Combined Heat & Power (CHP) Resource Guide

Second Edition

Integrated Energy Systems (IES)

Cooling, Heating and Power (CHP)

Cogeneration (Cogen)

Tri-generation (Trigen)

Cooling, Heating and Power for Buildings (CHPB)

Buildings Cooling, Heating and Power (BCHP)

Total Energy Systems (TES)

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and
Avalon Consulting, Inc.

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

MIDWEST CHP APPLICATION CENTER
In Partnership with the US DOE

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

PURPA Minimum Qualifying Facility (QF)

- >42.5% *(or >45% if < 15% Thermal Energy Recovered from Power Generation)*

$$\text{QF Efficiency} : \frac{(\text{kWe} \times 3412.8) + 1/2(\text{Useful Thermal Energy})}{\text{Fuel Input (Btu/h in LHV)}}$$

Welcome to the MAC's CHP Resource Guide

In 2003, the Midwest CHP Application Center (MAC) identified a need in the market place for a document that could be used as a ready reference for a wide range of interested parties considering the application of CHP systems. The document was to contain easy to find technical facts/information; answers to the most frequently asked questions, and "rules of thumb" regarding the evaluation and implementation of CHP. The Combined Heat & Power (CHP) Resource Guide was completed and made available in late 2003.

I am extremely pleased and excited with both the popularity and use of the Guide. In 2004, over 11,000 copies of the Guide were downloaded from our website. During the first ten months of 2005, over 14,000 additional copies have been downloaded.

The MAC is now releasing the Second Edition of the CHP Resource Guide dated September 2005. This updated version expands the sections on Steam Turbines, Generators and Inverters, and Grid Interconnection. The revised guide can again be downloaded from our website at http://www.chpcentermw.org/10-00_tools.html.

I'd like to tell you a little about who we are at the MAC. The MAC is located at the University of Illinois at Chicago – Energy Resources Center and is supported by the U.S. Department of Energy, the Oak Ridge National Laboratory, and the twelve states in our Midwest Region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin). The focus of the MAC is to provide unbiased information, education, and technical assistance in the application of CHP and in determining when it makes good technical and economic sense.

John J. Cuttica

Director, Midwest CHP Application Center

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Preface

The primary objective of this CHP Resource Guide is to provide a ready reference for the basic principles of Combined Heat & Power (CHP) and the “Rules–of–Thumb” that apply when considering the application of CHP. It is intended to complement the knowledge of those who have some idea of what CHP is by providing “packets” of information to serve as a refresher or provide reference to specific information to assist in performing a first level screening or assessment of the suitability of CHP to a particular facility. This Guide should be useful to energy engineers, energy auditors, facility operations directors/managers, or others (such as architects, owners or managers of commercial buildings or industrial plants, school district managers, city/town managers) who have some understanding of a buildings physical systems and who have possibly gone through some introductory training or workshop on CHP applications.

The primary focus of this CHP Resource Guide is on system sizes *below 20 MW*. However typically CHP systems can range from *10s of kilowatts (kW)* for small commercial applications, to *10s of megawatts (MW)* for university or small industrial applications; CHP systems for large industrial applications can range into *100s of MW*.

CHP is an important part of America’s energy future. 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%*.

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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CHP - Combined Heat and Power. Also known by the following other names and acronyms:

Cogen – Cogeneration	***Trigen*** – Trigeneration
CHPB - Cooling, Heating and Power for Buildings	***TES*** - Total Energy Systems
CCHP - Combined Cooling Heating and Power	***IES*** - Integrated Energy Systems
BCHP - Building Cooling, Heating and Power	**Recycled Energy Systems**

1.1 Definition

CHP is …

- an ***integrated*** system,
- ***located at or near*** a building or facility,
- satisfying ***at least a portion*** of the facility's ***electrical demand***, and
- ***utilizing*** the ***heat generated by the electric*** *(or shaft)* ***power generation equipment to provide heating, cooling, and /or dehumidification*** to a building and/or industrial process.

Major CHP Components

- **Prime Movers**
- **Electric Generators**
- **Heat - Recovery Equipment**
- **Thermally-Activated Machines**

1.2 Concept

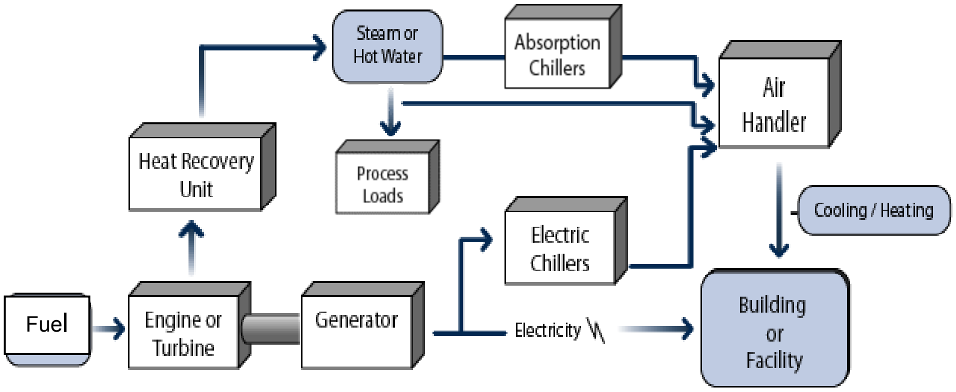

Figure 1-1 Conceptual Schematic Flow Diagram of a CHP System

1.3 Key Factors for CHP Financial Attractiveness

1. **Coincidence of Need for Electric Power *AND* Thermal Energy** - The ***more*** a facility needs ***electricity at the same time*** it needs ***thermal energy*** (heating, cooling, or dehumidification), the ***more attractive*** the savings and payback associated with CHP become.
2. **"Spark Spread"** – The ***higher*** the ***differential*** between the ***cost* of buying *electric*** power from the grid and the ***cost* of *fuel*** (usually natural gas) used for operating the

CHP system, the ***more attractive*** the savings and payback associated with CHP become .

3. **Installed Cost Differential** – The ***lower*** the ***differential*** between the installed costs of a ***CHP system*** and that of a ***conventional system***, the more attractive the savings and payback associated with CHP become.
4. **Economic value of power reliability is high** – Cost of power outages is high; Avoidance of power outage is very valuable.

1.4 Benefits

End User

+ **Reduced Energy Costs** – result of higher fuel use efficiencies and energy use savings
+ **Improved Electric Reliability** – result of less susceptibility to grid failures due to synchronous operation and parallel connection with the utility grid
+ **Improved Power Quality** – result of reducing line losses and voltage sags
+ **Improved Energy Security** – result of less susceptibility to natural disasters and/or terrorist attacks

Electric Utility

+ **Alternative** to ***Utility Distribution Grid Expansions / Upgrades***
+ **Increased Customer Options**

General Public

+ **Improved Environmental Quality** – result of lower "green house gases" and NOx emissions
+ **Conservation of National Energy Resources** – result of higher efficiency of fuel utilization

For a detailed discussion on the ***benefits*** of a CHP system, visit the Benefits section of the Midwest CHP Application Center website (http://www.chpcentermw.org/03-00_chp.html)

1.5 Barriers

Lack of Education and Awareness

- ***Case Studies***: Inconsistent and hard to find
- ***Lack of Familiarity***: Unfamiliar with CHP technologies, concepts, and benefits

Uncertainties

- ***Electric Restructuring***: Creates ***uncertainty*** in electricity ***pricing*** and ***reliability*** which often times leads to a ***"Wait and See"*** attitude
- ***Gas Price Volatility***: Creates ***uncertainty*** in savings and a ***fear*** of the ***unpredictable***
- ***Electric Utility Position***: ***Ambivalent*** at best, ***hostile*** at worse

Costs and Paybacks

- ***High First Cost***: ***Discourages*** investment ***despite*** energy ***cost savings***
- ***Under Estimating CHP Value***: Difficult to quantify benefits, such as ***avoidance*** of electric ***outages*** and ***reduced*** overall ***emissions***, etc.
- ***Unfavorable Utility Tariffs***: ***Standby charges***, ***backup rates***, ***exit fees***, etc.

Installation Issues

- **Permitting Process**: Sometimes ***may*** be ***long***, ***cumbersome***, and ***costly***
- **Grid Interconnect**: ***Inconsistent standards***, ***complex process***, and ***unpredictable / high costs***

SECTION 2: CHP TECHNOLOGIES

2.1 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 2-1 "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^{o}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^{o}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^{o}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 2-2 “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 2-3 “Rules-of -Thumb” for Fuel Cells

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

2.1.1 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 2-1*.

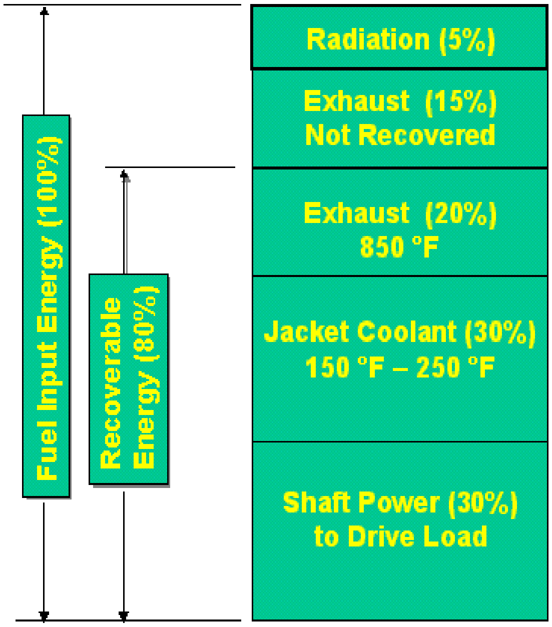

Figure 2-1 Energy Distributions for a Typical Reciprocating Engine

2.1.2 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 2-2* 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 2-3* 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 2-4* 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***.

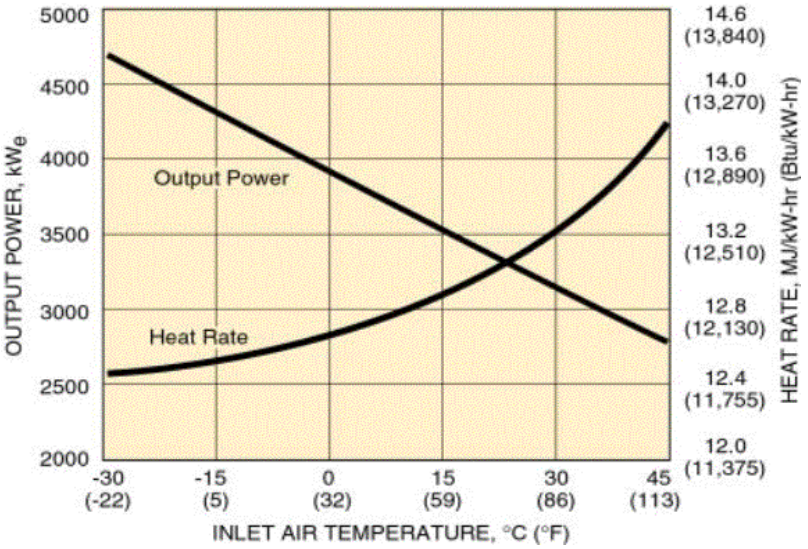

Figure 2-2 An Example of the Effect of Ambient Air Temperature on Power Output and Heat Rate

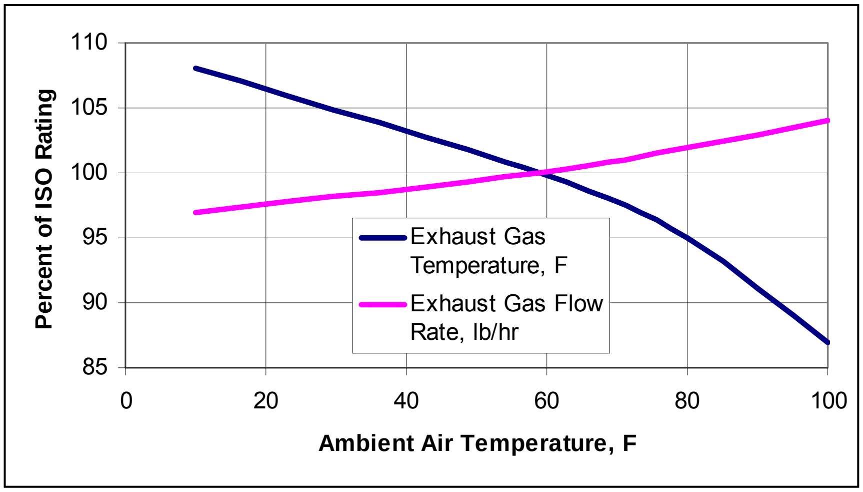

Figure 2-3 An Example of the Effect of Ambient Air Temperature on the Flow Rate and Temperature of Exhaust Gases

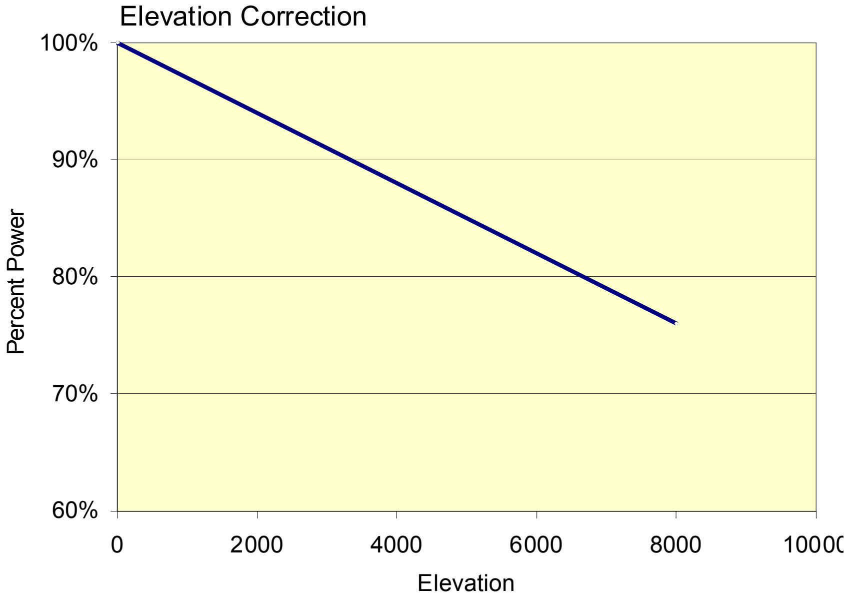

Figure 2-4 An Example of the Effect of Altitude (above sea level, feet) on the Electric Power Output

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2.1.3 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 2-5 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.

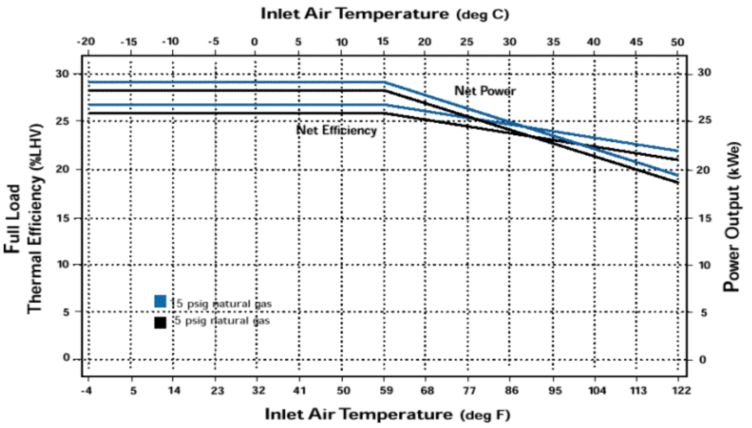

Figure 2-5 Effects of Ambient Temperature on the Electric Power Output and Fuel Efficiency of a Typical Microturbine

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2.1.4 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 2-4 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

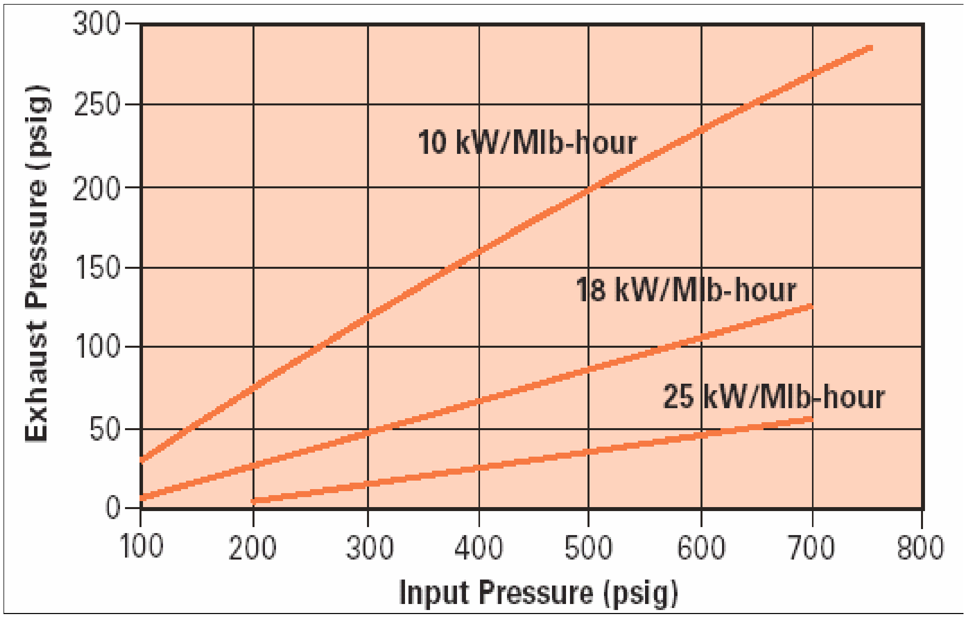

Figure 2-6 Effect of Steam Input and Exhaust Pressures on Electric Power Produced

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2.1.5 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 2-7* shows a process schematic of a fuel cell system.

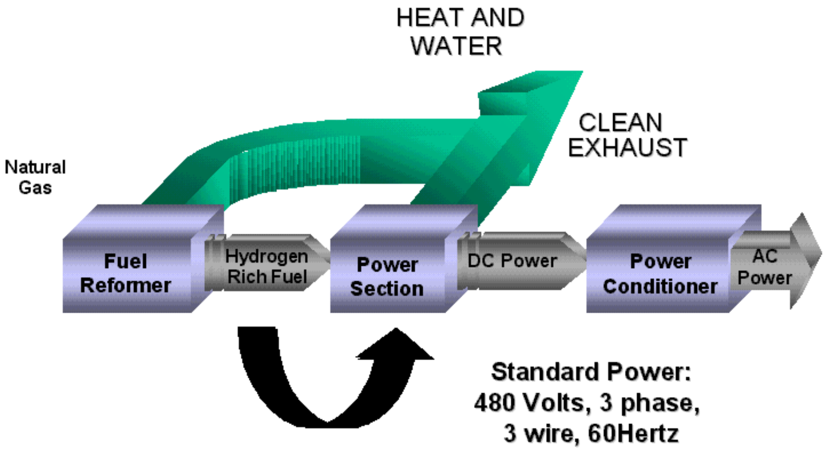

Figure 2-7 Process Schematic of a Fuel Cell

- ***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 2-5.*

Table 2-5 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

2.2 GENERATORS AND INVERTERS

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

CHP systems that utilize fuel cells and micro-turbines as their prime mover technology utilize inverter technology to provide utility grade electricity.

2.2.1 Generators

Characteristics

- 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:
    1. **Synchronous**
        - 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
        - More complex and costly to safely interconnect to the grid (must ensure that when the grid is not operating, 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)
    2. **Induction**
        - 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 goes "down". 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 goes down, the CHP system shuts down.
        - Simpler less costly to safely connect to the grid

2.2.2 Inverters

Characteristics

- 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 “down”

2.3 GRID INTERCONNECTION

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

2.3.1 Types of Utility Grids

- ➢ **Radial:** A single path for power flow from the power source to the end-users. Therefore, a failure of power source results in complete loss of power to all the end users on that line. Most common type grid and easiest to interconnect to.
- ➢ **Network:** A type of electric distribution system served by multiple transformers interconnected in an electrical network circuit. Network systems are generally used in large metropolitan areas that are densely populated.
    - These type grids are inherently more reliable than radial systems, but require more complicated and costly interconnect designs.
    - Many utilities will not allow on-site generators to interconnect with their Network systems.
    - Not being able to interconnect to network grids is a major barrier for CHP systems (usually located in densely populated areas with many potential applications)
    - Examples of CHP interconnection to Network systems do exist (Chicago, New York, Boston)

2.3.2 CHP/Grid Operating Modes

There are three general modes of operation for on-site generators relative to the utility grid:

- Stand-alone (totally isolated from the grid)
- Isolated from the grid with utility backup
- Parallel operation with the utility grid

Stand Alone System

- ➢ Serves designated facility loads independent of the utility grid
- ➢ Requires redundant system design to ensure adequate reliability
- ➢ Used by customers who are isolated from the grid by choice or by circumstances as in remote locations

Isolated Operation with Utility Grid Backup

- ➢ Open Transition Transfer
    - CHP normally serves designated facility loads independent of the utility grid

- Should a fault be detected that causes the CHP system to shutdown, the load is completely disconnected from the CHP system before it is connected to the grid
- When reconnecting the loads back to the CHP system, the load is again completely disconnected from the grid
- The transfer switch can be automatic or manual
- Because of the complete disconnect of the load from one source before connecting to the other source, there is brief power loss during the transfer which can cause a power surge when reconnecting loads
- The CHP system requires a synchronous generator since no grid excitation is available
- This is a common design for Emergency Generators and/or Standby Generators

- ➢ Closed Transition Transfer
  - Normally serves designated loads independent of the utility grid
  - Should a fault be detected that causes the CHP system to shut down, the transfer switch does not completely disconnect the load from the CHP system before it connects the load to the grid
  - The result is that the load is connected to both sources for a short period of time (normally 100 milliseconds to as much as 60 seconds)
  - The result is no power loss or power surge, but needs synchronization between the two sources for that transfer period
  - More complex than the open transition transfer design

Parallel Operation with the Utility Grid

This 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.

- ➢ 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 “downed” grid either by:
    - ❖ Utilizing induction generator
    - ❖ Circuitry to shut down the CHP system
    - ❖ Circuitry to ensure transfer of CHP system off the grid and onto disconnected loads (utilities often require very expensive redundant circuitry)
  - 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 goes down (blackouts and brownouts)

- ➢ 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 shut down).
    - 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 go "down", 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

2.3.3 Black Start Capability

Should the grid go "down" and the CHP system go down also, 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 to 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.

2.3.4 Grid Interconnection Standards

- ➢ The Institute of Electrical and Electronic Engines (IEEE) has already developed standardized technical interconnection protocols **(IEEE 1547)**

- ➢ The **Federal Energy Regulatory Commission (FERC) Order 2006** has developed standard procedures for interconnections of generators smaller then 20 MW. (For transmission grids only NOT for distribution grids)

- The MADRI (Mid-Atlantic Distributed Resources Initiative) Small Generator (10 MVA) Interconnection Procedures (August 2005) do address interconnecting small generators to network systems (www.energetics.com/MADRI/pdf/model_081805.pdf)
- Several states have also developed interconnection rules, protocols and procedures Visit the Web site in the following box for the status of interconnection protocols in various states.
- Interconnection protocols may be different for the **radial** and **network** systems and also depends on the number of feeders there are into a facility, and the size of CHP system being installed.
- Discuss, early in the project, the interconnection requirements of the electric utility or the independent systems operator (ISO) responsible for the electric grid in the CHP project location area

2.4 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 2.5.1) specially designed for such a heat source, or ***regenerating desiccant dehumidifiers*** (discussed later in Section 2.5.2).
  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***

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2.5 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 2-6 Absorption Chiller (lithium-Bromide-Water) System “Rules-of-Thumb”

ABORPTION 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 2-7 Absorption Refrigeration (Aqua-Ammonia) System “Rules-of-Thumb”

ABORPTION 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 2-8 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

“Rules-of-Thumb” for Steam Turbines are provided in Table 2-2 in Section 2.1 (Prime Movers)

2.5.1 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 2-8*

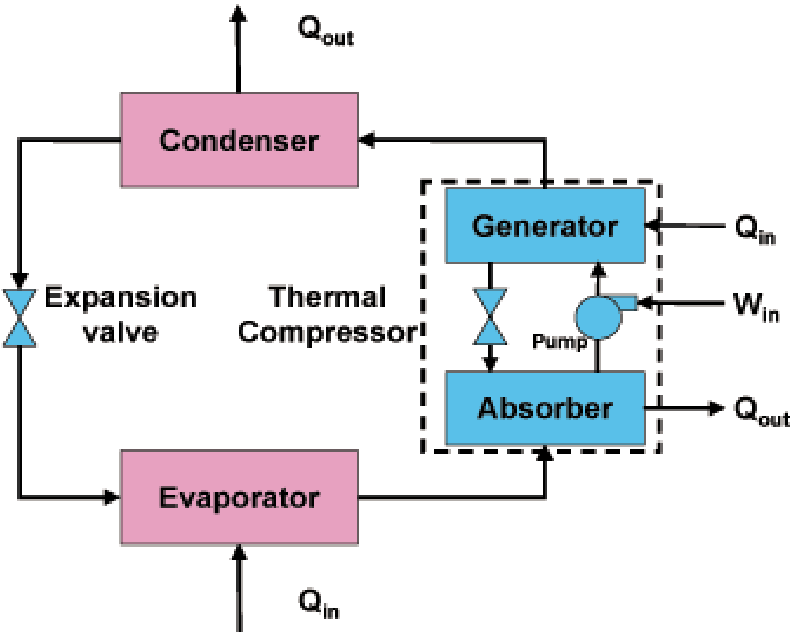

Figure 2-8 Process Schematic of an Absorption Chiller/Refrigeration System

- Commercially available **absorption systems** that can be utilized within a CHP system can ***operate on***:
  1. Steam,
  2. Hot Water, or
  3. 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.

2.5.1.1 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 chiller***s, 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.

2.5.1.2 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 I ton of refrigeration**
   - Less energy efficient (**lower COP**) than the single-stage systems
   - **Higher Cost** than the single-stage systems

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2.5.2 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 2-9*)
     - Usually used for dehumidifying air for ***commercial*** HVAC systems.
  2) **Liquid Desiccant** (*Figure 2-10*)
     - Generally used for ***industrial*** applications or in hospital ***operating rooms***.

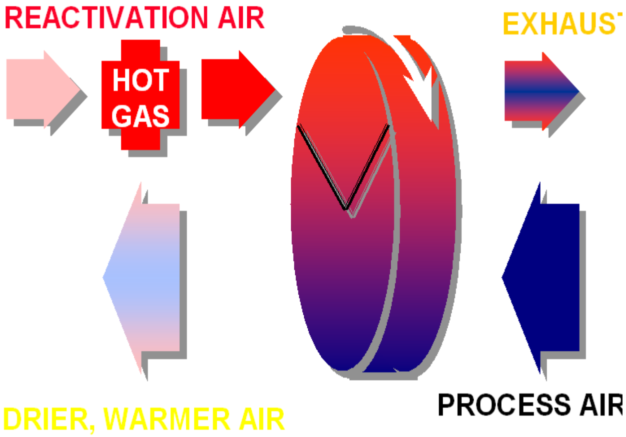

Figure 2-9 Solid Desiccant

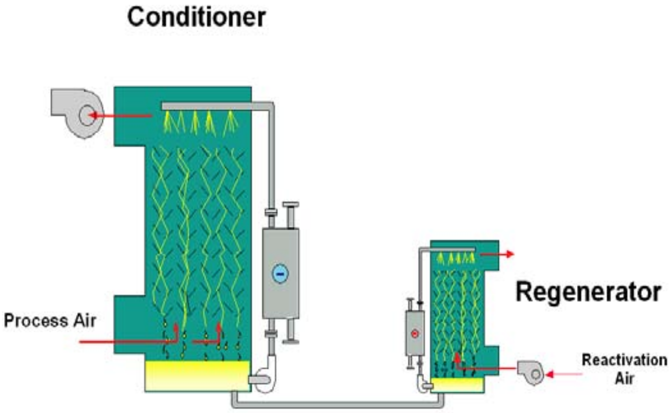

Figure 2-10   Liquid Desiccant

2.5.3 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.

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SECTION 3: APPLICATIONS

This chapter discusses some ***guidelines*** for making a ***PRELIMINARY determination*** if an application of a CHP system has the potential of being a ***technical*** and ***financial*** success.

CHP systems are generally ***more attractive*** for applications that have ***one or more*** of the following characteristics:

1. Good ***coincidence*** between ***electric*** and ***thermal*** loads,
2. Cost differential between electricity (total cost) and natural gas (total cost) – ***"Spark Spread" > $12/MMBtu***,
3. ***Long operating hours*** (greater than 3,000 hours/year),
4. Electric ***power quality*** and ***reliability*** is ***important***,
5. ***Larger size*** building / facility since that usually translates to a lower CHP initial cost differential and larger annual savings,

There are many commercial / institutional buildings and industrial plants that meet some or all of the above characteristics and the following are some of the ***examples where CHP applications are likely to be economically attractive*** depending upon their specific characteristics:

Commercial / Institutional Facilities

In a market assessment conducted for DOE/ORNL by Resource Dynamics Corporation, the ***potential*** building sector market for CHP was determined to be almost ***17 GW*** in ***2010***, and potentially ***growing*** to over ***35 GW*** by ***2020*** *(including CHP systems with absorption chillers, engine-driven chillers (EDCs), and heat and power-only systems)*. These values are based on installations that provide a ***minimum payback period of 10 years*** when compared to installing a conventional HVAC systems and purchasing electricity from the grid. Many postulated installations had payback periods much shorter than 10 years, with a significant portion having less than 4 years. As shown in *Figure 3-1* , the ***highest*** potential for CHP is in:

- **Office Buildings**
- **Hospitals**

Schools
- **Colleges**

- **Retail Applications**
- **Hotels**

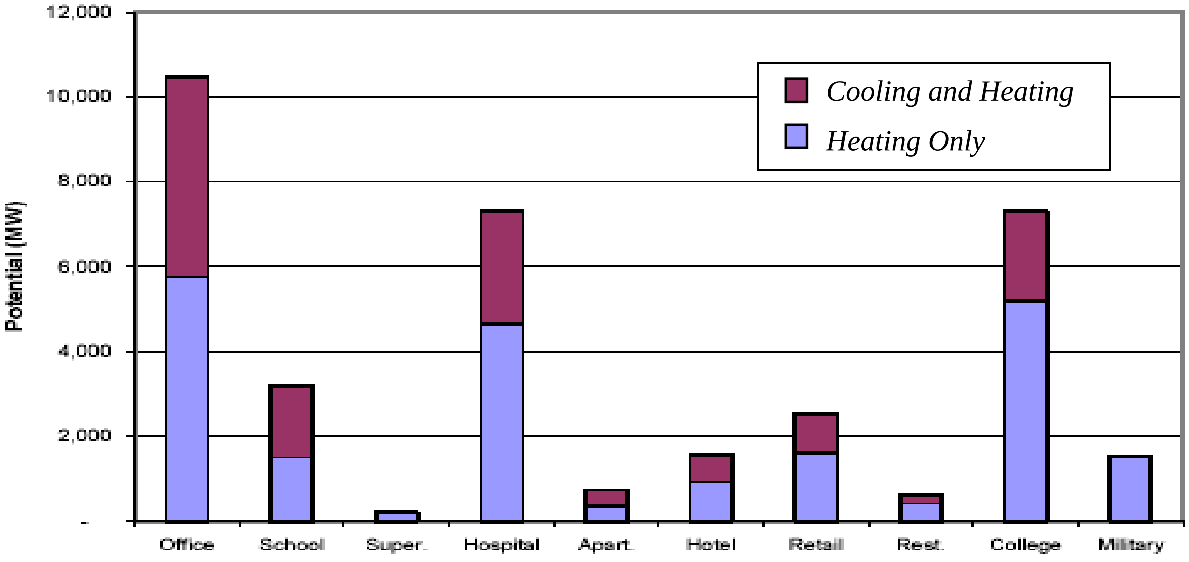


Figure 3-1 CHP Potential by Building Type

Industrial Plants

Some of the ***industries*** that are ***better suited*** for CHP are:

- ***Ethanol Production***
- ***Pulp and Paper Mills***
- ***Chemicals Manufacturing***
- ***Metals Production***
- ***Food Processing***
- ***District Energy Systems***
- ***Livestock Farms***
- ***Waste Water Treatment***
- ***Landfills***

3.1 Good Electric and Thermal Load Coincidence

The questions to be studied and evaluated are:

- **?** ***Does*** the application ***need heat*** at the ***same time*** that it ***needs electricity***?
- **?** ***How much heat*** (Btu/hr) does the application 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
Summer	✓ Water Heating ✓ Process Heating ✓ ***Space Cooling****
Fall / Spring	✓ Water Heating ✓ Process Heating ✓ 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 ***"¢s."***

- 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***. Therefore, a bit of ***"sleuthing"*** to ***utilize this energy*** often have positive effects.

3.2 Cost Differential Between Electricity and Natural Gas

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 facility*,* the ***cost differential between electricity and*** **natural gas** (**"*Spark Spread*"**) can be ***estimated*** as follows:

Table 3-1 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. b.	Average Annual Electric Cost (1.d.) **Minus** Average Annual Gas Cost (2.d)	$ $		/MMBTU /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.

Table 3-2 below provides ***"Rules-of-Thumb"*** that *estimates* the conversion for a ***$12/MMBTU "Spark Spread"*** between electric and natural gas costs based on average annual fuel cost.

Table 3-2 "Rules-of-Thumb" for *Acceptable Average Annual Fuel Cost*

Average Annual Electric Energy Cost *(¢/kWh)*	**Maximum Acceptable Average Annual Fuel Cost** *($/MMBtu)*
≤ 4	0
5	2.6
6	5.6
7	8.5
8	11
9	14
10	17

3.3 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 energy (kWh) AND 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 at this ***$12 cost differential*** 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***, especially in ***hospitals*** and ***industrial*** 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 become more favorable and a ***more detailed assessment should be done***.
- Between **3,000 and *5,000 hours/year*** payback may be sufficient enough to be financially favorable, and 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***.

3.4 Electric Power Reliability, Quality, and Prime Mover Selection

If electric ***power quality*** or ***reliability*** is an ***issue***, installing a ***CHP*** system will likely make ***more sense than*** installing ***backup power generation*** or ***power conditioning equipment***. ***Site-specific characteristics*** also help to ***determine*** what type of ***prime mover technology*** would be ***best suited*** for that specific application. A combination of these two items can help determine what prime mover technology is best suited for the site.

Power Reliability

- **Backup** and **Emergency** Power … are ***NOT*** the ***same***. Generally if emergency power is required for a facility, ***CHP*** will likely ***NOT meet*** the ***"quick" start requirements*** (< 8 seconds). Also most ***emergency generation*** systems are ***NOT designed*** to ***run continuously***.
- CHP can provide ***additional reliability*** to those sites that ***need emergency power*** by:
  1. ***Reducing*** the size of the ***emergency generators*** by allowing non-critical loads to be supplied off of the CHP system,
  2. ***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*** should there be a loss of utility power,
  3. Allowing more ***"business critical" loads*** to be ***kept on*** during utility grid ***outages*** or ***perturbations***.
  4. If ***absorption chillers*** are driven by the prime mover exhaust, they can provide 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 many 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.
- In addition, many of the ***generation technologies*** used in CHP applications, have ***integral power conditioning modules***. As an example, fuel cells need to convert DC to AC so they have integral power conditioning modules, as do many of the microturbines.

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.

- Section 2 provided the "Rules-of-Thumb" for the various prime mover technologies that can assist in making the selection based on prime mover size and output, quality/quantity of the exhaust energy, and availability. An additional ***"Rule-of-Thumb"*** utilizing the ***Thermal to Electric (T/P) ratio*** may help.

- **Calculate** 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 3-3*.

Table 3-3 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***

3.5 Larger Sized Buildings

- ***Sizing*** CHP system for the ***best payback*** is ***beyond the scope*** of this Resource Guide, but it is ***important*** to ***note*** that the cost of a CHP system ***decreases on a "cost per kW" basis***, **as its capacity increases**. Figure 3-2 provides an example of this decreasing overall cost effect for on-site generation and cogeneration systems It also shows generation capacity required for two sizes of typical office buildings in Chicago (IL) area.
- Table 3-4 provides **some typical floor areas** (in square feet) for several **types of buildings.**

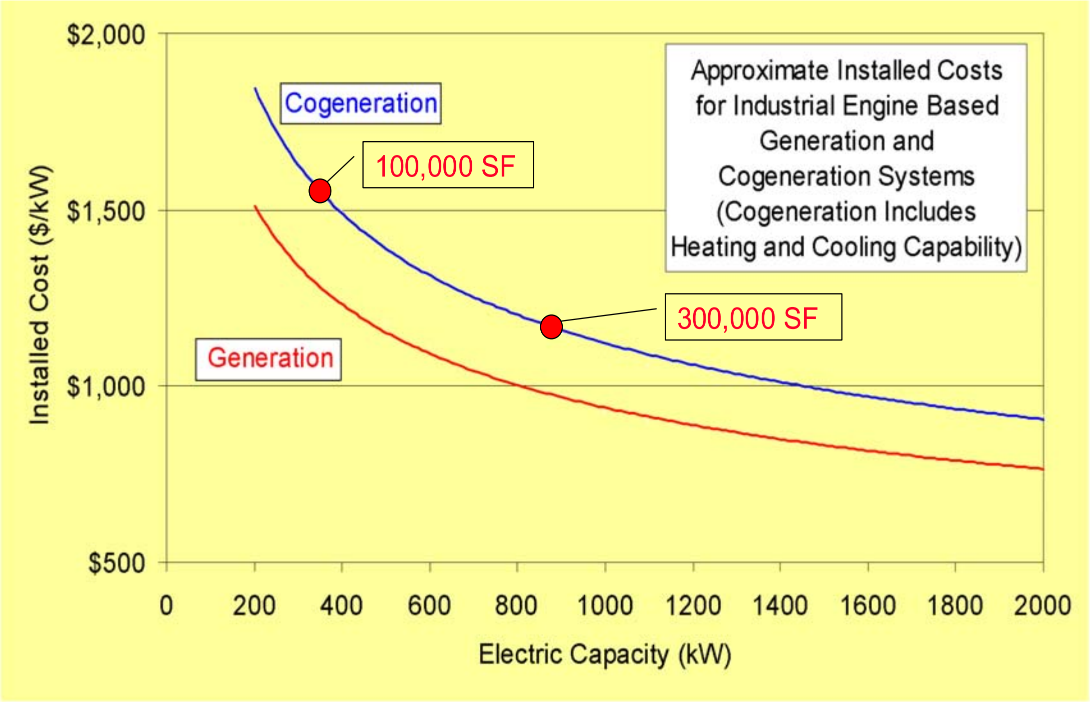


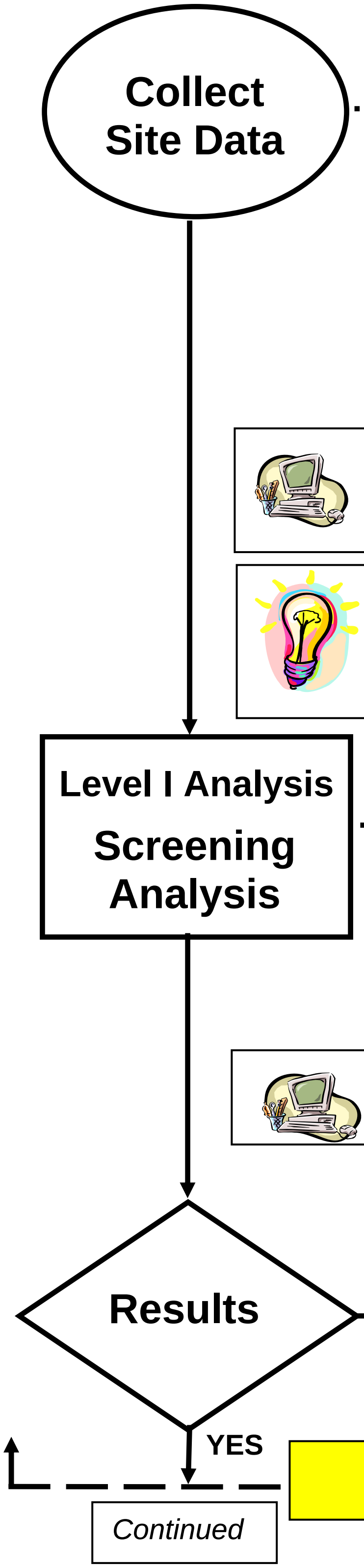
Figure 3-2 Effect of Engine-Based CHP System Capacity on Installed Cost

Table 3-4 Typical Sizes (Floor Areas) for Various Buildings

Building Application	Floor Area, Square Ft
Ice Arena	63,000
Hospital	500,000
Hotel (Large)	300,000
Hotel (Small)	40,000
Nursing Home	63,000
Office (High Rise)	300,000
Office (Low Rise)	30,000
Restaurant (Full Service)	5,000
Restaurant (Quick Service)	2,000
Retail Store	60000
School	165,000
Supermarket	32,000
Theater	40,000
Warehouse (Refrigerated)	50,000

SECTION 4: FEASIBILITY EVALUATION

Implementing a CHP system requires significant time, effort, and investment. Therefore, it's prudent to ***first estimate*** its ***financial*** *AND* ***technical*** feasibility using a systematic approach that incorporates the sequence of the process outlined below. The ***three levels*** of analyses have ***different scope***, ***depth of analysis*** and ***accuracy*** of total costs to complete, and require different levels of effort.



- **Minimum** Site Data Collection Recommended:
  - ✓ ***12 Months*** of ***Electric*** AND ***Fuel Bills***
  - ✓ ***Operating Hours*** of the Facility/ Building
  - ✓ ***Existing / Planned Heating*** AND ***Cooling*** (Space and Process)
  - ✓ ***Number*** of ***Electric Feeders*** and ***Meters*** to the Facility / Building
- **Appendix A** provides a ***detailed Site Data Collection Sheet*** that can be used when visiting and collecting data for a potential CHP site. Collecting the information requested in this data sheet will minimize the need for additional site visits and will allow more detailed analyses to be performed.

An ***electronic*** version of the ***Site Data Collection Sheet***, along with ***"Helpful Hints"*** is available at: *www.**CHPCenterMW.org/html/10_library.html#tools***

It often ***expedites*** the ***site visit*** and the ***gathering of information*** if the ***sample table*** shown in **Appendix A** is ***faxed*** AND ***discussed*** with he facility manager ***prior*** to the visit.

Purpose: Establish if a Site has the ***potential*** to be a "***Good: Candidate***" for CHP

- Uses **"Rules-of-Thumb"** to Perform Analysis
- Based on ***Annual Average Costs***
- Uses ***Average*** or ***"Estimated" Load Profiles***
- Best ± ***30%*** Accuracy
- ***Estimates Rough Savings***, ***Installation Cost***, and ***Payback***

A CHP **Screening Analysis Tool**, along with instructions for use, is ***available*** at: *www.**CHPCenterMW.org/html/10_library.html#tools***

Action: ***Discuss results*** and ***recommendations*** with ***end-user*** to determine if results ***merit further analysis***.

- ✓ ***Stress "limited accuracy"*** of results
- ✓ ***If*** potential savings and payback are ***acceptable*** to ***end-user*** a more ***detailed*** and ***accurate analysis*** should be ***recommended***.

Above addressed within the scope of this Guide!

Continued

Continued

Level II Analysis

Conceptual/ Financial Analysis

Purpose: To determine ***if CHP is a viable option***, both ***financially*** AND ***technically***.

- ***Detailed engineering*** AND ***financial*** model that ***preferably*** uses ***hourly load profiles*** (at a minimum monthly profiles).
- ***Costs*** based on ***energy profiles generated by model***.
- Accuracy ± ***20%***
- ***Conceptual one-line design*** including ***equipment sizing***.

A ***list*** and ***brief description*** of various ***Analysis Tools*** is available at: ***www.CHPCenterMW.org/html/10_library.html#tools***

Results

Action: ***Discuss result*** and ***recommendations*** with ***end-user*** to determine if a ***detailed engineering design*** and ***analysis*** is desirable.

- ✓ ***Conduct another site walk through*** to evaluate any additional site considerations or specific requirements.
- ✓ ***Discuss*** possible ***additional options*** and ***design possibilities***.
- ✓ ***If end user agrees*** AND has the ***financial capability*** to go forward at this point generally a ***contract*** will be signed to ***begin engineering design***.

YES

Level III Analysis

Detailed Engineering Analysis/ Design

Purpose: To ***develop*** AND ***design*** an ***actual CHP system***.

- ***Develop*** **detailed *engineering design*** and ***installation / construction drawings***.
- ***Procurement specifications issued***.
- ***Actual costs*** established.

The ***scope*** of this ***Resource Guide*** is ***limited to discussing ONLY screening analysis*** (Level I Analysis).

APPENDIX A WALKTHROUGH DATA

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)?		

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?

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

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

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?

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

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

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 B Software Tools For Evaluating The Economics Of CHP Systems

- BCHP Screening Tool (Free)
- Building Energy Analyzer ($780)
- Cogen Ready Reckoner (Free)
- D-Gen Pro ($675)
- GT Pro ($7,000)
- Heatmap CHP ($4,000)
- HUD CHP Screening Tool (Free)*
- Plant Design Expert ($3,000)
- RECIPRO ($1,500)
- SOAPP-CT.25 ($7,500)

For more details visit the Midwest CHP Application Website Center: http://www.chpcentermw.org/10-00_tools.html

* Available at http://www.ornl.gov/sci/engineering_science_technology/cooling_heating_power/success_analysis_HUD.htm

APPENDIX C FREQUENTLY ASKED QUESTIONS

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 generator’s 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 like natural 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.

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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!*