of the Cogeneration System is $900 per kW. However, at the 1500 kW size, an Emergency or Back-Up Generator would cost $350/kW. This means that the net cost of the cogeneration function to the facility is $550/kW. When this is used in the cogeneration analysis, the payback period becomes 2.4 years. This payback should be understood carefully – this is the payback for upgrading the back-up generators with cogeneration capability (adding heat exchangers, upgrading to continuous duty engines, adding electrical paralleling gear, and so on).

For Larger Facilities

Facilities with greater than 6 MW of peak demand can productively use a generator of over 3 MW. A gas turbine may be more practical for such a facility. The same process as outlined previously can be used. However, the chart in Figure 11 should replace Figure 7. Gas turbines produce enough hot exhaust to generate high-pressure steam (125 psig or greater), which may be of more use for hospital or industrial facilities.

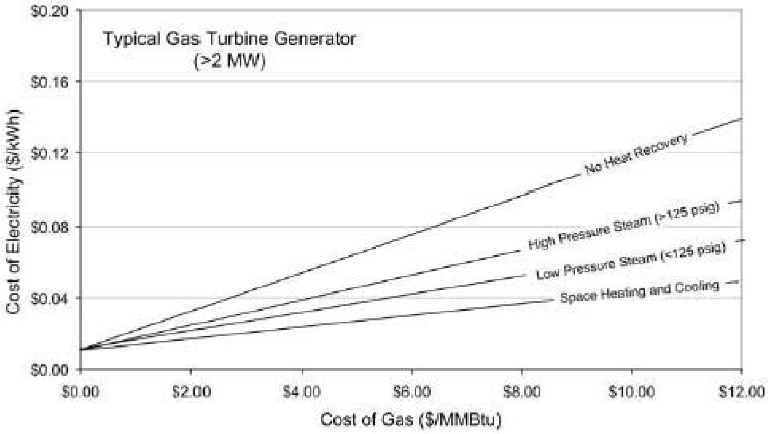


Figure 11: Cost of Electricity Graphs for a Typical Gas Turbine

Chart assumes an engine heat rate of ~10,000 Btu./kWh and a maintenance allocation of $0.008/kWh. Gas turbines reject all of the recoverable heat as high temperature exhaust, making this heat useful for high temperature applications such as high-pressure steam. Do not use this chart for recuperated turbines such as micro-turbines.

Summary

The procedure shown is sufficient for "first-cut" distributed generation or cogeneration economics. With these results, a facility owner has enough information to decide whether to proceed with a more detailed costing and economic analysis for such a system. This is usually done in conjunction with an engineering design firm experienced with such systems.

Appendix E: Summary of CHP Systems in U.S. Hospitals (by state)

	Facility Name	State	City	OpYear	Prime Mover	Capacity (kW)	Fuel Class
1	Sparks Regional Medical Center	AR	Fort Smith	1986	ERENG	8,500	NG
2	Tucson Medical Center Heating & Cooling	AZ	Tucson	1989	CT	750	NG
3	Kingman Regional Hosptial	AZ	Kingman	1986	ERENG	915	NG
4	Thunderbird Samaritan Hospital	AZ	Glendale		ERENG	630	NG
5	Grossmont Hospital District	CA	La Mesa	1985	CT	2,400	NG
6	San Antonio Community Hospital	CA	Ontario	1985	ERENG	2,700	NG
7	Agnews State Hospital	CA	San Jose	1990	CC	30,300	NG
8	Balboa Naval Hospital	CA	San Diego	1986	CT	4,600	NG
9	St. John's Hospital And Health Center	CA	Santa Monica	1990	CT	1,000	NG
10	Camarillo State Hospital / CA State Univ. Channel Islands	CA	Camarillo	1988	CC	27,000	NG
11	Victor Valley Hospital	CA	Victorville	1985	ERENG	130	NG
12	St. John Of God Hospital	CA	Los Angeles	1991	CT	120	NG
13	St. Luke Hospital	CA	Pasadena	1984	ERENG	1,000	NG
14	Veterans Administration Medical Center	CA	La Jolla	1989	CT	5,380	NG
15	Santa Barbara County Hospital	CA	Santa Barbara	1990	ERENG	350	NG
16	Anaheim Memorial Hospital	CA	Anaheim	1990	ERENG	350	NG
17	Pomerado Hospital	CA	Poway	1988	ERENG	350	NG
18	Mission Bay Hospital	CA	San Diego	1990	ERENG	240	NG
19	Burbank Community Hospital	CA	Burbank	1989	ERENG	50	NG
20	Delano Regional Medical Center	CA	Delano	1987	ERENG	99	NG
21	Presbyterian Intercommunity Hospital	CA	Whittier	1990	CT	575	NG
22	Brookside Hospital	CA	San Pablo	1987	ERENG	800	NG
23	Selma District Hospital	CA	Selma	1987	ERENG	60	NG
24	Sacred Heart Hospital	CA	Hanford	1989	ERENG	75	NG
25	Redlands Community Hospital	CA	Redlands	1990	CT	1,000	NG
26	St. Joseph Medical Center	CA	Stockton	1990	ERENG	600	NG
27	Kaiser Permanente Hospital - Riverside	CA	Riverside	1994	FCEL	400	NG
28	Kaiser Permanente Hospital - Anaheim	CA	Anaheim	1993	FCEL	200	NG
29	Cogeneration Facility	CA	Pomona	1987	ERENG	800	NG
30	Thompson Memorial Medical Center	CA	Burbank	1993	ERENG	60	NG
31	Kaiser Foundation Health Plan	CA	Pasadena	1997	ERENG	400	NG
32	Loma Linda University Hospital	CA	Loma Linda	1989	CC	13,000	NG
33	Napa Hospital	CA	Imola	1984	CT	1,600	NG
34	Kaweah Delta District Hospital	CA	Visalia	1984	ERENG	1,700	NG
35	Olive View Medical Center	CA	Sylmar	1987	CC	5,780	NG
36	Palomar Medical Center	CA	Escondido	1986	ERENG	1,200	NG
37	Saint Agnes Medical Center	CA	Fresno	1983	CT	7,000	NG
38	Commerce Veterans Center	CA	Commerce		B/ST	32,890	NG
39	Henry Mayo Newhall Hospital	CA	Valencia	1987	ERENG	450	NG
40	Chino Valley Medical Center	CA	Chino	2003	ERENG	780	NG
41	Eisenhower Medical Center	CA	Rancho Mirage	2002	ERENG	5,000	NG
42	Motion Picture and Television Hospital	CA	Woodland Hills	2005	ERENG	450	NG
43	Hoag Hospital	CA	Newport Beach	2005	ERENG	4,500	NG
44	Desert Valley Hospital	CA	Victorville	2005	ERENG	650	NG
45	Hospital	CA	Fremont	2007	ERENG	150	NG
46	Metropolitan State Hospital Norwalk	CA	Norwalk	1988	CC	30,700	NG
47	Childrens Hospital And Health Center	CA	San Diego	1983	CT	6,100	NG
48	Pleasant Valley Convalescent Hospital	CA	Oxnard	1988	ERENG	60	NG
49	Ojai Convalescent Hospital Project	CA	Ojai	1988	ERENG	60	NG
50	Hartford Hospital	CT	Hartford	1988	CC	12,200	NG
51	Norwalk Hospital	CT	Norwalk	1992	CT	2,400	NG
52	Norwich State Hospital	CT	Norwich	1965	B/ST	2,000	OIL
53	Connecticut Valley Hospital	CT	Middletown	1970	B/ST	2,100	OIL
54	Winthrop Health Care Center	CT	New Haven	1987	ERENG	75	NG
55	Vernon Manor Health Care Facility LLC	CT	Vernon	1997	ERENG	60	NG
56	Cromwell Crest	CT	Cromwell	1997	ERENG	75	NG
57	St. Francis Hospital	CT	Hartford	2003	FCEL	200	NG
58	St. Vincents Hospital	FL	Jacksonville	1990	CT	1,200	NG
59	St. Joseph's Hospital	FL	Tampa	1993	ERENG	1,500	NG
60	Baptist Hospital	FL	Jacksonville	1972	CT	13,100	NG
61	West Dade Facility	FL	Miami	1990	ERENG	810	OIL

62	Health Care Center	FL	Miami	1994	CT	1,500	NG
63	Florida State Hospital	FL	Chattahoochee	1995	B/ST	6,500	OIL
64	Kona Community Hospital	HI	Kona	2003	ERENG	455	OIL
65	Hilo Medical Center	HI	Hilo	2003	ERENG	730	OIL
66	Kauai Veterans Memorial Hospital	HI	Kauai	2004	ERENG	275	OIL
67	Iowa Methodist Medical Center	IA	Des Moines	1987	ERENG	3,500	NG
68	Delaware County Memorial Hospital	IA	Manchester	1985	ERENG	120	NG
69	Mercy Health Center - St Mary'S Unit	IA	Dyersville	1987	ERENG	60	NG
70	Mercy Hospital	IA	Council Bluffs	1970	ERENG	1,840	NG
71	Little Company Of Mary Hospital	IL	Evergreen Park	1989	CT	3,700	NG
72	Condel Memorial Hospital	IL	Libertyville	1985	ERENG	500	NG
73	Hospital Power Plant	IL	Hinsdale	1996	ERENG	3,200	NG
74	South Suburban Hospital	IL	Hazel Crest	1986	ERENG	1,900	NG
75	Northwest Community Hospital	IL	Arlington Hts.	1996	ERENG	4,400	NG
76	Lake Forest Hospital	IL	Lake Forest	1996	ERENG	3,200	NG
77	IL Dept of Mental Health	IL	Kankakee	1996	ERENG	1,100	NG
78	Resurrection Hospital	IL	Chicago	1989	ERENG	1,450	NG
79	Gottlieb Memorial Hospital	IL	Melrose Park		ERENG	1,600	NG
80	Northwestern University	IL	Evanston	1991	ERENG	800	NG
81	Christ Hospital	IL	Oak Lawn	2002	ERENG	2,000	NG
82	North Chicago Energy Center	IL	North Chicago	2003	CT	13,020	NG
83	St. Mary of Nazareth Hospital	IL	Chicago	1993	ERENG	2,400	NG
84	Westside VA Medical Center	IL	Chicago	2003	CT	4,000	NG
85	St. Anthony's Medical Center	IN	Crown Point	1990	CC	2,748	NG
86	Elkhart General Hospital	IN	Elkhart	1991	ERENG	745	NG
87	Medical Area Total Energy Plant	MA	Boston	1985	B/ST	62,800	NG
88	Jordan Hospital	MA	Plymouth	1994	ERENG	1,050	NG
89	Heywood Memorial Hospital	MA	Gardner	1995	ERENG	280	NG
90	Atlantic Adventist Healthcare	MA	Burlington	1969	B/ST	1,900	NG
91	Monson Healthcare	MA	Palmer	1991	B/ST	149	OIL
92	Eastern Maine Medical Center	ME	Bangor	2005	CT	4,400	NG
93	Oakwood Hospital	MI	Dearborn	1989	ERENG	1,350	NG
94	Buttercourt Hospital	MI	Grand Rapids	1999	CT	4,345	NG
95	Hutzel Hospital	MI	Detroit	1988	CT	1,600	NG
96	William Beaumont Hospital	MI	Royal Oak	1992	ERENG	3,800	OIL
97	Botsford Kidney Center	MI	Livonia	2000	ERENG	75	NG
98	Mayo Clinic	MN	Rochester	1999	CT	5,200	NG
99	Fairview Ridges Hospital	MN	Burnsville	1989	ERENG	150	NG
100	Franklin Heating Station	MN	Rochester	1951	B/ST	11,300	NG
101	Saint Marys Hospital Power Plant	MN	Rochester	1971	CC	12,900	NG
102	Missouri State Hospital	MO	St. Louis	1977	Z-NA	5,000	COAL
103	Baptist Medical Center	MS	Jackson	1991	CT	4,200	NG
104	Albemarle Hospital	NC	Elizabeth City	1996	ERENG	1,825	OIL
105	New Hampshire Hospital Plant	NH	Concord	1985	B/ST	2,000	WOOD
106	Cheshire Medical Center	NH	Keene	1988	ERENG	840	OIL
107	Crotched Mt Rehab Center	NH	Greenfield	1990	ERENG	1,400	OIL
108	St. Joseph's Cogen Project	NJ	Patterson	1997	ERENG	2,200	NG
109	East Orange General Hospital	NJ	East Orange	2003	MT	260	NG
110	Edison Estates Convalescent Center	NJ	Edison	1985	ERENG	60	NG
111	Betty Bacharach Rehabilitation Hospital	NJ	Pomona	1990	ERENG	150	NG
112	Cranford Health & Extended Care Facility	NJ	Cranford	1994	ERENG	72	NG
113	Lovelace Medical Center	NM	Albuquerque	1987	ERENG	1,150	NG
114	St. Vincent Hospital	NM	Santa Fe	2003	MT	60	NG
115	VAMC Las Vegas	NV	Las Vegas	1999	CT	1,000	NG
116	South Oaks Hospital	NY	Amityville	1990	ERENG	1,200	NG
117	Methodist Hospital	NY	Brooklyn	1990	ERENG	3,760	NG
118	St. Mary's Hospital	NY	Brooklyn	1994	ERENG	1,200	NG
119	Lutheran Medical Center Hospital	NY	Brooklyn	1993	ERENG	1,600	NG
120	Newark-Wayne Hospital	NY	Newark	1995	ERENG	290	NG
121	Yonkers General Hospital	NY	Yonkers	1989	ERENG	500	OIL
122	Staten Island Hospital	NY	Staten Island	1988	ERENG	22	NG
123	Montefiore Medical Center	NY	Bronx	1994	CT	10,570	NG
124	Staten Island Univ Hospital South	NY	Staten Island	1992	ERENG	1,200	NG
125	Central General Hospital	NY	Plainview	1990	ERENG	150	NG
126	Massapequa General Hospital	NY	Seaford	1990	ERENG	120	NG
127	Kingsbrook Jewish Medical Center	NY	Brooklyn	1991	ERENG	500	NG

128	Mercy Medical Center	NY	Rockville Center	1991	ERENG	1,340	NG
129	St. Charles Hospital	NY	Port Jefferson	1992	ERENG	670	NG
130	Southampton Hospital	NY	Southampton	1992	ERENG	500	NG
131	St. Lukes/Roosevelt Hospital Center	NY	New York	1993	B/ST	150	zOTR
132	Staten Island University Hospital / North Shore	NY	Staten Island	1997	ERENG	4,475	NG
133	Ellis Hospital Facility	NY	Schenectady	2001	ERENG	560	NG
134	Wyoming County Hospital	NY	Warsaw	2001	ERENG	560	NG
135	Gas Chiller CHP demo	NY	Geneva	2004	ERENG	400	NG
136	Cortland Memorial Hospital	NY	Cortland	2003	ERENG	3,075	NG
137	Bronx Center for Rehabilitation and Health Care	NY	Bronx	2001	ERENG	150	NG
138	Golden Gate Rehab Center	NY	Staten Island	2003	ERENG	150	NG
139	Iola Health Facility	NY	Rochester	2004	ERENG	2,700	NG
140	Genesee Memorial Hospital	NY	Batavia	2000	ERENG	300	NG
141	Lake Shore Hospital	NY	Silver Creek	2003	ERENG	400	NG
142	Clifton Springs Hospital	NY	Clifton Springs	1994	ERENG	600	NG
143	Jewish Home and Hospital	NY	Bronx	2005	ERENG	400	NG
144	Chemung County Health Center	NY	Elmira	2006	ERENG	300	NG
145	St. Lawrence Psychiatric Center	NY	Ogdensburg	1993	CC	83,000	NG
146	Deaconess Hospital	OH	Cleveland	1987	ERENG	665	NG
147	St. Charles Hospital	OH	Toledo	1999	ERENG	1,100	NG
148	Crozer-Chester Medical Center	PA	Chester	1988	ERENG	3,100	NG
149	Einstein Hospital	PA	Philadelphia	1992	ERENG	1,000	NG
150	York Hospital	PA	York	1986	ERENG	2,500	NG
151	Ebensburg Center/State Hospital	PA	Cambria Township	1990	B/ST	55,000	WAST
152	Holy Spirit Hospital	PA	Camp Hill	1987	CT	665	NG
153	Presbyterian Medical Center Of Oakmont	PA	Oakmont	1994	FCEL	200	NG
154	Children's Hospital	PA	Philadelphia	1996	ERENG	3,040	NG
155	Landmark Medical Center-Fogarty Unit	RI	North Smithfield	1987	ERENG	220	NG
156	RI State Hospital / Central Power Plant	RI	Cranston	1932	B/ST	9,000	NG
157	Rhode Island Hospital	RI	Providence	1974	B/ST	10,400	NG
158	Providence VA Medical Center	RI	Providence	2002	B/ST	52	OIL
159	Butler Hospital	RI	Providence	2005	MT	240	NG
160	South County Hospital	RI	Wakefield	2001	FCEL	200	NG
161	James H. Quillen VA Medical Center / East TN State Univ.	TN	Mountain Home	2001	ERENG	7,000	NG
162	Austin State Hospital	TX	Austin	1990	CT	2,200	NG
163	Lackland AFB Hospital	TX	San Antonio	1998	CT	10,400	NG
164	Vista Hills Medical Center	TX	El Paso	1986	ERENG	180	NG
165	Thomason Hospital Central Plant	TX	El Paso	1996	ERENG	2,400	NG
166	Providence Memorial Hospital	TX	El Paso	1987	ERENG	4,200	NG
167	Dell Childrens Hospital	TX	Austin	2006	CT	4,600	NG
168	Holy Cross Hospital	UT	Salt Lake City	1989	ERENG	460	NG
169	Primary Children's Medical Center	UT	Salt Lake City	1990	ERENG	1,800	NG
170	Bon Secours	VA	Portsmouth	2000	B/ST	100	zOTR
171	Johston-Willis Hospital Facility	VA	Richmond	1994	ERENG	3,000	NG
172	North Country Hospital	VT	Newport	2005	B/ST	274	WOOD
173	St. Mary's Hospital Medical Center	WI	Madison	1972	CT	900	NG
174	Milwaukee Regional Medical Center	WI	Milwaukee	1994	B/ST	5,000	COAL
175	Beloit Memorial Hospital	WI	Beloit	2000	ERENG	3,000	NG

Appendix F: Frequently Asked Questions (we may want to include additional questions pertaining to hospitals)

What is combined heat and power, CHP?

Combined heat and power refers to recovering waste heat when electricity is generated and using it to create high temperature hot water or steam. Steam or hot water can then be used for space heating, producing domestic hot water, or powering dehumidifiers and water chillers for air conditioning.

Why is there so much interest in CHP?

There are two different driving forces behind CHP. First, recent problems in electrical transmission and distribution systems have heightened concerns about availability and cost of electricity. These have led in turn to interest in distributed generation and subsequently the use of waste heat from power generation. The Department of Energy is interested in CHP because of .resource efficiency.. If coal or natural gas is burned at a power plant to produce electricity, less than a third of the energy content of the fuel is delivered to customers as useful power. The.resource efficiency. is less than 33%. If a CHP plant captures 68% of the energy in the exhaust gas and for space heating or hot water, the resource efficiency becomes 78% (33% + (68% x 67%)). Therefore, much more of the fuel energy content is used, and fossil fuel consumption and CO_2 emissions are reduced.

Is CHP the same as cogeneration?

Yes. CHP and cogeneration are basically the same thing. Cogeneration has been generally identified with district heating and large utility owned power plants or industrial power production and plant operation, while CHP is generally associated with a smaller scale, privately owned operation. It frequently refers to generation of heat and power for university campuses, military bases, hospitals, and hotels. New technologies for small-scale power production are opening opportunities for CHP in medium and small sized buildings.

What is the difference between CHP, CCHP, BCHP, DER, IES?

Many new terms and acronyms are being commonly used that mean basically the same thing: generation of electricity at or near a customer.s facility so that waste heat from electric generation equipment can be recovered and used. The terms differ as to where the emphasis is placed. CCHP stresses that combined cooling, heating, and power production occur, whereas combined heating and power in CHP may or may not use the recovered heat for cooling purposes. BCHP is just CHP applied to a building as opposed to a district heating system or industrial process. DER is distributed energy resources: the use of small generating facilities close to consumers, either with or without heat recovery. IES is an integrated energy system that recovers waste heat from on-site or near-site power generation to provide hot water, steam, heating, cooling, or dehumidification of air for buildings.

Why can't I use my backup generator for on-site power production?

Generator durability and fuel deliverability/storage are the reasons. The primary problem with using backup generators for on site power generation concerns their emissions, NOx and SOx, although noise and durability can also be problems. Most urban areas limit the maximum number of hours that IC engine driven backup generators can be operated each year because of their NOx and SOx emission levels. Generators for CHP systems can operate upwards of 8000 hours per year, which greatly exceeds most backup generators usage capability, which is typically limited to less than 200 hours per year. Some models may be able to handle such high usage, others may not. In addition, diesel-powered generators will require a lot of fuel storage at site.

Backup generators have been around for decades, what is new about on-site power generation?

Recent developments have pushed to make on-site power generation cleaner, cheaper, and quieter. Backup generators typically use diesel-fired internal combustion engines with a multitude of moving parts and relatively high emissions of pollutants NOx and SOx. Advanced recip engines have been developed that use natural gas and reduce emissions. Microturbines have been developed which have very low emissions of pollutants and extremely few moving parts making them attractive from an environmental and maintenance point of view. Gas turbines are also being marketed in smaller capacities so that they have appeal beyond large utilities and factories. Fuel cells continue to be developed with a promise of higher efficiencies and lower emissions than any other source of electricity and heat. Finally, strides are being made to reduce emissions from IC engine driven generators to reduce their environmental impact.

What types of power generators can I buy?

The most common type of on site power generation is using an IC engine-driven generator.

They are available in a broad range of capacities and can have very high efficiencies. A couple of manufacturers are producing microturbine generators and there are products under development by additional companies and in additional sizes from the current manufacturers.

Gas turbine generators are sold for applications requiring greater capacities and one brand of fuel cell is available. Many different companies are in the process of developing fuel cells for on site power generation and more products will become available.

How are generators classified, what is a kW?

Generators are classified by the .combustion. system and their rated electrical output. Combustion refers to whether an IC engine, microturbine, gas turbine, or fuel cell is used to convert the fuel to mechanical energy. It is in quotes because while most of these technologies use a combustion process, fuel cells use a chemical process without combustion. The electrical output or capacity is the number of kilowatts (kW) or megawatts (MW) of power generated. A kilowatt or megawatt is a measure of the rate of energy use or production. How much energy is consumed or produced is measured in kilowatt- or megawatt-hours. One kilowatt is equal to 1000 watts. A 100 watt light bulb has an electrical load of 0.100 kilowatts; if the bulb is left on for 10 hours it consumes 1000 watt-hours or 1.0 kilowatt-hours (kWh).

What are gas turbines?

A gas turbine burns a gas or liquid fuel to produce rotary motion, the turbine blades spin about a central axis. The turbine and air compressor are mounted on a central shaft; the electric generator can be mounted on the same shaft or on a second shaft and driven by a gear drive. The rotary motion requires fewer moving parts than the reciprocating action of an IC engine and consequently produces fewer vibrations and needs less maintenance. Gas turbines were developed for marine engines in boats and jet engines in airplanes as well as in large industrial turbines for utility power generation. The smaller gas turbine generators are aeroderivatives, descendants of jet aircraft engines.

What are microturbines?

Microturbines are a fairly recent innovation bringing the advantages of gas turbines to markets for smaller applications. They employ an air compressor and turbine blades on a single shaft. Some employ a recuperator to boost their efficiency and air bearings to reduce maintenance costs. Products are available ranging from 30 kW to 200 kW of capacity; this range will eventually expand to include 300 kW generators.

What is a recuperator and why is it important?

A recuperator is an internal heat exchanger that is used to recover energy from the turbine exhaust and use it to pre-heat inlet air. Using some of the exhaust energy to heat the air before mixing it with the fuel for combustion allows the same combustion temperatures and generating capacity to be reached using less fuel. Recuperators can double the efficiency of microturbine generators. Recuperators are used to increase the efficiency of microtubrines.

What is an HRSG?

A heat recovery steam generator, or HRSG, is used to recover energy from the hot exhaust gases in power generation. It is a bank of tubes that is mounted in the exhaust stack. Exhaust gases at as much as 1000°F heat the tubes. Water pumped through the tubes can be held under high pressure to temperatures of 370°F or higher or it can be boiled to produce steam. The HRSG separates the caustic compounds in the flue gases from the occupants and equipment that use the waste heat.

What are fuel cells?

Fuel cells are devices that use a chemical reaction to produce an electric current. Some of the fuel cells can achieve very high efficiencies. They are frequently compared to batteries where the chemicals needed for the reactions are stored within the battery itself. Fuel cells differ in that they are connected to a source of fuel, almost always molecular hydrogen. Hydrogen is combined with oxygen from the air to produce water and electric current; electrons flow between the cathode and anode of the fuel cell through an external circuit and while positive chemical ions flow in the opposite direction within the fuel cell itself. Fuel cells are categorized by the substance used for ionic flow in the fuel cell; phosphoric acid (PAFC) proton exchange membranes (PEMFC), solid oxide (SOFC), molten carbonate (MCFC), etc.

Can I buy a fuel cell?

There is only one fuel cell suitable for CHP applications is commercially available in the spring of 2001. It is a 200 kW phosphoric acid fuel cell. Many other products are under development worldwide but are not yet on the market.

What is a reformer?

Generally speaking, fuel cells use molecular hydrogen as their fuel and oxygen from the air to produce electricity. A reformer is a device that allows a fuel cell to use a hydrocarbon fuel like natural gas or propane as the fuel. It uses a catalyst, water, and heat to break down the
hydrocarbon releasing hydrogen as fuel to the fuel cell and carbon dioxide to the atmosphere.

What is a desiccant dehumidifier?

Dehumidifiers by definition remove humidity from the air. Normally this is done by finned cooling tubes in a heat exchanger cooling the moisture in the air below the dew point temperature so the moisture condenses and drips into a condensate pan or drain. This process is energy intensive because it requires cooling the tubes and air below temperatures that are comfortable for occupants, and therefore often has to be reheated. Desiccants are chemical compounds that have an affinity for water vapor, in a sense they absorb it like a sponge. A desiccant dehumidifier may deploy solid desiccants (e.g. silica gel) deposited on honeycombed surfaces to provide lots of area for water vapor to be absorbed. Blowing air through these surfaces removes moisture from it before it enters the building and thereby reduces humidity levels. Liquid desiccants (e.g. lithium chloride solution in water) are also used in spray systems for dehumidifying air , but are usually reserved for special applications

How do desiccant dehumidifiers use waste heat in a CHP system?

Desiccant materials can be heated to remove water vapor from them. This is done in a practical application by building the desiccant into a wheel that rotates through the building supply and exhaust air. For example, supply air being brought into a building is passed through the left side of the wheel where the desiccant absorbs water vapor. Exhaust air is heated and blown through the right side of the wheel where it removes the moisture from the desiccant (regeneration) and then vented outdoors. The wheel is rotated slowly so the desiccant has sufficient residency time to transfer the moisture to and from the desiccant media. Steam or hot water from a HRSG can be used to provide the heat needed to raise the exhaust air temperature to regenerate the desiccant.

What is a chiller?

Most small buildings, such as houses use a forced air distribution system to provide hot or cold air for comfort conditioning. Large buildings frequently use a hydronic distribution system and pump chilled water to air handling units to provide cool air for air conditioning. A chiller is the machine that cools water to around 44°F for distribution to the air handling units.

What is an absorption chiller?

Absorption chillers use heat and a chemical solution to produce chilled water. A gas burner is usually used to produce the heat with a mixture of lithium bromide and water as the chemical solution. Recovered waste heat in the form of hot water or steam can be used to power an indirect-fired absorption chiller (they use electricity for solution pumps, but only a small fraction of the electricity that electric motor driven chillers require). Some absorption chillers can also use hot exhaust gases directly and eliminate the need more producing hot water or steam.

What are single- and double-effect absorption chillers?

Without getting technical, the number of .effects. in a chiller reflects the number of times energy is used. A single-effect machine uses heat just once to produce chilled water. A double-effect machine contains heat exchangers to recover heat left over from the first stage of cooling to produce additional refrigerant vapor and more cooling. Double-effect is more efficient than single-effect. Triple-effect chillers are under development.

What is a cooling tower?

Every type of air conditioning or refrigeration process is a means of moving heat from where it is not wanted to medium where it can be rejected. The radiator of a car is a dry, finned-tube heat exchanger that is used to reject engine heat to the outdoor air efficiently. A cooling tower is essentially a wet heat exchanger used to reject heat from a chiller or excess heat from a HRSG. The water spray over tube banks in a cooling tower is more efficient at rejecting heat than a dry heat exchanger. It allows lower operating pressures in the chiller and greater efficiencies.

What is power conditioning?

Utilities in the U.S. distribute electricity at standard conditions with specifications for voltage, frequency, and type. Consequently most of our electrical appliances are designed for 60 Hz, alternating current. Power conditioning is the process of taking whatever electricity is produced by a generator and converting it to meet the industry standards so it can be used without damaging whatever is plugged in, be it a hair dryer, television, or computer. Power conditioning is an essential part of on site power generation.

What is NOx and why is it called a pollutant?

NOx is an abbreviation or acronym used to refer to nitric oxide (NO) and nitrogen dioxide (NO2). Both of these chemical compounds contribute to urban smog and can contribute to acid rain so their emissions are carefully controlled by government agencies. They can be formed during high temperature combustion from nitrogen in the air. Careful control of the combustion process or treatment of exhaust gases is needed to keep emissions low.

What is SOx and why is it a pollutant?

SOx encompasses a group of chemical compounds of sulfur and oxygen, but it predominantly it refers to sulfur dioxide, SO2. Sulfur dioxide is formed during combustion from sulfur compounds in the fuel and oxygen in the air. Liquid and solid fuels like gasoline and coal contain sulfur compounds and cause SOx in the flue emissions; SOx is not an issue with gaseous fuels likenatural gas and propane. Sulfur dioxide dissolves in water forming sulfuric acid, the principal constituent of acid rain. SOx emissions are strictly regulated.

What is SCR?

SCR stands for selective catalytic reduction and is a process for removing NOx from exhaust gases in order to meet pollution control requirements.

CONVERSION FACTORS

Electrical to Thermal					
Energy	1	kWh	=	3,412.8	Btu
	1	BTU	=	778	ft-lbs
Rate of Energy = Power	1	kW	=	3,412.8	Btu/h
	1	hp	=	2,545	Btu/h
Fuel Oil #2	1	Gallon	=	130,000	Btu
Fuel Oil #6	1	Gallon	=	143,000	Btu
Natural Gas	1	Therm	=	100,000	Btu
Refrigeration Tons	1	RT	=	12,000	Btu/h
	1	RT-h	=	12,000	Btu
Steam to Thermal					
Energy	1	lbs steam*	=	1,000	Btu
Rate of Energy = Power	1	lbs stm/h*	=	1,000	Btu/h
NOx Emission	1	ppm@ 15% oxygen	=	0.0472	lb/MWh

** Use actual enthalpy values from steam tables at given pressure and temperature for more accuracy!*